6-1 INTRODUCTION

We have seen in Chapter 5 that thyristors can be operated as switches. If a thyristor switch is connected between ac supply and load, the power flow can be controlled by varying the rms value of ac voltage applied to the load; and this type of power circuit is known as an *ac voltage controller*. The most common applications of ac voltage controllers are: industrial heating, on-load transformer tap changing, light controls, speed control of polyphase induction motors, and ac magnet controls. For power transfer, two types of control are normally used:

1. On–off control
2. Phase-angle control

In on–off control, thyristor switches connect the load to the ac source for a few cycles of input voltage and then disconnect it for another few cycles. In phase control, thyristor switches connect the load to ac source for a portion of each cycle of input voltage.

The ac voltage controllers can be classified into two types: (1) single-phase controllers and (2) three-phase controllers. Each type can be subdivided into (a) unidirectional or half-wave control and (b) bidirectional or full-wave control. There are various configurations of three-phase controllers depending on the connections of thyristor switches.

Since the input voltage is ac, thyristors are line commutated; and phase-control thyristors, which are relatively inexpensive and slower than fast-switching thyristors, are normally used. For applications up to 400 Hz, if TRIACs are available to meet the voltage and current ratings of a particular application, TRIACs are more commonly used.

Due to line or natural commutation, there is no need of extra commutation circuitry and the circuits for ac voltage controllers are very simple. Due to the nature of output waveforms, the analysis for the derivations of explicit expressions for the performance parameters of circuits are not simple, especially for phase-angle-controlled converters with *RL* loads. For the sake of simplicity, resistive loads are considered in this chapter to compare the performances of various configurations.

6-2 PRINCIPLE OF ON–OFF CONTROL

The principle of on–off control can be explained with a single-phase full-wave controller as shown in Fig. 6-1a. The thyristor switch connects the ac supply to load for a time t_n; the switch is turned off by a gate pulse inhibiting for time t_0. The on-time, t_n, usually consists of an integral number of cycles. The thyristors are turned on at the zero-voltage crossings of ac input voltage. The gate pulses for thyristors T_1 and T_2 and the waveforms for input and output voltages are shown in Fig. 6-1b.

This type of control is applied in applications, which have a high mechanical inertia and high thermal time constant (e.g., industrial heating and speed control of motors). Due to zero voltage switching of thyristors, the harmonics generated by switching actions are reduced.

For a sinusoidal input voltage, $v_s = V_m \sin \omega t = \sqrt{2}\, V_s \sin \omega t$. If the input voltage is connected to load for n cycles and is disconnected for m cycles, the rms output (or load) voltage can be found from

$$
\begin{aligned}
V_o &= \left[\frac{n}{2\pi(n + m)} \int_0^{2\pi} 2V_s^2 \sin^2 \omega t \, d(\omega t)\right]^{1/2} \\
&= V_s \sqrt{\frac{n}{m + n}} = V_s \sqrt{k}
\end{aligned}
\tag{6-1}
$$

where $k = n/(m + n)$ and k is called the *duty cycle*. V_s is the rms phase voltage. The circuit configurations for on–off control are similar to those of phase control and the performance analysis is also similar. For these reasons, the phase-control techniques are only discussed and analyzed in this chapter.

