UNIT – V
AC –AC CONVERTERS

Introduction to AC voltage controllers

AC voltage controllers (**ac line voltage controllers**) are employed to vary the RMS value of the alternating voltage applied to a load circuit by introducing Thyristors between t he load and a constant voltage ac source. The RMS value of alternating voltage applied to a load circuit is controlled by controlling the triggering angle of the Thyristors in the **AC Voltage Controller circuits**.

In brief, **an AC Voltage Controller** is a type of thyristor power converter which is used to convert a fixed voltage, fixed frequency ac input supply to obtain a variable voltage ac output. The RMS value of the ac output voltage and the ac power flow to the load is controlled by varying (adjusting) the trigger angle 'α'

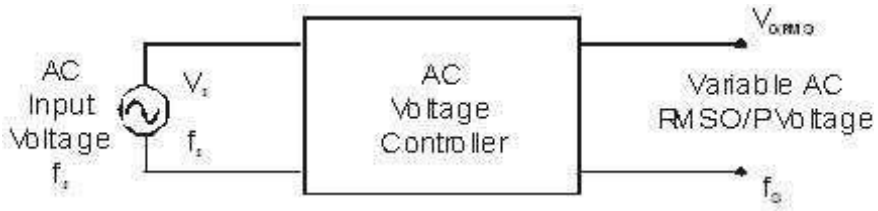


Figure: 3.1 Block diagram of AC voltage controller

Control strategies: There are two different types of thyristor control used in practice to control the ac power flow

1. On-Off control
2. Phase control

These are the two ac output voltage control techniques. In On-Off control technique Thyristors are used as switches to connect the load circuit to the ac supply (source) for a few cycles of the input ac supply and then to disconnect it for few input cycles. The Thyristors thus act as a high speed contactor (or high speed ac switch).

Phase control

In phase control the Thyristors are used as switches to connect the load circuit to the input ac supply, for a part of every input cycle. That is the ac supply voltage is chopped using Thyristors during a part of each input cycle.

The thyristor switch is turned on for a part of every half cycle, so that input supply voltage appears across the load and then turned off during the remaining part of input half cycle to disconnect the ac supply from the load.

By controlling the phase angle or the trigger angle 'α' (delay angle), the output RMS voltage across the load can be controlled.

The trigger delay angle 'α' is defined as the phase angle (the value of ωt) at which the thyristor turns on and the load current begins to flow.

Thyristor **AC Voltage Controllers** use ac line commutation or ac phase commutation. Thyristors in **AC Voltage Controllers** are line commutated (phase commutated) since the input supply is ac. When the input ac voltage reverses and becomes negative during the negative half cycle the current flowing through the conducting thyristor decreases and falls to zero. Thus the ON thyristor naturally turns off, when the device current falls to zero.

Phase control Thyristors which are relatively inexpensive, converter grade Thyristors which are slower than fast switching inverter grade Thyristors are normally used.

For applications upto 400Hz, if Triacs are available to meet the voltage and current ratings of a particular application, Triacs are more commonly used.

Due to ac line commutation or natural commutation, there is no need of extra commutation circuitry or components and the circuits for **AC Voltage Controllers** are very simple.
Due to the nature of the output waveforms, the analysis, derivations of expressions for performance parameters are not simple, especially for the phase controlled **AC Voltage Controllers** with RL load. But however most of the practical loads are of the RL type and hence RL load should be considered in the analysis and design of **AC Voltage Controllers** circuits.

Type of ac voltage controllers

The ac voltage controllers are classified into two types based on the type of input ac supply applied to the circuit.

- **Single Phase AC Controllers**
- **Three Phase AC Controllers**

Single Phase AC Controllers operate with single phase ac supply voltage of 230V RMS at 50Hz in our country. **Three Phase AC Controllers** operate with 3 phase ac supply of 400V RMS at 50Hz supply frequency.

Performance parameters of ac voltage controllers

- RMS Output (Load) Voltage

$$V_{O(RMS)} = \left[\frac{n}{2\pi (n+m)} \int_0^{2\pi} V_m^2 \sin^2 \omega t . d(\omega t) \right]^{1/2}$$

$$V_{O(RMS)} = \frac{V_m}{\sqrt{2}} \sqrt{\frac{n}{(m+n)}} = V_{i(RMS)} \sqrt{k} = V_S \sqrt{k}$$

$$V_{O(RMS)} = V_{i(RMS)} \sqrt{k} = V_S \sqrt{k}$$

Where $V_S = V_{i(RMS)}$ = RMS value of input supply voltage.

- Duty Cycle

$$k = \frac{t_{ON}}{T_O} = \frac{t_{ON}}{(t_{ON} + t_{OFF})} = \frac{nT}{(m+n)T}$$

Where, $k = \frac{n}{(m+n)}$ = duty cycle (d).

- RMS Load Current

$$I_{O(RMS)} = \frac{V_{O(RMS)}}{Z} = \frac{V_{O(RMS)}}{R_L}; \quad \text{for a resistive load } Z = R_L.$$

- Output AC (Load) Power

$$P_O = I^2_{O(RMS)} \times R_L$$

- Input Power Factor

$$PF = \frac{P_O}{VA} = \frac{\text{output load power}}{\text{input supply volt amperes}} = \frac{P_O}{V_S I_S}$$

$$PF = \frac{I^2_{O(RMS)} \times R_L}{V_{i(RMS)} \times I_{in(RMS)}}; \qquad I_S = I_{in(RMS)} = \text{RMS input supply current.}$$

The input supply current is same as the load current $I_{in} = I_O = I_L$

Hence, RMS supply current = RMS load current; $I_{in(RMS)} = I_{O(RMS)}$

$$PF = \frac{I^2_{O(RMS)} \times R_L}{V_{i(RMS)} \times I_{in(RMS)}} = \frac{V_{O(RMS)}}{V_{i(RMS)}} = \frac{V_{i(RMS)}\sqrt{k}}{V_{i(RMS)}} = \sqrt{k}$$

$$PF = \sqrt{k} = \sqrt{\frac{n}{m+n}}$$

Applications of ac voltage controllers

- Lighting / Illumination control in ac power circuits.
- Induction heating.
- Industrial heating & Domestic heating.
- Transformers tap changing (on load transformer tap changing).
- Speed control of induction motors (single phase and poly phase ac induction motor control).
- AC magnet controls.

