Engineering and Architecture Analog Electronics Fundamentals **EEE223** Lec 5

Full-Wave Rectifier

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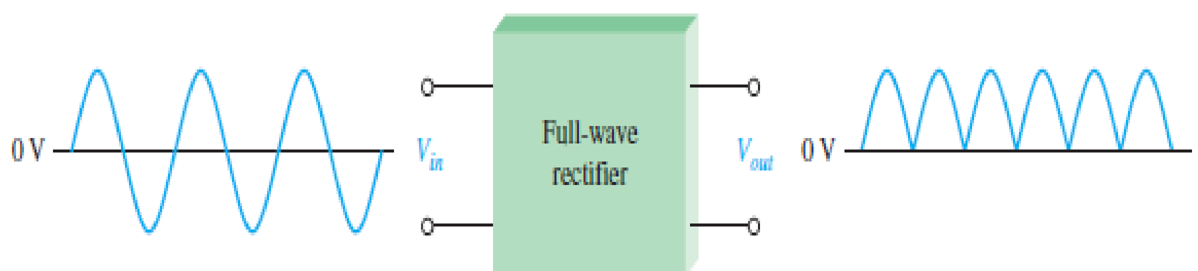
A Full-Wave Rectifier

– A **full-wave rectifier** allows unidirectional (one-way) current through the load during the entire 360° of the input cycle.

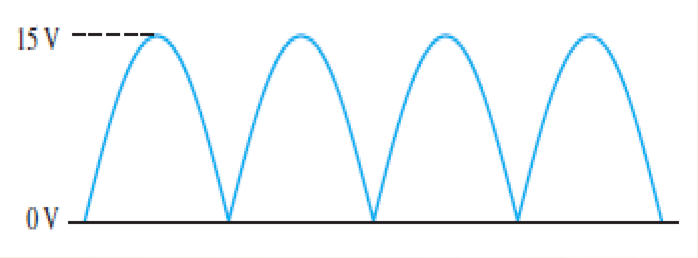


– The number of positive alternations that make up the full-wave rectified voltage is twice that of the half-wave voltage for the same time interval. The average value, for a full-wave rectified sinusoidal voltage is twice that of the half-wave, as shown in the following formula:

$$V_{AVG} = \frac{2V_p}{\pi}$$

EXAMPLE 2–5 Find the average value of the full-wave rectified voltage in Figure 2–30.

FIGURE 2–30



Solution

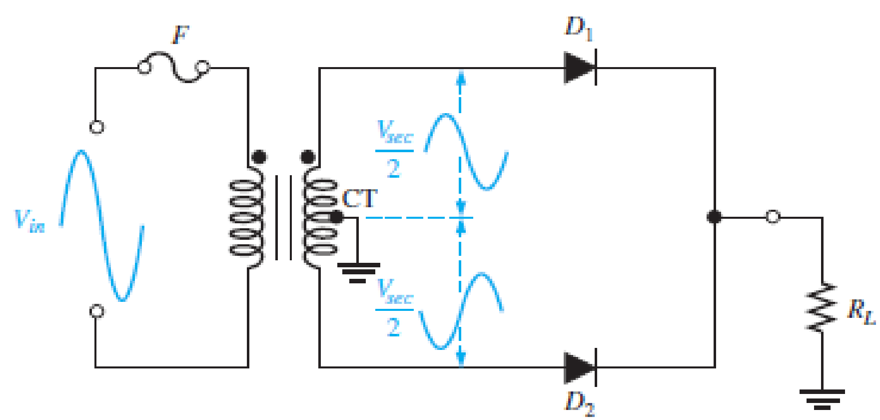
$$V_{AVG} = \frac{2V_p}{\pi} = \frac{2(15\text{ V})}{\pi} = 9.55\text{ V}$$

V_{AVG} is 63.7% of V_p.

