16.4.3 A SWITCHED POWER SUPPLY USINGA DIODE

In this example, we will analyze the behavior of the diode-based switched power supply circuit shown in Figure 16.15. Notice that this circuit is similar to that in Figure 12.41, with the switch S_2 replaced with a diode. As before, the purpose of the circuit is to convert the DC input voltage V to a different DC output voltage v_{OUT}. The MOSFET in the circuit operates as a switch, and the square-wave input to the MOSFET is shown in Figure 16.16. As before, we are interested in determining the behavior of v_{OUT} over time. As we will see shortly, the diode in the circuit also acts a switch, and results in an output waveform that is largely the same as that of the circuit in Figure 12.41.

We will assume that the switch S_1 has zero resistance associated with its ON state, and that the diode is ideal, so that the model in Figure 16.6 applies. Specifically, this means that the diode turns on and behaves like a short circuit when a positive current (i_D) flows through it. The diode turns off and behaves like an open circuit when the voltage (v_D) across it is negative.

When the switch S_1 is closed, it shorts the terminal connecting the diode and the inductor to ground. Assuming that v_{OUT} is non-negative, the diode being reverse biased is off. The DC voltage V appears directly across the inductor as illustrated in Figure 16.17, and the inductor current i_L ramps up. Since S_1 is the on for time T, the inductor current builds up to

$$i_L = \frac{VT}{L} \tag{16.34}$$

as shown in Figure 16.16. Meanwhile, if there is no applied load at v_{OUT}, the capacitor voltage v_{OUT} remains constant.

Next, when S_1 is opened, the inductor current cannot instantaneously go to 0. Instead, the current finds a path through the diode (thereby turning it on) and into the capacitor. In its ON state, the diode behaves like a short circuit, and so the driven LC circuit shown in Figure 16.18 results. The current i_L in the

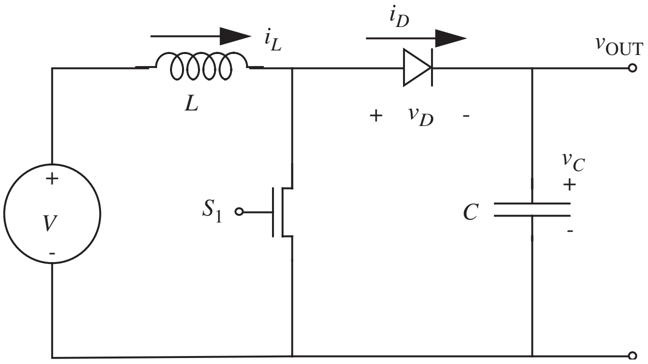

FIGURE 16.15 A switched power supply circuit with diode and a switch.