Single phase AC voltage controller with R load

AC to AC voltage converters operates on the AC mains essentially to regulate the output voltage. Portions of the supply sinusoid appear at the load while the semiconductor switches block the remaining portions. Several topologies have emerged along with voltage regulation methods, most of which are linked to the development of the semiconductor devices.

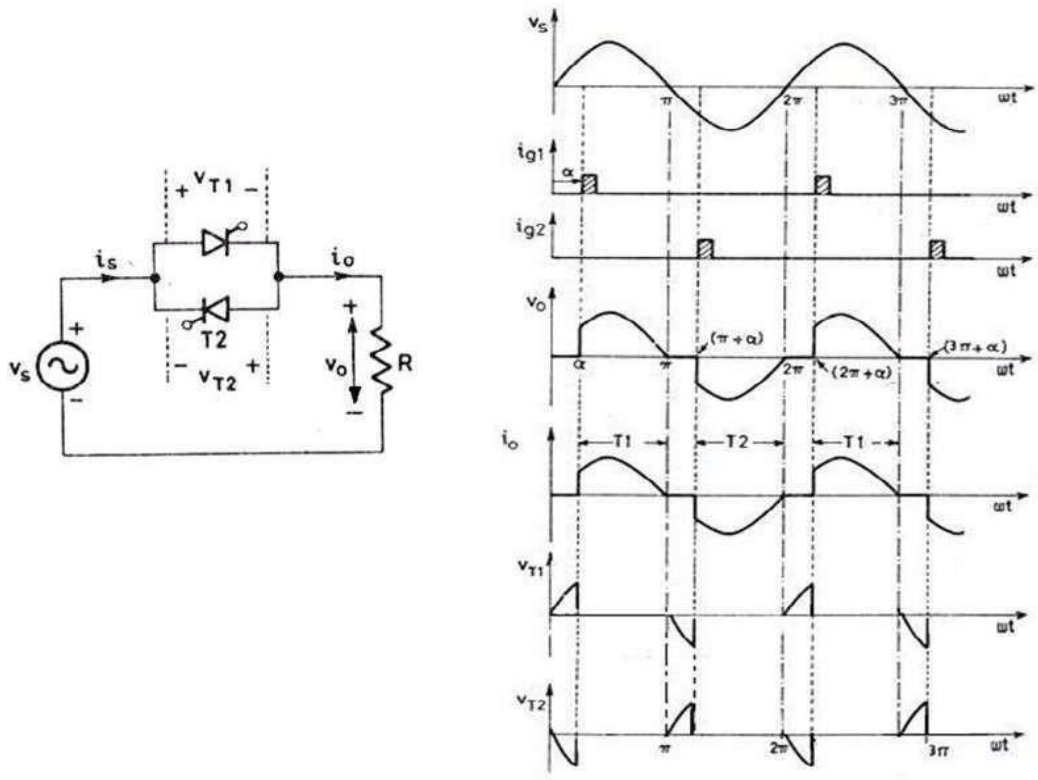


Figure: 3.2 Circuit diagram and output waveforms of AC voltage controller with R load

Fig. 2.35 illustrates the operation of the PAC converter with a resistive load. The device(s) is triggered at a phase-angle 'α' in each cycle. The current follows the voltage wave shape in each half and extinguishes itself at the zero crossings of the supply voltage. In the two-SCR topology, one SCR is positively biased in each half of the supply voltage. There is no scope for conduction overlap of the devices. A single pulse is sufficient to trigger the controlled devices with a resistive load. In the diode-SCR topology, two diodes are forward biased in each half. The SCR always receives a DC voltage and does not distinguish the polarity of the supply. It is thus always forward biased. The bi-directional TRIAC is also forward biased for both polarities of the supply voltage.

The rms voltage Vrms decides the power supplied to the load. It can be computed as

$$V_{rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} 2V^2 \sin^2 \omega t \quad d\omega t}$$
$$= V\sqrt{1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}}$$

Power Factor

The power factor of a nonlinear deserves a special discussion. Fig. 2.35 shows the supply voltage and the non-sinusoidal load current. The fundamental load/supply current lags the supply voltage by the φ1, 'Fundamental Power Factor' angle. Cosφ1 is also called the 'Displacement Factor'. However this does not account for the total reactive power drawn by the system. This power factor is inspite of the actual load being resistive! The reactive power is drawn also y the trigger-angle dependent harmonics. Now

$$power \quad factor = \frac{average \quad power}{apparent \quad voltamperes} = \frac{P}{VI_L}$$
$$= \frac{VI_{L1}\cos\phi_1}{VI_L}$$

$$distortion \quad factor = \frac{I_{L1}}{I_L}$$

The Average Power, P drawn by the resistive load is

$$P = \frac{1}{2\pi}\int_0^{2\pi} vi_L \quad d\omega t \quad = \frac{1}{\pi}\int_{\alpha}^{\pi} \frac{2V^2}{R}\sin^2 \omega t \quad dwt$$
$$= \frac{2V^2}{R\pi}\left[\pi - \frac{\alpha}{2} + \frac{\sin 2\alpha}{2}\right]$$

Single phase AC voltage controller with RL load

With inductive loads the operation of the PAC is illustrated in Fig 2. 36. The current builds up from zero in each cycle. It quenches not at the zero crossing of the applied voltage as with the resistive load but afterthat instant. The supply voltage thus continues to be impressed on the load till the load current returns to zero. A single-pulse trigger for the TRIAC) or the anti parallel SCR has no effect on the devices if it (or the anti-parallel device) is already in conduction in the reverse direction. The devices would fail to conduct when they are intended to, as they do not have the supply voltage forward biasing them when the trigger pulse arrives. A single pulse trigger will work till the trigger angle $\alpha > \varphi$, where φ is the power factor angle of the inductive load. A train of pulses is required here. The output voltage is controllable only between triggering angles φ and 180°. The load current waveform is further explained in Fig. 26.6. The current is composed of two components. The first is the steady state component of the load current, i_{ss}