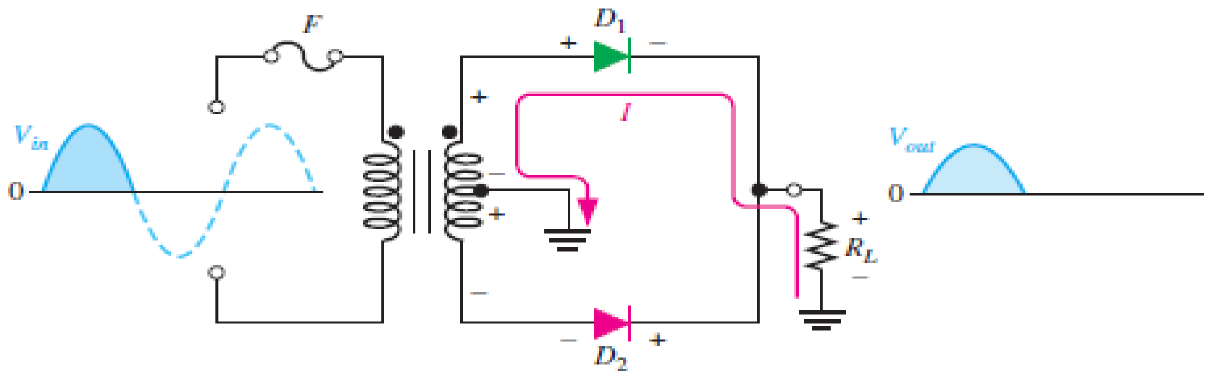
Related Problem Find the average value of the full-wave rectified voltage if its peak is 155 V.

Center-Tapped Full-Wave Rectifier Operation

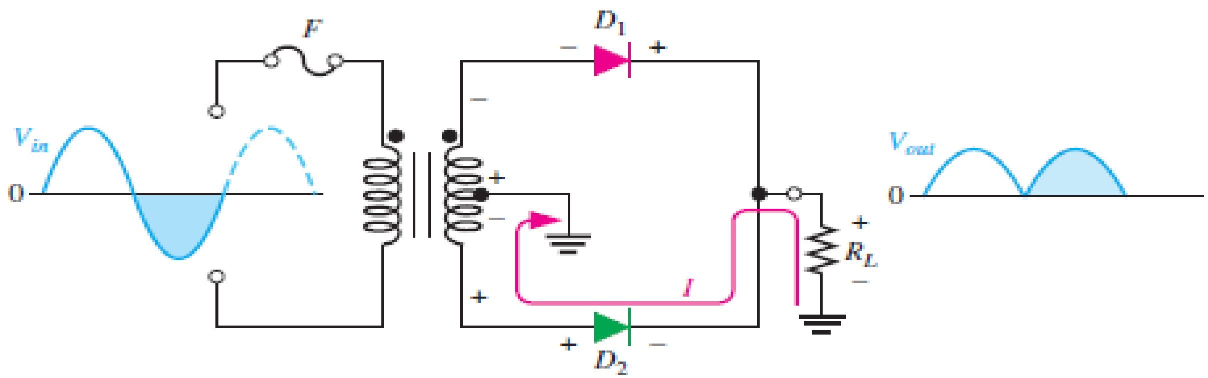
– A **center-tapped rectifier** is a type of full-wave rectifier that uses two diodes connected to the secondary of a center-tapped transformer. The input voltage is coupled through the transformer to the center-tapped secondary. Half of the total secondary voltage appears between the center tap and each end of the secondary winding as shown.



– For a positive half-cycle of the input voltage, the polarities of the secondary voltages are as shown in Figure (a) This condition forward-biases diode *D*1 and reverse-biases diode *D*2. The current path is through *D*1 and the load resistor *RL*, as indicated. For a negative half-cycle of the input voltage, the voltage polarities on the secondary are as shown in Figure (b). This condition reverse-biases *D*1 and forward-biases *D*2. The current path is through *D*2 and *RL*, as indicated. Because the output current during both the positive and negative portions of the input cycle is in the same direction through the load, the output voltage developed across the load resistor is a full-wave rectified dc voltage, as shown.



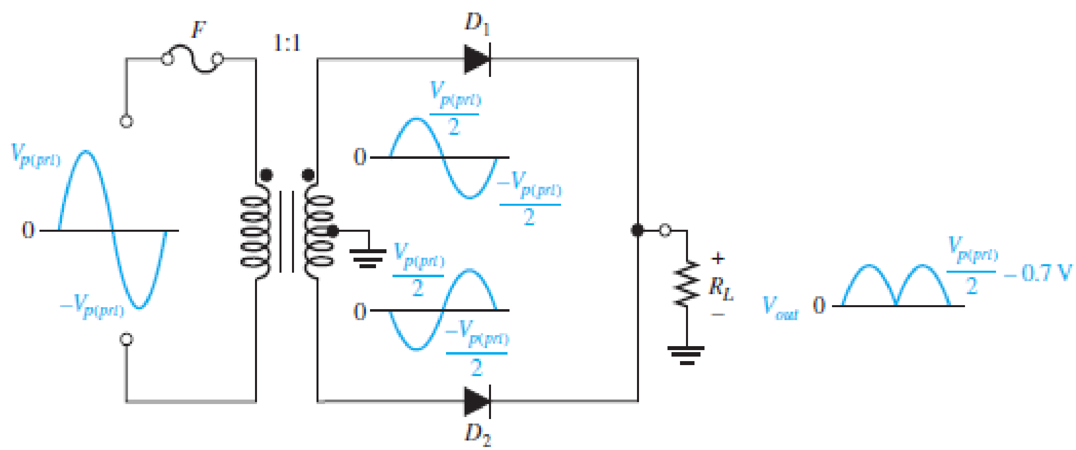
(a) During positive half-cycles, D_1 is forward-biased and D_2 is reverse-biased.



