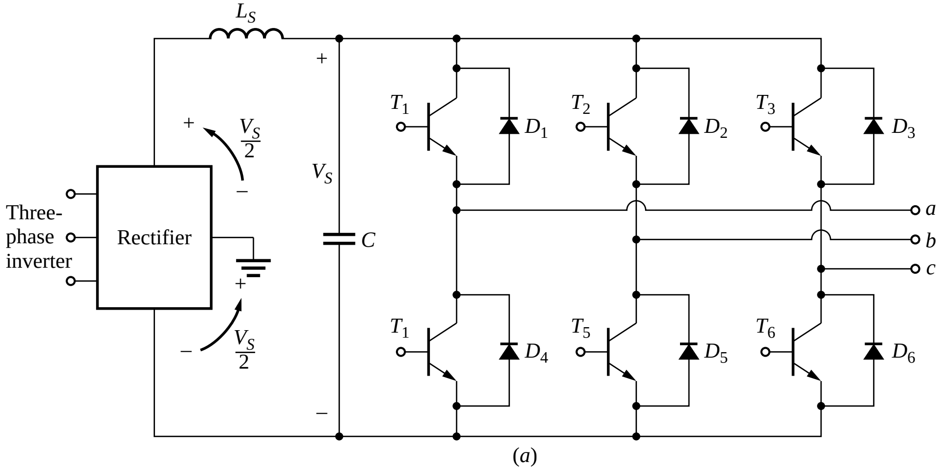
Pulse-Width Modulation Inverters

Pulse-width modulation is the process of modifying the width of the pulses in a pulse train in direct proportion to a small control signal; the greater the control voltage, the wider the resulting pulses become. By using a sinusoid of the desired frequency as the control voltage for a PWM circuit, it is possible to produce a high-power