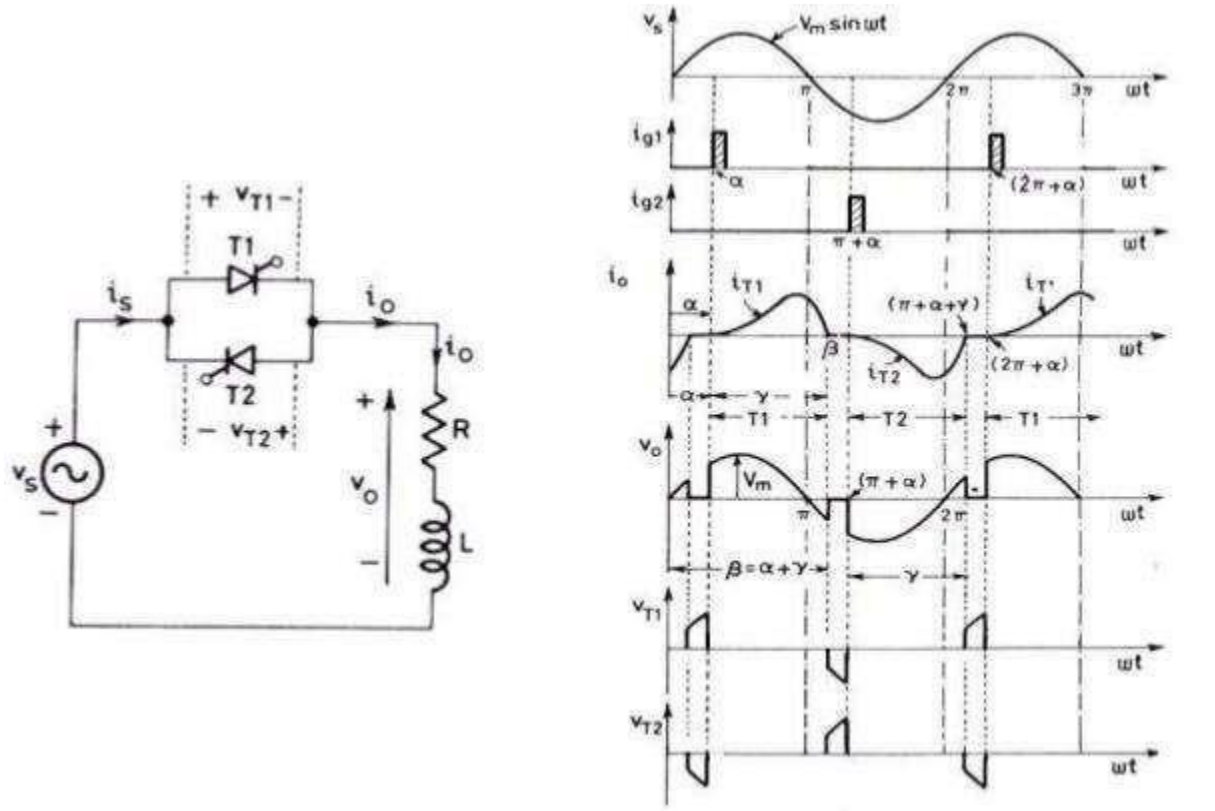


Figure: 3.3 Circuit diagram and output waveforms of AC voltage controller with RL load

With an inductance in the load the distinguishing feature of the load current is that it must always start from zero. However, if the switch could have permanently kept the load connected to the supply the current would have become a sinusoidal one phase shifted from the voltage by the phase angle of the load, φ. This current restricted to the half periods of conduction is called the 'steady-state component' of load current iss. The 'transient component' of load current itr, again in each half cycle, must add up to zerowith this iss to start from zero. This condition sets the initial value of the transient component to that of the steady state at the instant that the SCR/TRIAC is triggered. Fig. 2. 36 illustrates these relations. When a device is in conduction, the load current is governed by the equation

$$L\,di/dt + Ri = v_s$$

$$i_{load} = \frac{\sqrt{2}V}{Z}\left[\ \sin(\omega t - \phi) + \sin(\alpha - \phi)e^{-\frac{R}{L}\left(\alpha/\omega - t\right)}\ \right]$$

Since at t = 0, $i_{load} = 0$ and supply voltage $v_s = \sqrt{2}V\sin\omega t$ the solution is of the form the instant when the load current extinguishes is called the extinction angle β. It can be inferred that there would be no

transients in the load current if the devices are triggered at the power factor angle of the load. The load current I that case is perfectly sinusoidal.

Numerical Problems

1. A single phase voltage controller is employed for controlling the power flow from 230V, 50Hz source into a load circuit consisting of R=3 Ω and ωL=4 Ω. Calculate

(i) the range of firing angle

(ii) the maximum value of rms load current

(iii) the maximum power and power factor

(iv) The maximum values of average and rms thyristor currents.

Solution:

i. For controlling the load the minimum value of firing angle α = load phase angle

$$\varphi = tan^{-1}\frac{wL}{R} = tan^{-1}\frac{4}{3} = 53.13\ ^\circ$$

The maximum possible value of α is 180^0

So the firing angle control range is $53.13\ ^\circ \quad \alpha \quad 180^\circ$

ii. The maximum value of rms value of load current occurs when α = Φ = 53.13^0

But at this value of firing angle, the power circuit of ac voltage controller behaves as if load is directly connected to ac source. Therefore maximum value of rms load current is

$$I_0 = \frac{230}{\sqrt{R^2+(wL)^2}} = \frac{230}{\sqrt{3^2+4^2}} = 46A$$

iii. Maximum power = $I_0^2 xR = 46^2 x3 = 6348W$

Power factor = $\frac{I0^2 XR}{VsIo} = \frac{46x3}{230} = 0.6$

iv. Average thyristor current is maximum when α = Φ and conduction angle $\gamma = M$

$$I_{TAVG} = \frac{1}{2\pi}\int_{\alpha}^{\alpha+\pi} \frac{Vm}{Z}\sin(wt-\varphi)\,(wt)$$

$$= \frac{Vm}{\pi Z} = \frac{\sqrt{2}\times 230}{\pi\times\sqrt{3^2+4^2}} = 20.707A$$

Similarly maximum value of thyristor current is

$$I_{Trms} = \left\{\frac{1}{2\pi}\int_{\alpha}^{\alpha+\pi} \frac{Vm^2}{Z^2}\sin^2(wt-\alpha)\,(wt)\right\}^{1/2}$$

$$= \frac{Vm}{2Z} = \frac{\sqrt{2}\times 230}{2\times\sqrt{3^2+4^2}} = 32.527A$$

2. An ac voltage controller uses a TRIAC for phase angle control of a resistive load of 100Ω. Calculate the value of delay angle for having an rms load voltage of 220 volts. Also calculate the rms value of TRIAC current. Assume the rms supply voltage to be 230V.