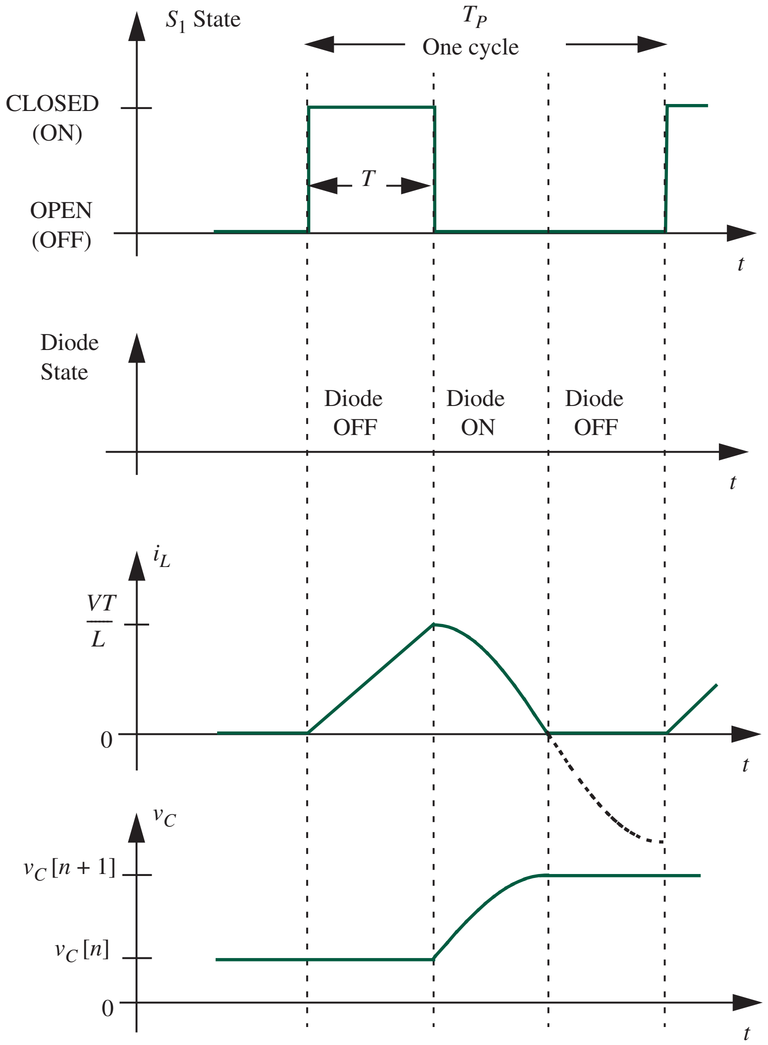

FIGURE 16.16 Switched power supply operation.

LC circuit follows a sinusoidal pattern as illustrated in Figure 16.16. Because of the flow of current into the capacitor, its voltage v_{OUT} starts to increase, and it too follows a sinusoidal pattern.

As i_L follows its sinusoidal pattern, it soon reaches zero and the positive voltage on the capacitor attempts to drive it negative. At this instant, the diode turns off and disconnects the capacitor from the rest of the circuit, so in the absence of a load, the capacitor maintains its voltage.

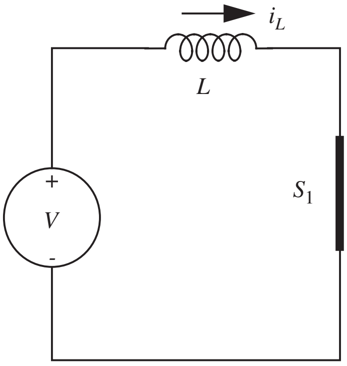

FIGURE 16.17 The equivalent circuit when S_1 is closed and the diode is open.

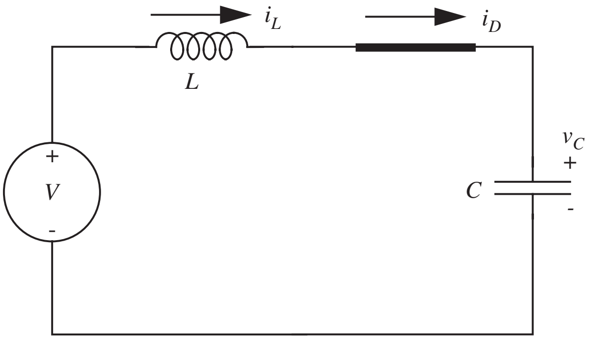

FIGURE 16.18 The equivalent LC circuit when S_1 is open and the diode is ON.