waveform whose *average* voltage varies sinusoidally in a manner suitable for driving ac motors.

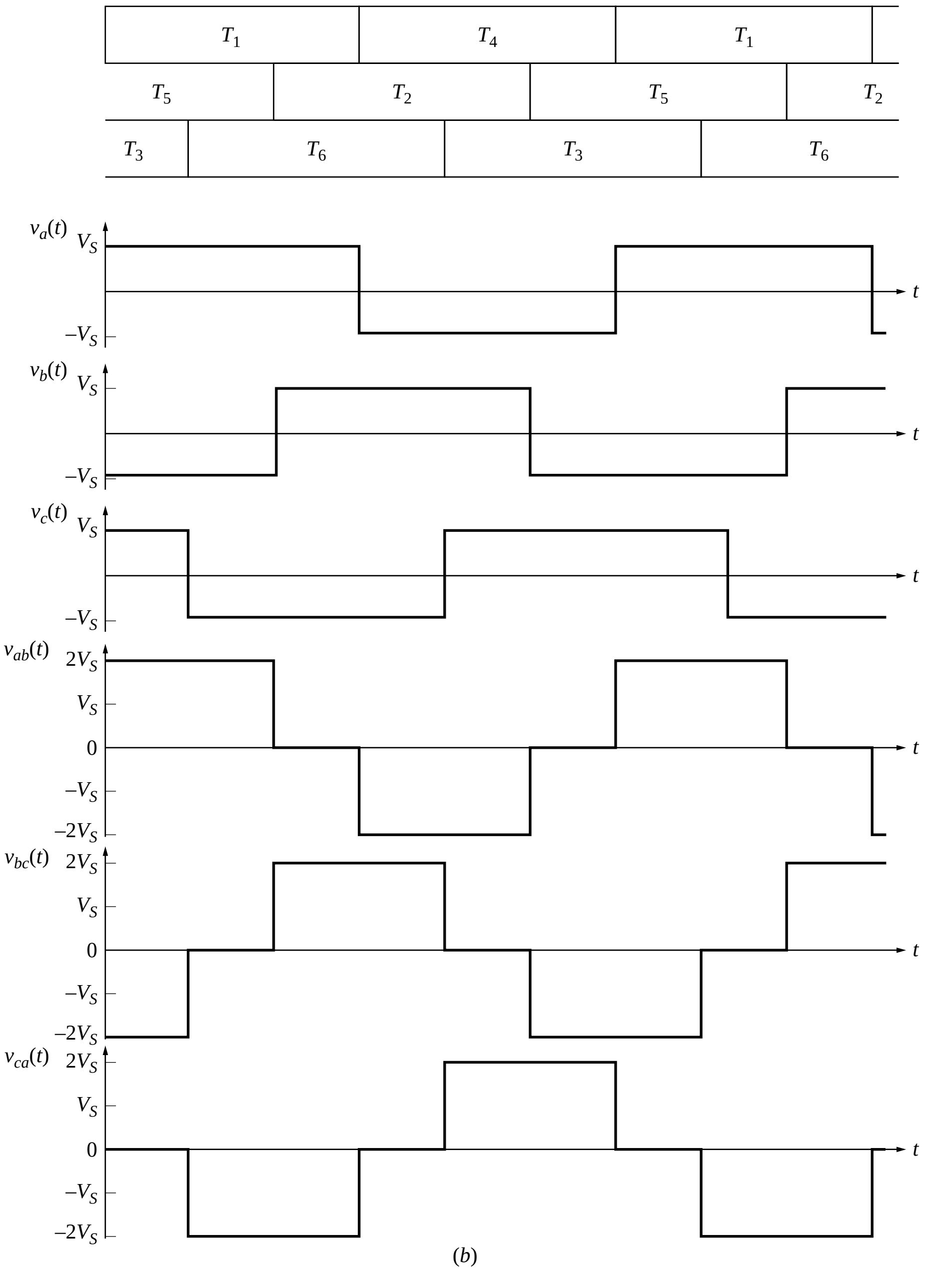
The basic concepts of pulse-width modulation are illustrated in Figure 3–55. Figure 3–55*a* shows a single-phase PWM inverter circuit using IGBTs. The states of $IGBT_1$ through $IGBT_4$ in this circuit are controlled by the two comparators shown in Figure 3–55*b*.