3. The ac voltage controller uses on-off control for heating a resistive load of R = 4 ohms and the input voltage is Vs = 208V, 60Hz. If the desired output power is P_O = 3KW, determine the

(a) duty cycle δ

(b) input power factor

Sketch waveforms for the duty cycle obtained in (a)

Introduction to Cyclo converters

The **Cycloconverter** has been traditionally used only in very high power drives, usually aboveone megawatt, where no other type of drive can be used. Examples are cement tube mill drives above 5 MW, the 13 MW German-Dutch wind tunnel fan drive, reversible rolling mill drives andship propulsion drives. The reasons for this are that the traditional **Cycloconverter** requires alarge number of thyristors, at least 36 and usually more for good motor performance, together with a very complex control circuit, and it has some performance limitations, the worst of which is an output frequency limited to about one third the input frequency .

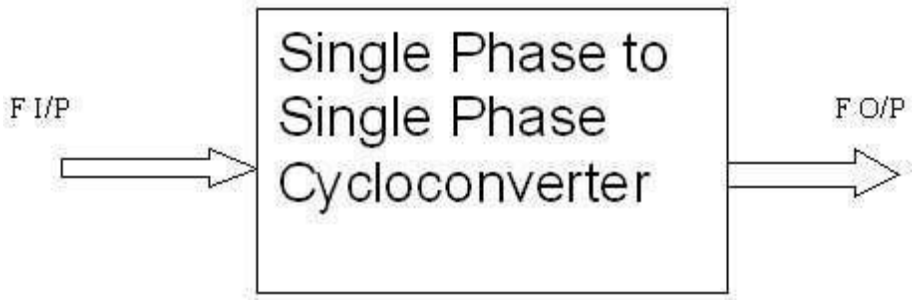


Figure 3.11 Block diagram of cycloconverters

The **Cycloconverter** has four thyristors divided into a positive and negative bank of two thyristors each. When positive current flows in the load, the output voltage is controlled by phase control of the two positive bank thyristors whilst the negative bank thyristors are kept off and vice versa when negative current flows in the load. An idealized output waveform for a sinusoidal load current and a 45 degrees load phase angle is shown in Figure 3.11. It is important to keep the non conducting thyristor bank off at all times, otherwise the mains could be shorted via the two thyristor banks, resulting in waveform distortion and possible device failure from the shorting current. A major control problem of the **Cycloconverter** is how to swap between banks in the shortest possible time to avoid distortion whilst ensuring the two banks do not conduct at the same time. A common addition to the power circuit that removes the requirement to keep one bank off is to place a centre tapped inductor called a circulating current inductor between the outputs of the two banks. Both banks can now conduct together without shorting the mains. Also, the circulating current in the inductor keeps both banks operating all the time, resulting in improved output waveforms. This technique is not often used, though, because the circulating current inductor tends to be expensive and bulky and the circulating current reduces the power factor on the input

In a **1-φ Cycloconverter,** the output frequency is less than the supply frequency. These converters require natural commutation which is provided by AC supply. During positive half cycle of supply, Thyristors P1 and N2 are forward biased. First triggering pulse is applied to P1 and hence it starts conducting.

As the supply goes negative,P1 gets off and in negative half cycle of supply, P2 and N1 are forward biased. P2 is triggered and hence it conducts. In the next cycle of supply,N2 in positive half cycle andN1 in negative half cycle are triggered. Thus, we can observe that here the output frequency is 1/2 times the supply frequency.

Operation Principles

The following sections will describe the operation principles of the **Cycloconverter** starting from the simplest one, **single-phase to single-phase (1f-1f) Cycloconverter.**

Single-phase to Single-phase (1 Φ-1 Φ) Cycloconverter

To understand the operation principles of **Cycloconverters**, the single-phase to single- phase **Cycloconverter** (Fig. 3.12) should be studied first. This converter consists of back-to-back connection of two full-wave rectifier circuits. Fig 3.13 shows the operating waveforms for this converter with a resistive load.

Zero Firing angle, i.e. thyristors act like diodes. Note that the firing angles are named as αP for the positive converter and αN for the negative converter. The input voltage, vs is an ac voltage at a frequency, fi as shown in Fig. 3.13. For easy understanding assume that all the thyristors are fired at α=0°

Consider the operation of the **Cycloconverter** to get one-fourth of the input frequency at the output. For the first two cycles of vs, the positive converter operates supplying current to the load. It rectifies the input voltage; therefore, the load sees 4 positive half cycles as seen in Fig.
3.13. In the next two cycles, the negative converter operates supplying current to the load in the reverse direction. The current waveforms are not shown in the figures because the resistive load current will have the same waveform as the voltage but only scaled by t he resistance. Note that when one of the converters operates the other one is disabled, so that there is no current circulating between the two rectifiers.