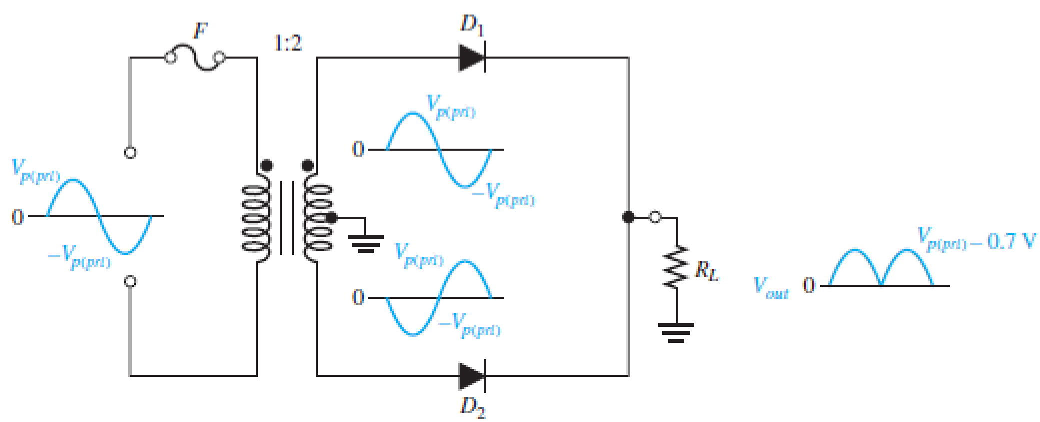
(b) During negative half-cycles, D_2 is forward-biased and D_1 is reverse-biased.

Effect of the Turns Ratio on the Output Voltage

– If the transformer's turns ratio is 1, the peak value of the rectified output voltage equals half the peak value of the primary input voltage less the barrier potential, as illustrated in Figure. Half of the primary voltage appears across each half of the secondary winding ($Vp(sec) = Vp(pri)$).



– In order to obtain an output voltage with a peak equal to the input peak (less the diode drop), a step-up transformer with a turns ratio of $n = 2$ must be used. In this case, the total secondary voltage (*Vsec*) is twice the primary voltage (2 *Vpri*), so the voltage across each half of the secondary is equal to *Vpri.*



- In any case, the output voltage of a center-tapped full-wave rectifier is always one-half of the total secondary voltage less the diode drop, no matter what the turns ratio.

$$V_{out} = \frac{V_{sec}}{2} - 0.7\text{ V}$$

- ***Peak Inverse Voltage*** Each diode in the full-wave rectifier is alternately forward-biased and then reverse-biased. The maximum reverse voltage that each diode must withstand is the peak secondary voltage *Vp*(*sec*).

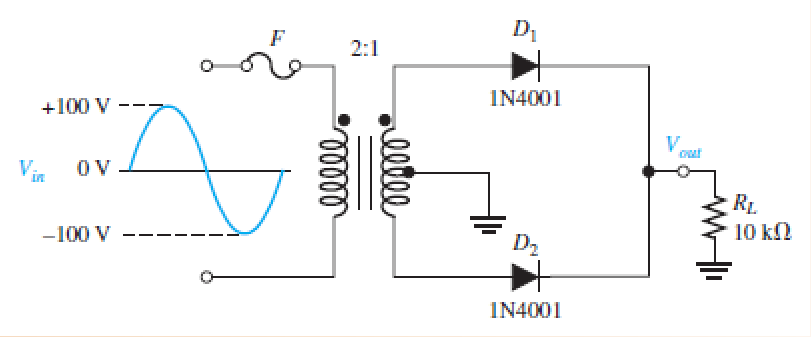
$$\text{PIV} = 2V_{p(out)} + 0.7\text{ V}$$

EXAMPLE 2–6

(a) Show the voltage waveforms across each half of the secondary winding and across R_L when a 100 V peak sine wave is applied to the primary winding in Figure 2–36.