A *comparator* is a device that compares the input voltage $v_{in}(t)$ to a reference signal and turns transistors on or off depending on the results of the test. Comparator *A* compares $v_{in}(t)$ to the reference voltage $v_x(t)$ and controls IGBTs T_1 and T_2 based on the results of the comparison. Comparator *B* compares $v_{in}(t)$ to the reference voltage $v_y(t)$ and controls IGBTs T_3 and T_4 based on the results of the comparison. If $v_{in}(t)$ is greater than $v_x(t)$ at any given time *t*, then comparator *A* will turn on T_1 and turn off T_2. Otherwise, it will turn off T_1 and turn on T_2. Similarly, if $v_{in}(t)$ is greater than $v_y(t)$ at any given time *t*, then comparator *B* will turn off T_3 and turn on T_4. Otherwise, it will turn on T_3 and turn off T_4. The reference voltages $v_x(t)$ and $v_y(t)$ are shown in Figure 3–55*c*.



(*a*)

FIGURE 3–54
(*a*) A three-phase voltage source inverter using power transistors.



(*b*)

FIGURE 3–54 (concluded)
(*b*) The output phase and line voltages from the inverter.

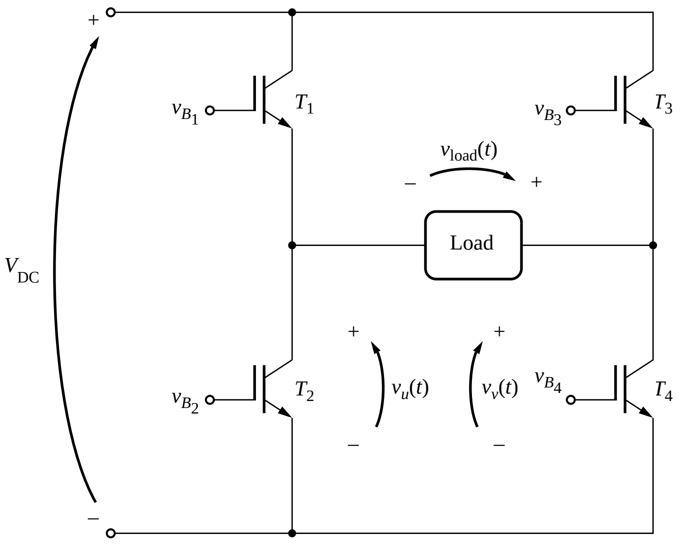


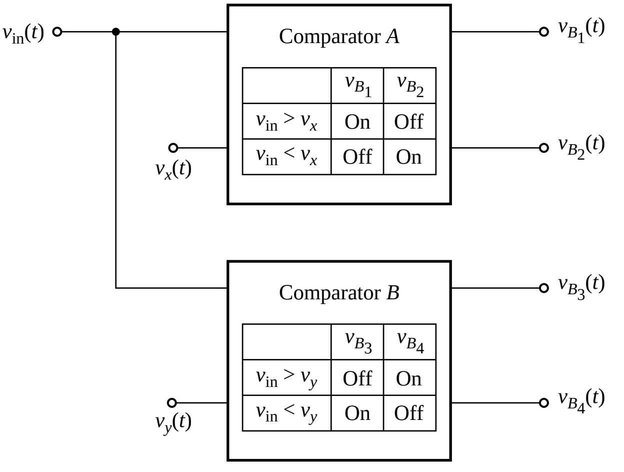
FIGURE 3–55
The basic concepts of pulse-width modulation. (*a*) A single-phase PWM circuit using IGBTs.

To understand the overall operation of this PWM inverter circuit, see what happens when different control voltages are applied to it. First, assume that the control voltage is 0 V. Then voltages $v_u(t)$ and $v_v(t)$ are identical, and the load voltage out of the circuit $v_{load}(t)$ is zero (see Figure 3–56).

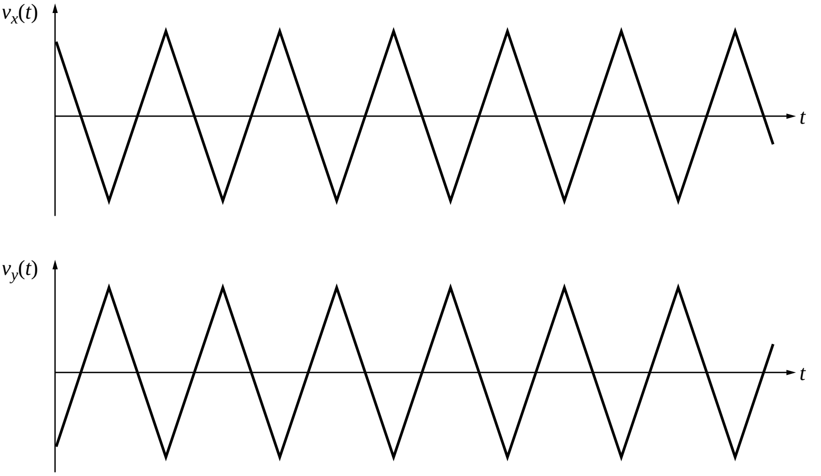
Next, assume that a constant positive control voltage equal to one-half of the peak reference voltage is applied to the circuit. The resulting output voltage is a train of pulses with a 50 percent duty cycle, as shown in Figure 3–57.

Finally, assume that a sinusoidal control voltage is applied to the circuit as shown in Figure 3–58. The width of the resulting pulse train varies sinusoidally with the control voltage. The result is a high-power output waveform whose average voltage over any small region is directly proportional to the average voltage of the control signal in that region. The *fundamental frequency* of the output waveform is the same as the frequency of the input control voltage. Of course, there are harmonic components in the output voltage, but they are not usually a concern in motor-control applications. The harmonic components may cause additional heating in the motor being driven by the inverter, but the extra heating can be compensated for either by buying a specially designed motor or by *derating* an ordinary motor (running it at less than its full rated power).