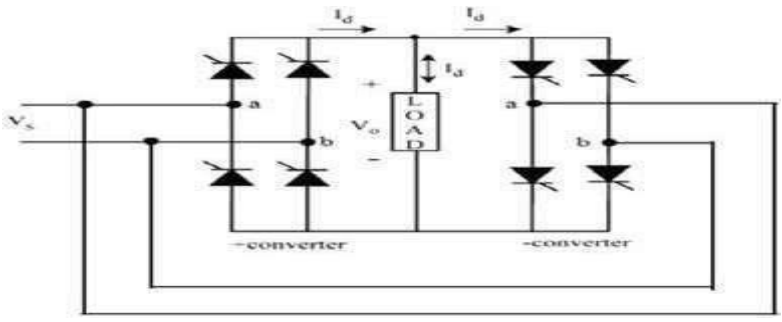


Figure 3.12 circuit diagram of cycloconverter

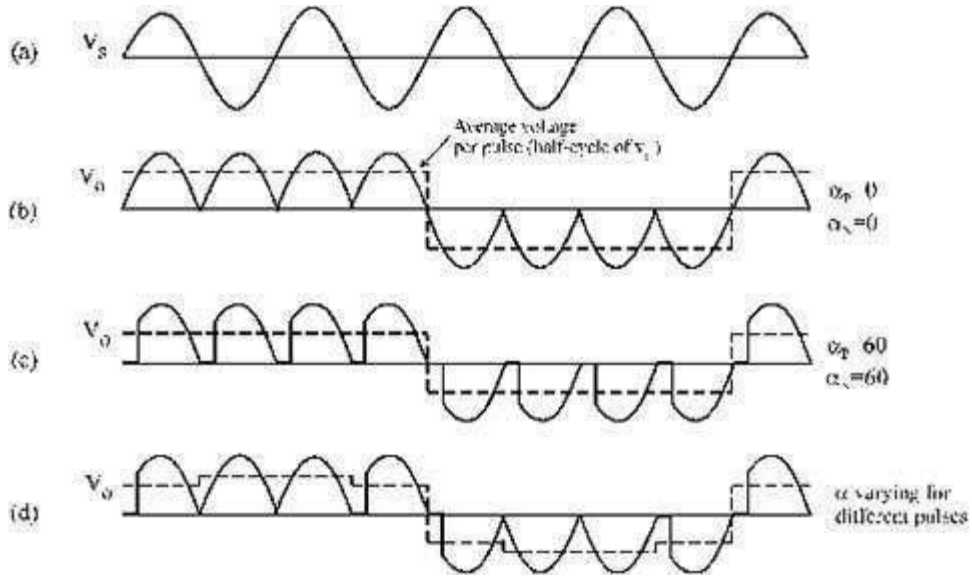


Figure 3.13 Input and output waveforms of cycloconverter

Single phase midpoint Cyclo converters

Basically, these are divided into two main types, and are given below

Step-down cyclo-converter

It acts like a step-down transformer that provides the output frequency less than that of input, fo < fi.

Step-up cyclo-converter

It provides the output frequency more than that of input, fo > fi.

In case of step-down cyclo-converter, the output frequency is limited to a fraction of input frequency, typically it is below 20Hz in case 50Hz supply frequency. In this case, no separate commutation circuits are needed as SCRs are line commutated devices.

But in case of step-up cyclo-converter, forced commutation circuits are needed to turn OFF SCRs at desired frequency. Such circuits are relatively very complex. Therefore, majority of cyclo-converters are of step-down type that lowers the frequency than input frequency.