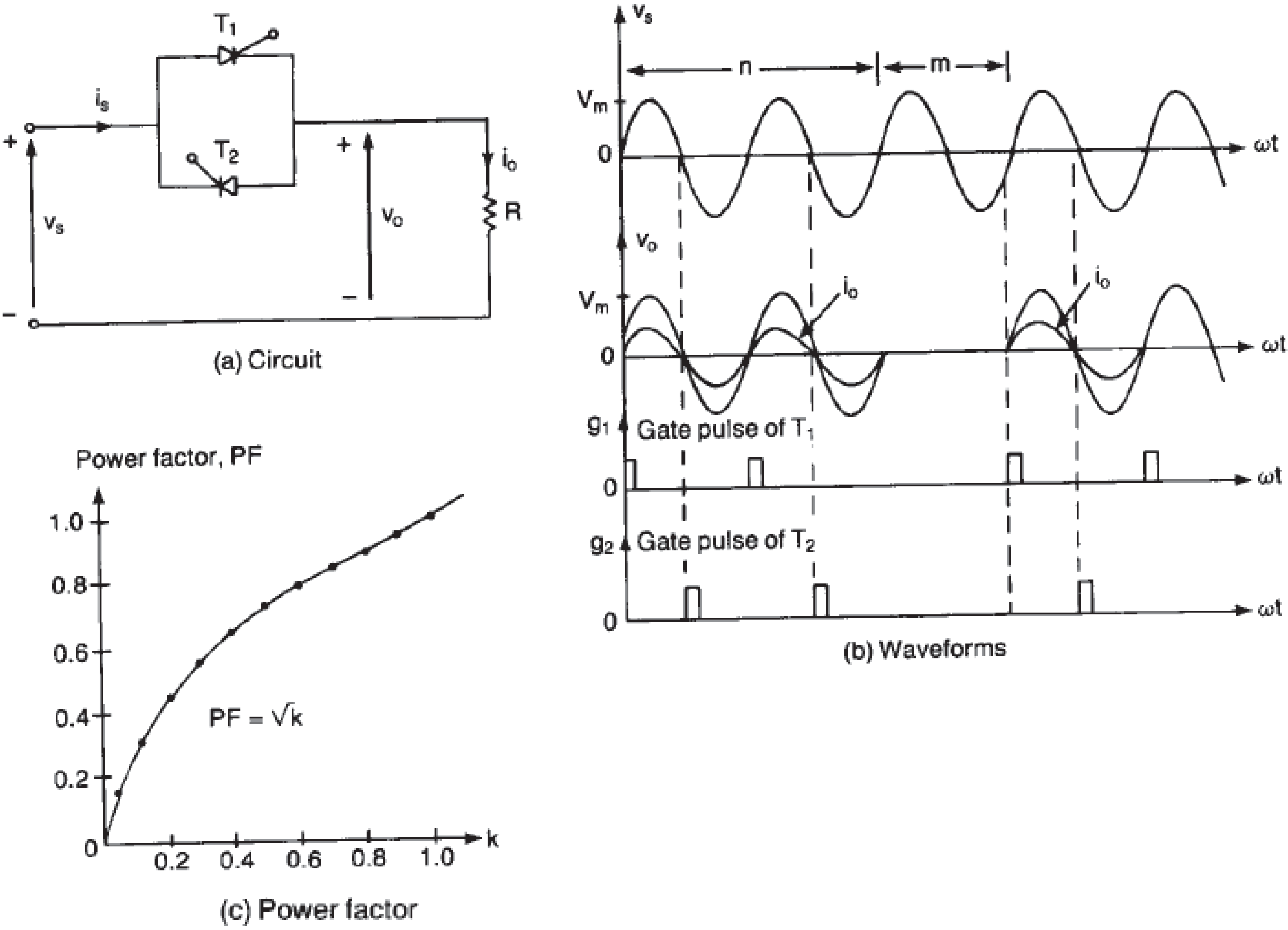

Figure 6-1 On-off control.

Note. The power factor and output voltage vary with the square root of the duty cycle. The power factor is poor at the low value of duty the cycle, k, and is shown in Fig. 6-1c.

6-4 SINGLE-PHASE BIDIRECTIONAL CONTROLLERS WITH RESISTIVE LOADS

The problem of dc input current can be prevented by using bidirectional (or full-wave) control, and a single-phase full-wave controller with a resistive load is shown in Fig. 6-3a. During the positive half-cycle of input voltage, the power flow is controlled by varying the delay angle of thyristor T_1; and thyristor T_2 controls the power flow during the negative half-cycle of input voltage. The firing pulses of T_1 and T_2 are kept 180° apart. The waveforms for the input voltage, output voltage, and gating signals for T_1 and T_2 are shown in Fig. 6-3b.

If $v_s = \sqrt{2}\, V_s \sin \omega t$ is the input voltage and the delay angles of thyristors T_1 and T_2 are equal $\alpha_1 = \alpha_2 = \alpha$, the rms output voltage can be found from

$$\begin{aligned} V_o &= \left[\frac{2}{2\pi}\int_{\alpha}^{\pi} 2V_s^2 \sin^2 \omega t \; d(\omega t)\right]^{1/2} \\ &= \left[\frac{4V_s^2}{4\pi}\int_{\alpha}^{\pi} (1 - \cos 2\omega t)\; d(\omega t)\right]^{1/2} \qquad (6\text{-}8) \\ &= V_s\left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2} \end{aligned}$$

By varying α from 0 to π, V_o can be varied from V_s to 0.