This cycle repeats, dumping some amount of charge into the capacitor each cycle. We can compute the increase in v_{OUT} very quickly using an energy argument similar to that used in Example 12.4 as follows: At the end of the ramp, the inductor current is given by Equation 16.34, and so the energy stored in the inductor is given by:

$$w_M = \frac{V^2 T^2}{2L}.$$

Since the capacitor is charged by the inductor until i_L becomes zero, the energy (w_M) stored in the inductor is transferred completely to the capacitor in each cycle. After n cycles, the energy stored in the capacitor becomes n times the energy transferred in a single cycle, plus any energy initially stored on the capacitor (say $w_E[0]$):

$$w_E[n] = n\frac{V^2 T^2}{2L} + w_E[0].$$

Unlike Example 12.4, the capacitor must start with $v_C = V$, since it is connected by a diode instead of a switch to a voltage source. Unlike the switch, which can be forced to stay off, the (ideal) diode turns on if V is greater than v_C. Therefore,

$$w_E[0] = \frac{1}{2}CV^2.$$

Since $w_E[n] = Cv_{\text{OUT}}[n]^2/2$, we can derive the voltage after n cycles as:

$$v_{\text{OUT}}[n] = V\sqrt{\frac{nT^2}{LC} + 1}.$$

Substituting, $\omega_o = 1/\sqrt{LC}$, we have

$$v_{\text{OUT}}[n] = V\sqrt{nT^2\omega_o^2 + 1}.$$

If $nT^2\omega_o^2 \gg 1$, we get

$$v_{\text{OUT}}[n] = VT\omega_o\sqrt{n}.$$

Finally, when a load is added to the circuit as shown in Figure 16.19, the capacitor begins to discharge through the load. Suppose we wish to maintain the voltage v_{OUT} at a specified average value, say v_{REF}, then in each cycle, we must arrange to have the capacitor charged up by the same amount of charge that it supplies to the load. This can be accomplished by using a feedback system as shown in Figure 16.20.

In the circuit in Figure 16.20, the controller compares v_{OUT} to v_{REF}, and if v_{OUT} falls below v_{REF}, it increases the duration T for which the switch S_1 is kept ON, thereby increasing v_{OUT}. Conversely, the controller decreases the duration T if v_{OUT} increases past the value of v_{REF}. Thus, v_{OUT} is kept close to v_{REF} throughout.

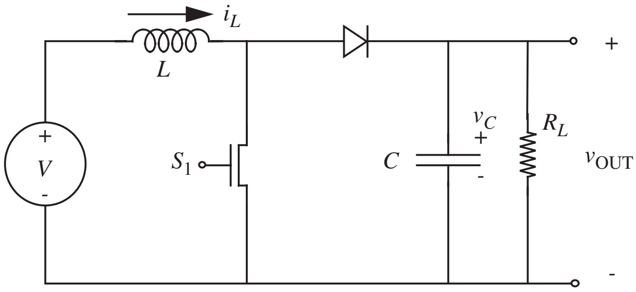

FIGURE 16.19 Adding a load.

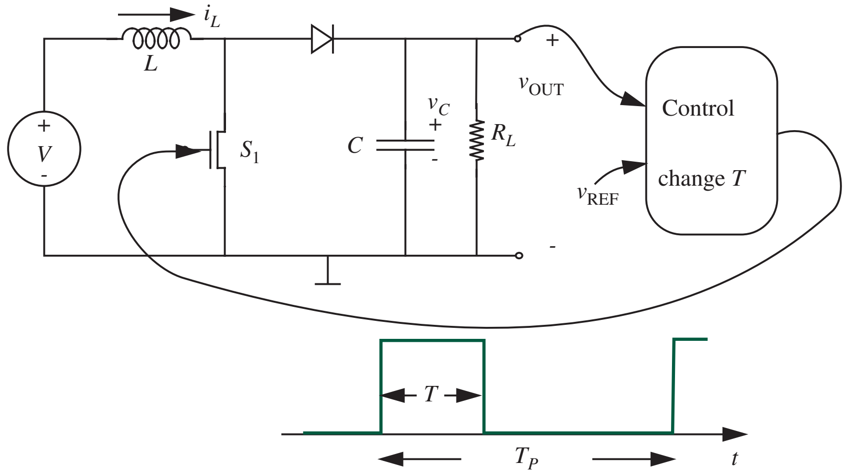

FIGURE 16.20 Feedback system to maintain a voltage v_{REF} at the load.