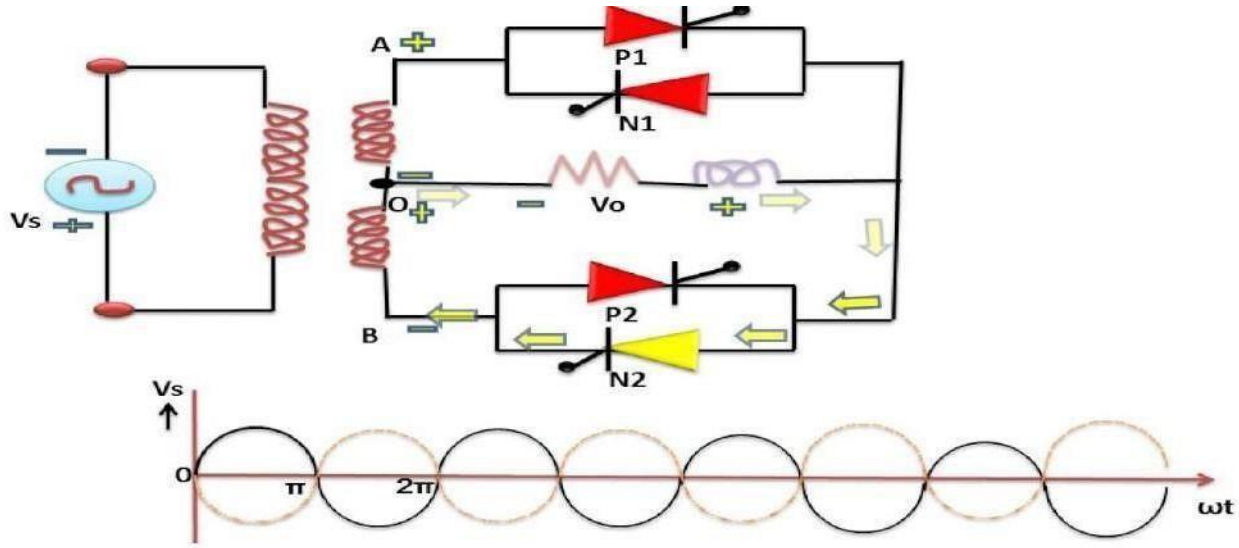


Figure 3.14 circuit diagram of midpoint cycloconverter

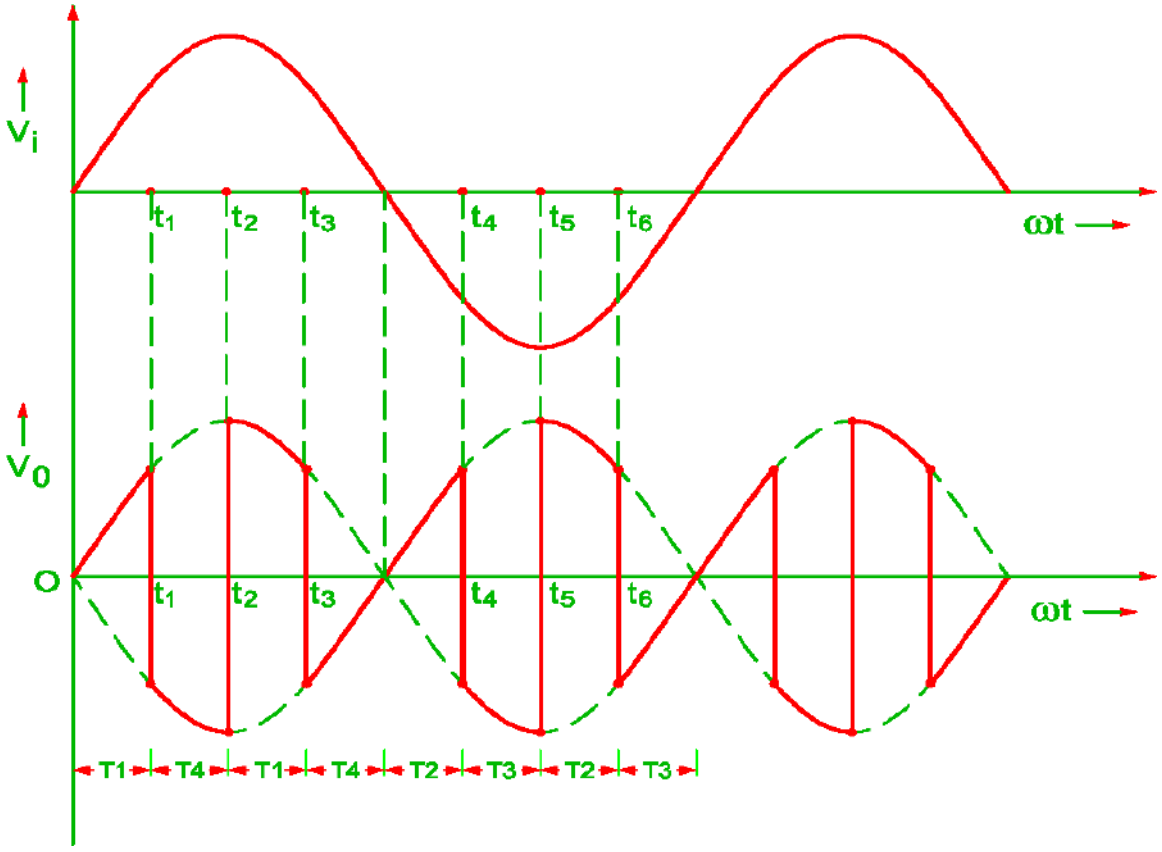


Figure 3.15 Input and output waveforms of midpoint cycloconverter

It consists of single phase transformer with mid tap on the secondary winding and four thyristors. Two of these thyristors P1, P2 are for positive group and the other two N1, N2 are for the negative group. Load is connected between secondary winding midpoint 0 and the load terminal. Positive directions for output voltage and output current are marked in figure 3.14

In figure 3.14 during the positive half cycle of supply voltage terminal a is positive with respect to terminal b. therefore in this positive half cycle, both p1 and N2 are forward biased from wt= 0 to Π. As such SCR P1 is turned on at wt = 0 so that load voltage is positive with terminal A and 0 negative. Now the load voltage is positive. At instant t1 P1 is force commutated and forward biased thyristor N2 is turned on so that load voltage is negative with terminal 0 and A negative. Now the load voltage is negative. Now N2 is force commutated and P1 is turned on the load voltage is positive this is a continuous process and will get step up cyclo converter output

Bridge configuration of single phase Cyclo converter

The equivalent circuit of a cyclo-converter is shown in figure below. Here each two quadrant phase controlled converter is represented by a voltage source of desired frequency and consider that the output power is generated by the alternating current and voltage at desired frequency.

The diodes connected in series with each voltage source represent the unidirectional conduction of each two quadrant converter. If the output voltage ripples of each converter are neglected, then it becomes ideal and represents the desired output voltage.

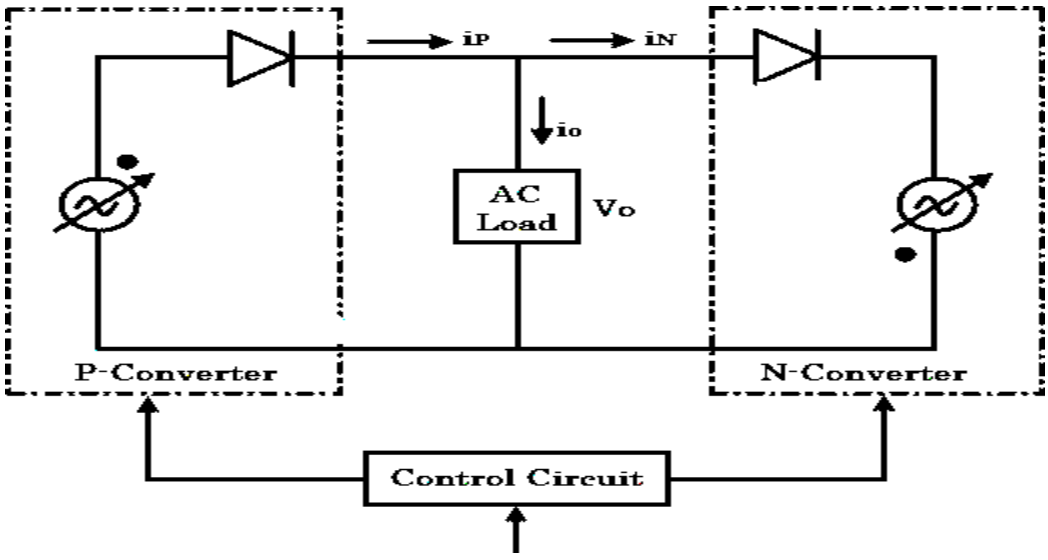


Figure 3.16 Block diagram of bridge type cycloconverter

If the firing angles of individual converters are modulated continuously, each converter produces same sinusoidal voltages at its output terminals.

So the voltages produced by these two converters have same phase, voltage and frequency. The average power produced by the cyclo-converter can flow either to or from the output terminals as the load current can flow freely to and from the load through the positive and negative converters.

Therefore, it is possible to operate the loads of any phase angle (or power factor), inductive or capacitive through the cyclo-converter circuit.

Due to the unidirectional property of load current for each converter, it is obvious that positive converter carries positive half-cycle of load current with negative converter remaining in idle during this period.

Similarly, negative converter carries negative half cycle of the load current with positive converter remaining in idle during this period, regardless of the phase of current with respect to voltage.

This means that each converter operates both in rectifying and inverting regions during the period of its associated half cycles.

The figure below shows ideal output current and voltage waveforms of a cyclo-converter for lagging and leading power factor loads. The conduction periods of positive and negative converters are also illustrated in the figure.