In Fig. 6-3a, the gating circuits for thyristors T_1 and T_2 must be isolated. It is possible to have a common cathode for T_1 and T_2 by adding two diodes as shown in Fig. 6-4. Thyristor T_1 and diode D_1 conduct together during the positive half-cycle; and thyristor T_2 and diode D_2 conduct during the negative half-cycle. Since this circuit can have a common terminal for gating signals of T_1 and T_2, only one isolation circuit is required, but at the expense of two power diodes. Due to two power devices conducting at the same time, the conduction losses of devices would increase and efficiency would be reduced.

A single-phase full-wave controller can also be implemented with one thyristor and four diodes as shown in Fig. 6-5a. The four diodes act as a bridge rectifier. The voltage across thyristor T_1, and its current, are always unidirectional. With a resistive load, the thyristor current would fall to zero due to natural commutation in every half-cycle, as shown in Fig. 6-5b. However, if there is a large inductance in the circuit, thyristor T_1 may not be turned off in every half-cycle of input voltage, and this may result in a loss of control. Three power devices conduct at the same time and the efficiency is also reduced. The bridge rectifier and thyristor (or transistor) act as a *bidirectional switch*, which is commercially available as a single device with a relatively low on-state conduction loss.

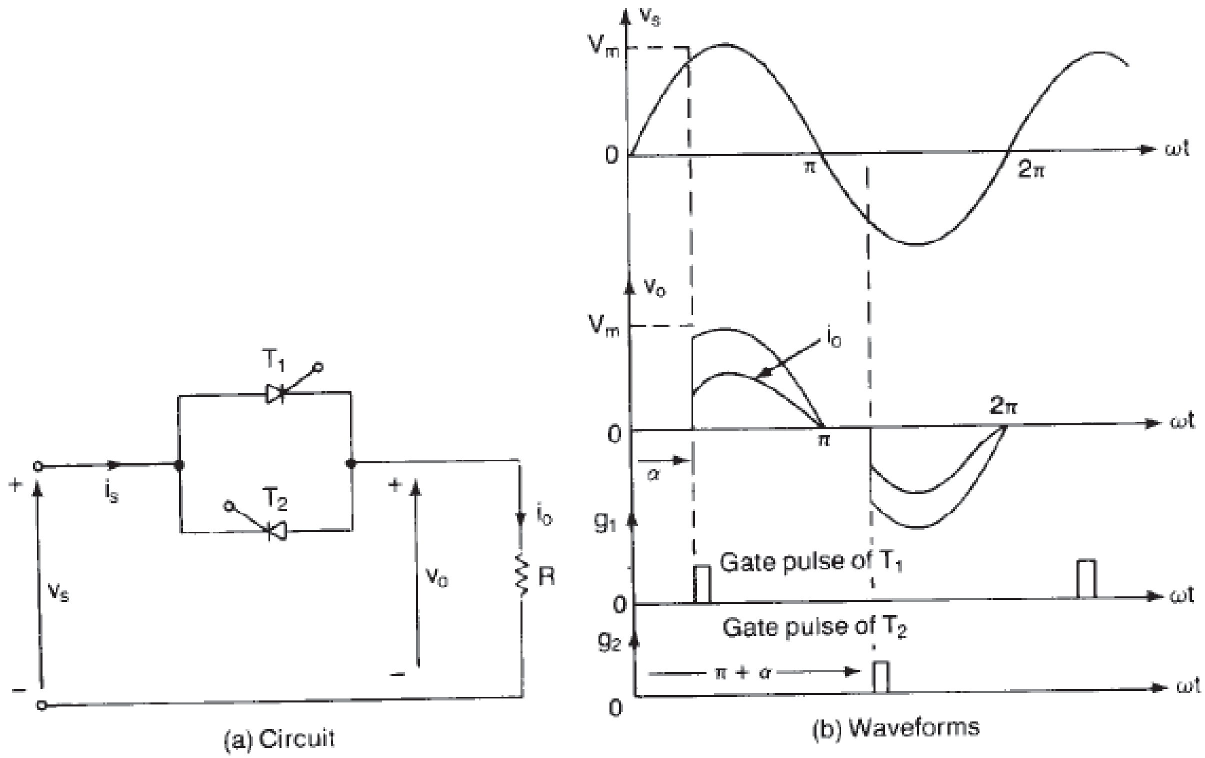

Figure 6-3 Single-phase full-wave controller.