(b) What minimum PIV rating must the diodes have?

▶ **FIGURE 2–36**



Solution

(a) The transformer turns ratio $n = 0.5$. The total peak secondary voltage is

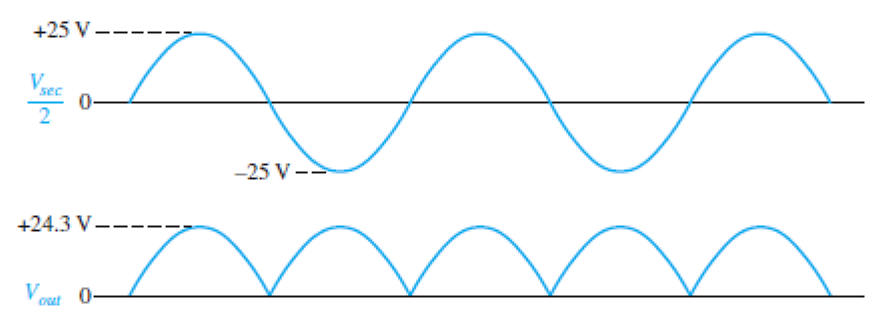
$$V_{p(sec)} = nV_{p(pri)} = 0.5(100\text{ V}) = 50\text{ V}$$

There is a 25 V peak across each half of the secondary with respect to ground. The output load voltage has a peak value of 25 V, less the 0.7 V drop across the diode. The waveforms are shown in Figure 2–37.

(b) Each diode must have a minimum PIV rating of

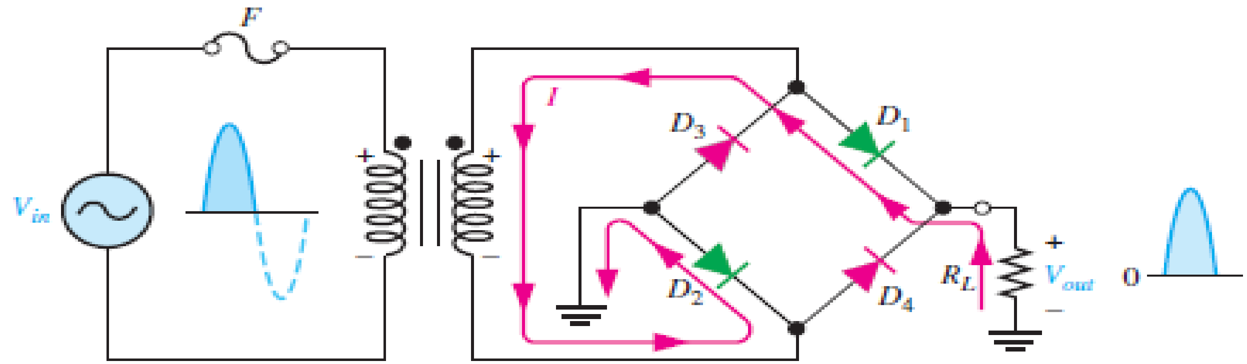
$$\text{PIV} = 2V_{p(out)} + 0.7\text{ V} = 2(24.3\text{ V}) + 0.7\text{ V} = \mathbf{49.3\text{ V}}$$