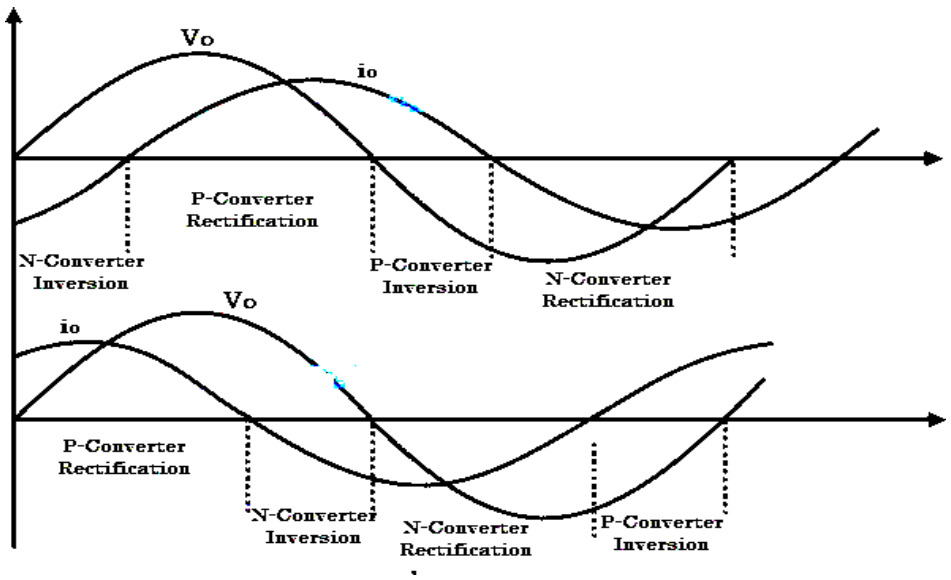


Figure 3.17 cycloconverter waveforms

The positive converter operates whenever the load current is positive with negative converter remaining in idle. In the same manner negative converter operates for negative half cycle of load current.

Both rectification and inversion modes of each converter are shown in figure. This desired output voltage is produced by regulating the firing angle to individual converters.

Single-phase to single-phase cyclo-converters

These are rarely used in practice; however, these are required to understand fundamental principle of cyclo-converters.

It consists of two full-wave, fully controlled bridge thyristors, where each bridge has 4 thyristors, and each bridge is connected in opposite direction (back to back) such that both positive and negative voltages can be obtained as shown in figure below. Both these bridges are excited by single phase, 50 Hz AC supply.

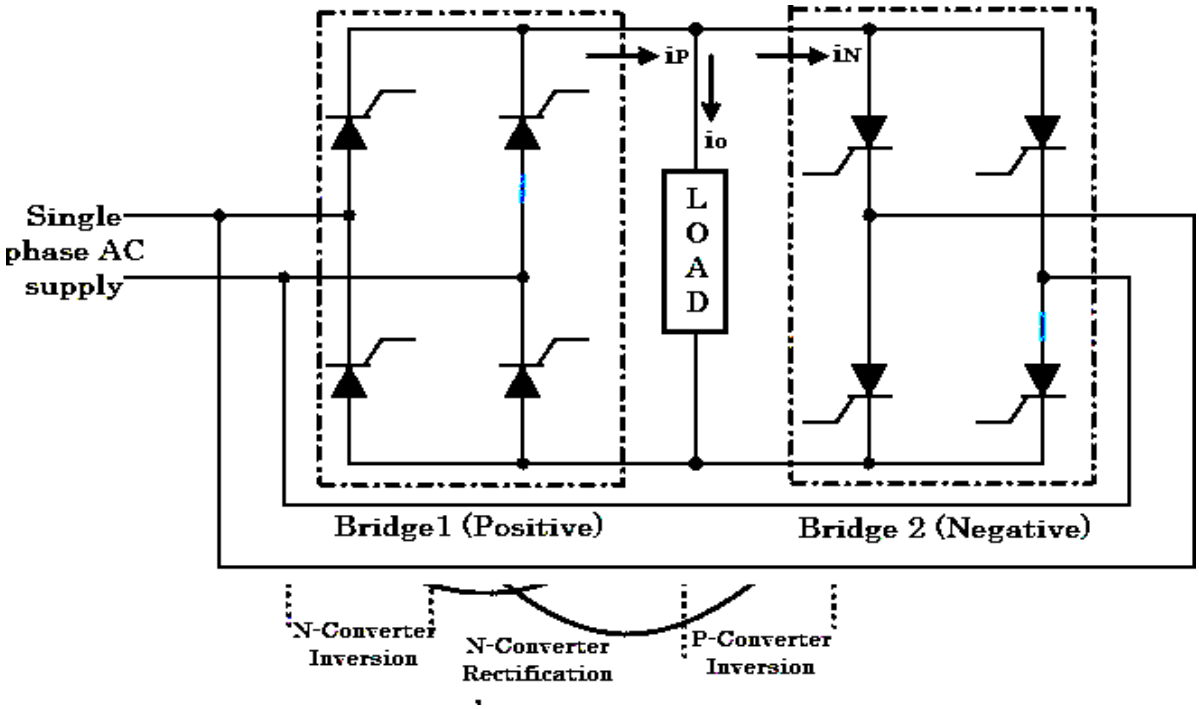


Figure 3.18 Circuit diagram of bridge type cycloconverter

During positive half cycle of the input voltage, positive converter (bridge-1) is turned ON and it supplies the load current. During negative half cycle of the input, negative bridge is turned ON and it supplies load current. Both converters should not conduct together that cause short circuit at the input.

To avoid this, triggering to thyristors of bridge-2 is inhibited during positive half cycle of load current, while triggering is applied to the thyristors of bridge-1 at their gates. During negative half cycle of load current, triggering to positive bridge is inhibited while applying triggering to negative bridge.

By controlling the switching period of thyristors, time periods of both positive and negative half cycles are changed and hence the frequency. This frequency of fundamental output voltage can be easily reduced in steps, i.e., 1/2, 1/3, 1/4 and so on.