A complete three-phase PWM inverter would consist of three of the single-phase inverters described above with control voltages consisting of sinusoids shifted by 120° between phases. Frequency control in a PWM inverter of this sort is accomplished by changing the frequency of the input control voltage.



(*b*)



(*c*)

FIGURE 3–55 (concluded)
(*b*) The comparators used to control the on and off states of the transistors. (*c*) The reference voltages used in the comparators.

A PWM inverter switches states many times during a single cycle of the resulting output voltage. At the time of this writing, reference voltages with frequencies as high as 12 kHz are used in PWM inverter designs, so the components in a PWM inverter must change states up to 24,000 times per second. This rapid switching means that PWM inverters require faster components than CSIs or VSIs. PWM inverters need high-power high-frequency components such as GTO thyristors, IGBTs, and/or power transistors for proper operation. (At the time of this writing, IGBTs have the advantage for high-speed, high-power switching, so they are the preferred component for building PWM inverters.) The control voltage fed to the comparator circuits is usually imple-

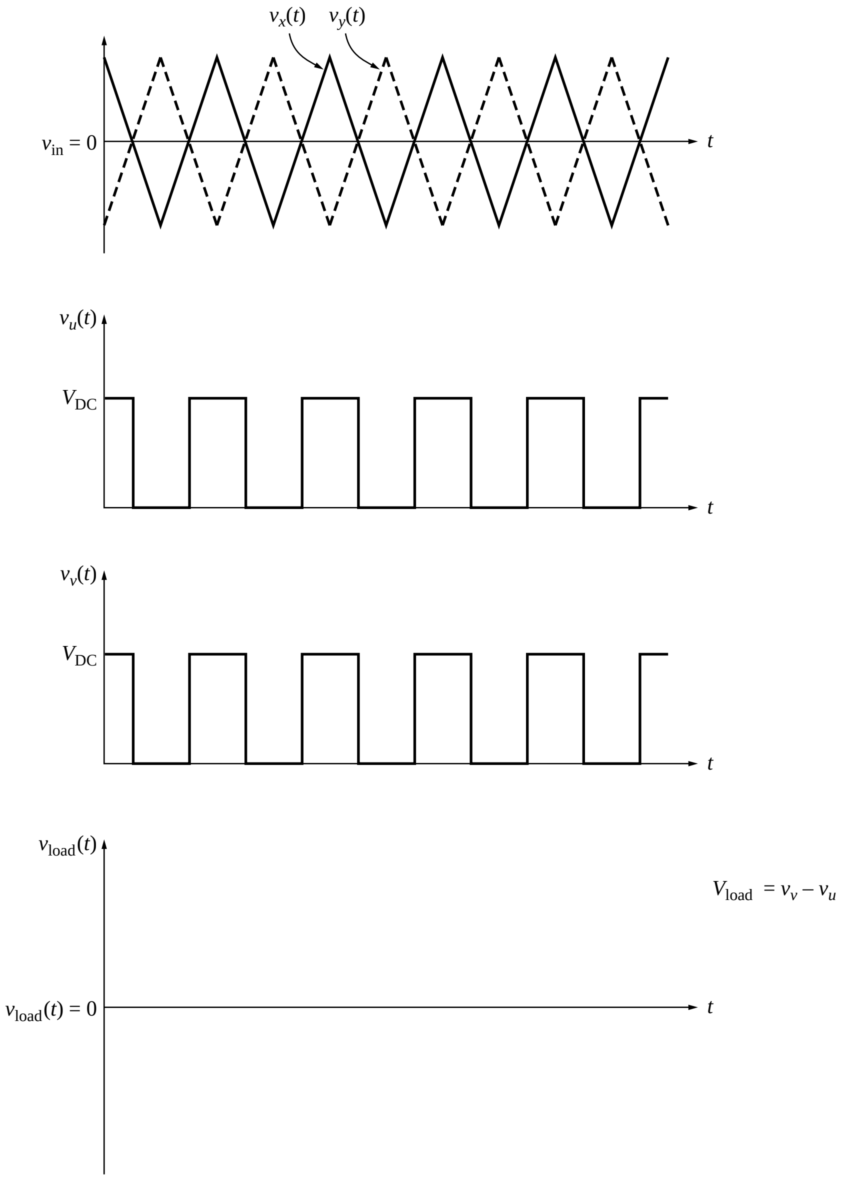


FIGURE 3–56
The output of the PWM circuit with an input voltage of 0 V. Note that $v_u(t) = v_v(t)$, so $v_{load}(t) = 0$.