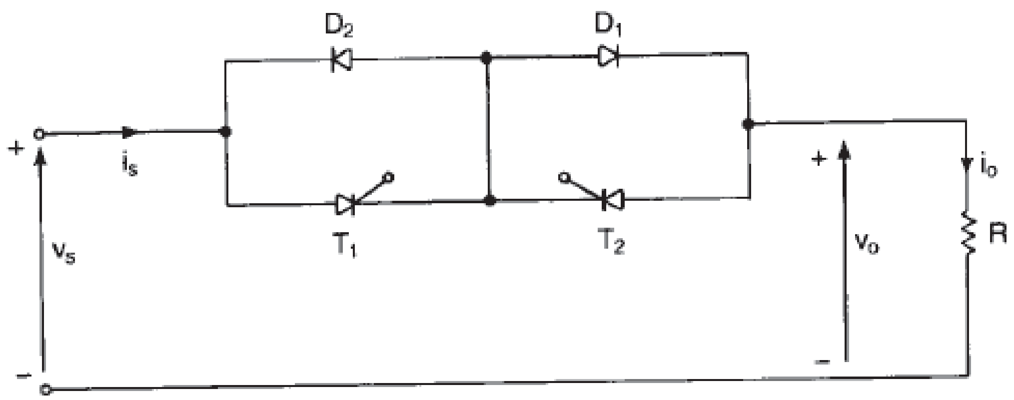

Figure 6-4 Single-phase full-wave controller with common cathode.

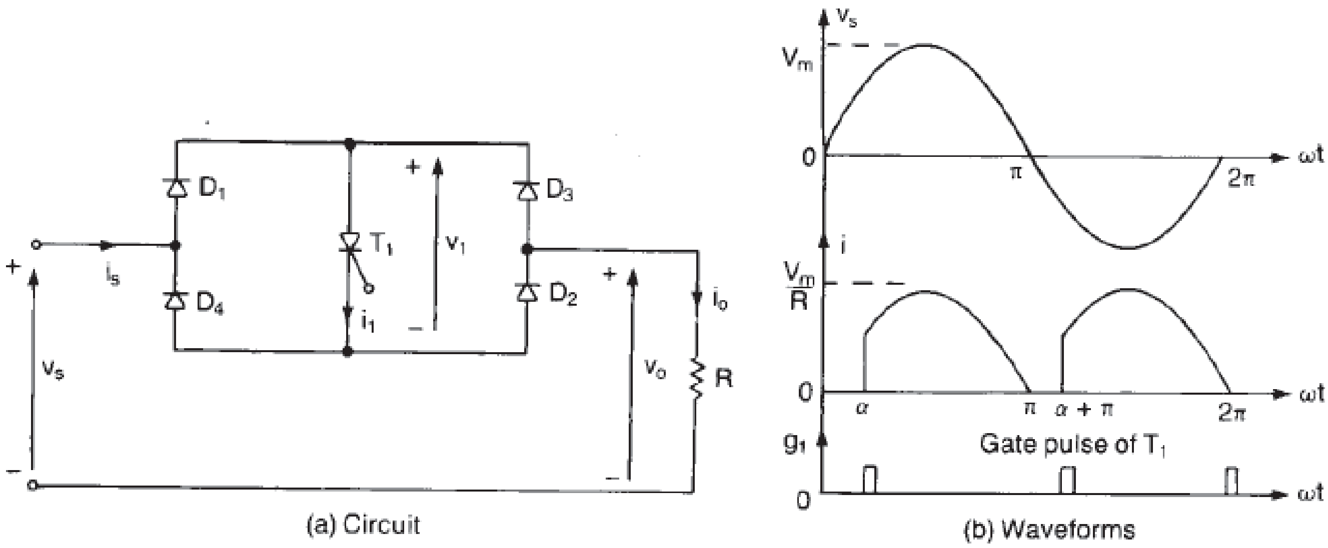

Figure 6-5 Single-phase full-wave controller with one thyristor.