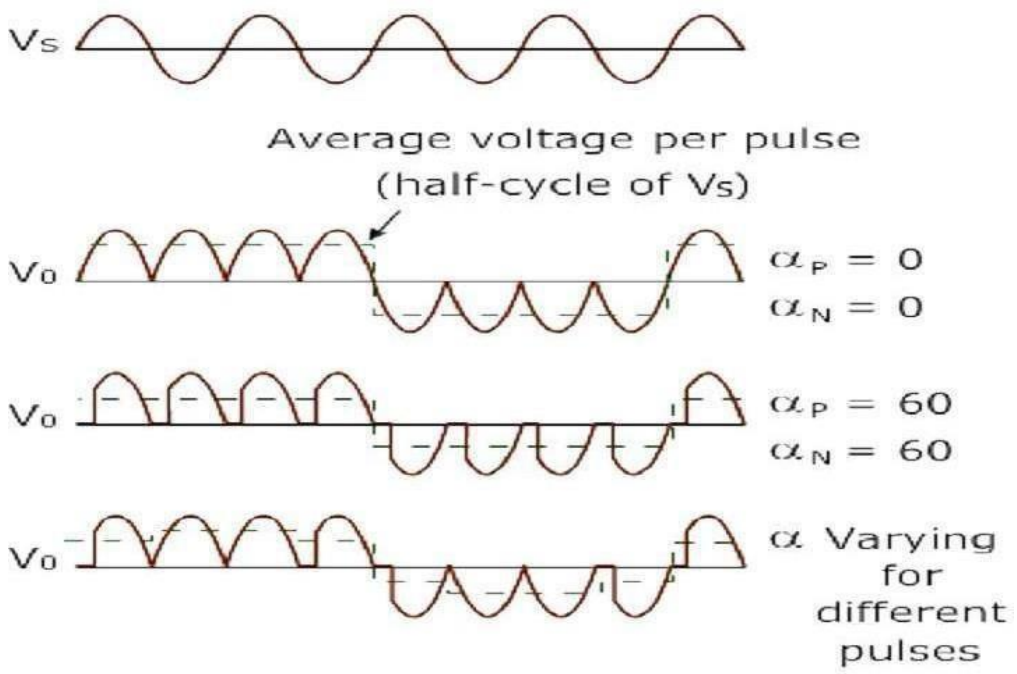


Figure 3.19 Input and output waveforms of bridge type cycloconverter

The above figure shows output waveforms of a cyclo-converter that produces one-fourth of the input frequency. Here, for the first two cycles, the positive converter operates and supplies current to the load.

It rectifies the input voltage and produce unidirectional output voltage as we can observe four positive half cycles in the figure. And during next two cycles, the negative converter operates and supplies load current.

Here current waveforms are not shown because it is a resistive load in where current (with less magnitude) exactly follows the voltage.

Here one converter is disabled if another one operates, so there is no circulating current between two converters. Since the discontinuous mode of control scheme is complicated, most cyclo-converters are operates on circulating current mode where continuous current is allowed to flow between the converters with a reactor.

This circulating current type cyclo-converter can be operated on with both purely resistive (R) and inductive (R-L) loads.

1. A single-phase to single-phase cycloconverter is supplying and inductive load comprising of a Resistance of 5Ω and an inductance of 40 mH from a 230 V, 50 Hz single-phase supply It is Required to provide an output frequency which is 1/3 of the input frequency. If the converters are Operated as semi converter such that $0 \leq \alpha \leq \pi$ and firing delay angle is120°. Neglecting the Harmonic content of load voltage, determine:
   (a) rms value of output voltage.
   (b) rms current of each thyristor and
   (c) input power factor.

   Solution:

$$E = 230\ \text{V}, f_1 = 50\ \text{Hz}, \alpha_p = \frac{2\pi}{3}$$

$$f_0 = 50/2 = 16.2/3\ \text{Hz}, R = 5\Omega, L = 40\ \text{mH}.$$

$$\omega_0 = 2\pi \times 50/3 = 104.72\ \text{rad/s}.$$

$$X_L = \omega_0 L = 104.72 \times 40 \times 10^{-3} = 4.188\ \Omega$$

$$Z_L = \sqrt{5^2 + (4.188)^2} = 6.52\ \Omega.$$

$$\theta = \tan^{-1}(\omega_0 L/R) \cong 40°.$$

(a) For $O \leq \alpha \leq \pi$, *rms* value of output voltage,

$$E_o = E \cdot \left[\frac{1}{\pi}\left(\pi - \alpha_p + \frac{\sin 2\alpha_p}{2}\right)\right]^{1/2}$$

$$= 230 \cdot \left[\frac{1}{\pi}\left\{\left(\pi - \frac{2\pi}{3}\right) + \frac{\sin 240}{2}\right\}\right]^{1/2}$$

$$= 101.6\ \text{V}$$

(b) RMS value of load current, $I_o = \frac{E_o}{Z_L}$

$$= \frac{101.6}{4.188} = 24.26\ \text{A}.$$

The *rms* current through each converter group is

$$I_P = I_N = \frac{I_o}{\sqrt{2}} = 17.1542 \text{ A.}$$

and the *rms* current through each thyristor

$$I_{Trms} = \frac{I_p}{\sqrt{2}} = \frac{17.1542}{\sqrt{2}} = 12.13 \text{ A.}$$

(c) *rms* input current, $I_i = I_o = 24.26$ A.

The volt-amp rating $= E \cdot I_i = 230 \times 24.26 = 5580$ VA

The output power, $P_o = E_o \cdot I_o \cdot \cos\theta = 101.6 \times 24.26 \times \cos 40°$

$= 1888.1$ watts.

$$\therefore \quad \text{Power factor} = \frac{P_o}{E \cdot I_i} = \frac{1888}{5580}$$

$= 0.3384$ (lagging)

Now, $\quad \text{P.F.} = \frac{m_f}{\sqrt{2}} \cdot \cos\phi$

$m_f = \cos(180 - \alpha_p) = \cos 60° = 0.5$

$\cos\phi = \cos 40 = 0.766.$

Hence, $\quad P_f = \frac{0.5}{\sqrt{2}} \cdot \cos 40 = 0.27$

2. In a standard A single-phase bridge-type cyclo-converter has input voltage of 230V, 50Hz and load of R=10Ω. Output frequency is one-third of input frequency. For a firing angle delay of 30°, Calculate (i) rms value of output voltage (ii) rms current of each converter (iii) rms current of each thyristor (iv) input power factor.
3. A single-phase to single-phase mid-point cyclo-converter is delivering power to a resistive load. The supply transformer has turns ratio of 1: 1: 1. The frequency ratio is fo/fs = 1/5. The firing angle delay α for all the four SCRs are the same. Sketch the time variations of the following waveforms for α = 0° and α = 30°(a) Supply voltage (b) Output current and (c) Supply current. Indicate the conduction of various thyristors also.