mented digitally by means of a microcomputer mounted on a circuit board within the PWM motor controller. The control voltage (and therefore the output pulse width) can be controlled by the microcomputer in a manner much more sophisticated than that described here. It is possible for the microcomputer to vary the control voltage to

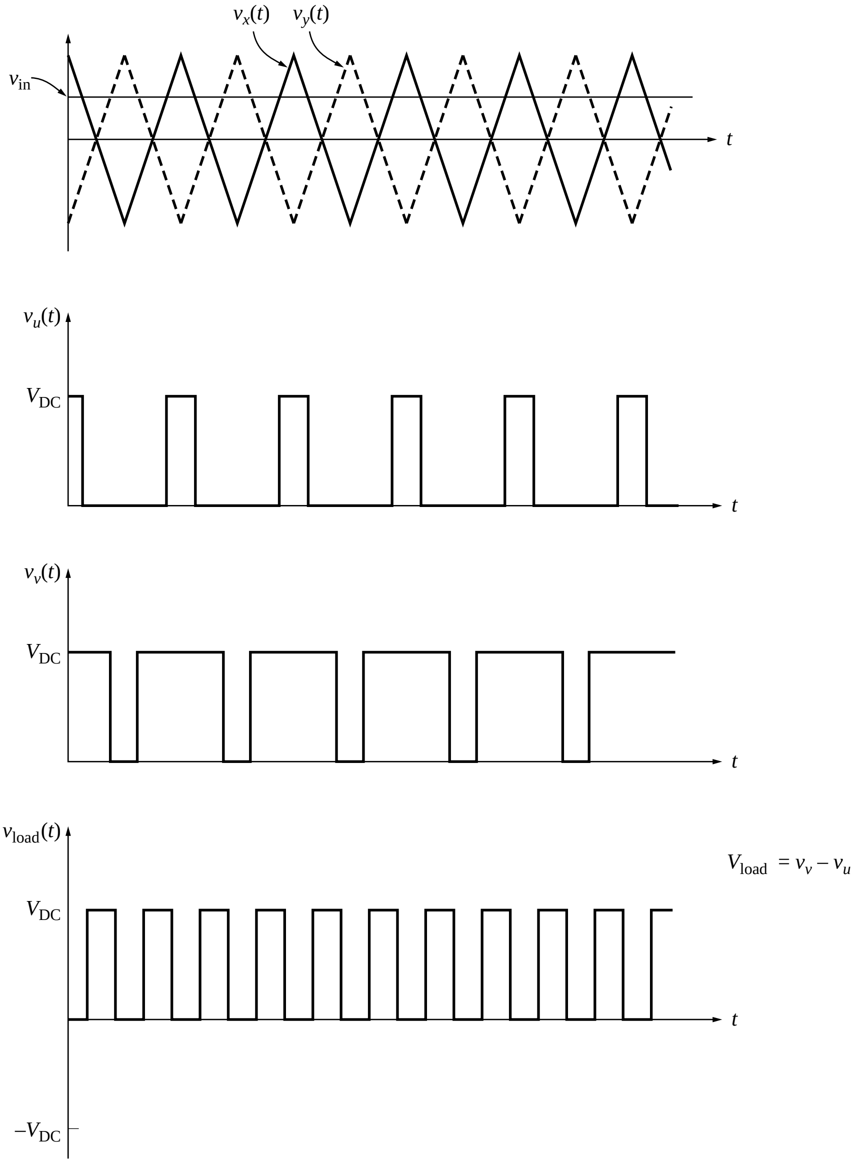


FIGURE 3–57
The output of the PWM circuit with an input voltage equal to one-half of the peak comparator voltage.

achieve different frequencies and voltage levels in any desired manner. For example, the microcomputer could implement various acceleration and deceleration ramps, current limits, and voltage-versus-frequency curves by simply changing options in software.

A real PWM-based induction motor drive circuit is described in Section 7.10.

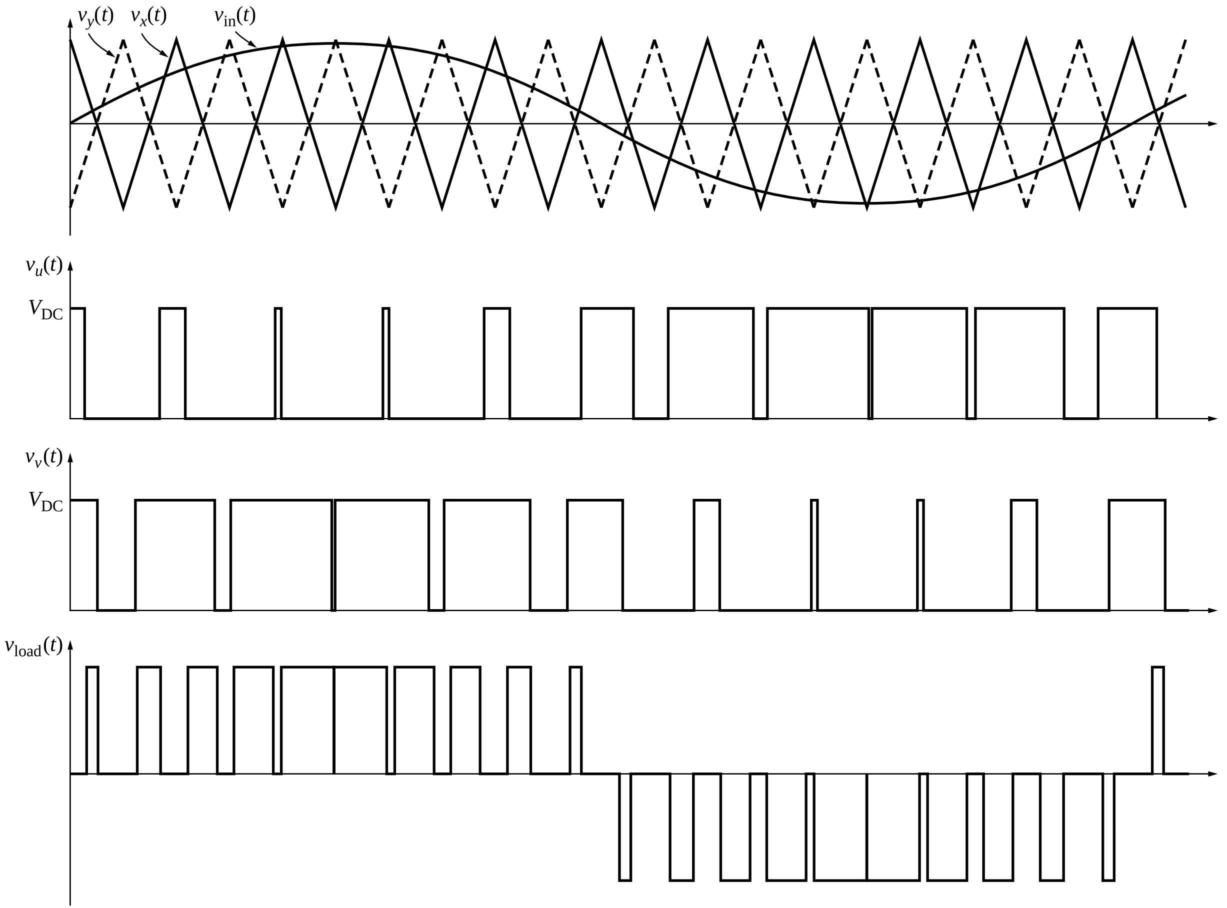


FIGURE 3–58
The output of the PWM circuit with a sinusoidal control voltage applied to its input.