▶ **FIGURE 2–37**

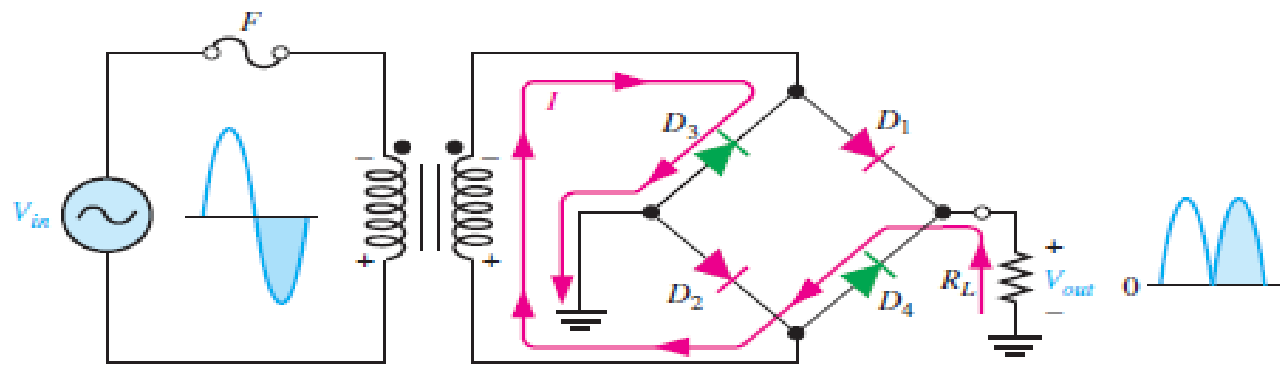


Bridge Full-Wave Rectifier Operation

- The **bridge rectifier** uses four diodes connected as shown in Figure. When the input cycle is positive as in part (a), diodes *D*1 and *D*2 are forward-biased and conduct current in the direction shown.
- A voltage is developed across *RL* that looks like the positive half of the input cycle. During this time, diodes *D*3 and *D*4 are reverse-biased.



(a) During the positive half-cycle of the input, D_1 and D_2 are forward-biased and conduct current. D_3 and D_4 are reverse-biased.

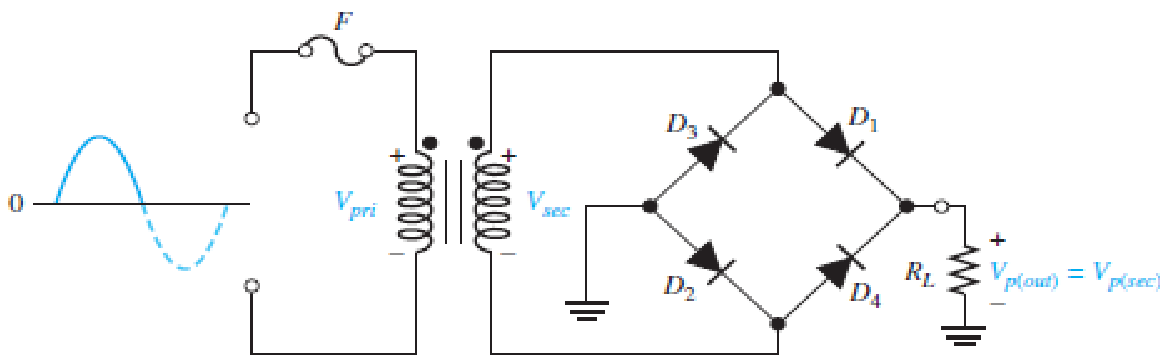


(b) During the negative half-cycle of the input, D_3 and D_4 are forward-biased and conduct current. D_1 and D_2 are reverse-biased.

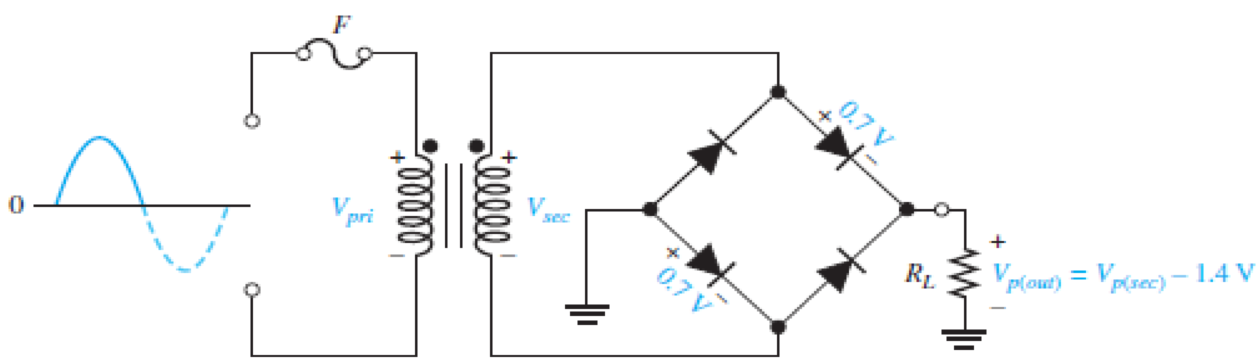
– When the input cycle is negative as in Figure (b), diodes *D*3 and *D*4 are forward biased and conduct current in the same direction through *RL* as during the positive half-cycle. During the negative half-cycle, *D*1 and *D*2 are reverse-biased. A full-wave rectified output voltage appears across *RL* as a result of this action. Therefore:

$$V_{p(out)} = V_{p(sec)} - 1.4\text{ V}$$

$$\text{PIV} = V_{p(out)} + 0.7\text{ V}$$



(a) Ideal diodes

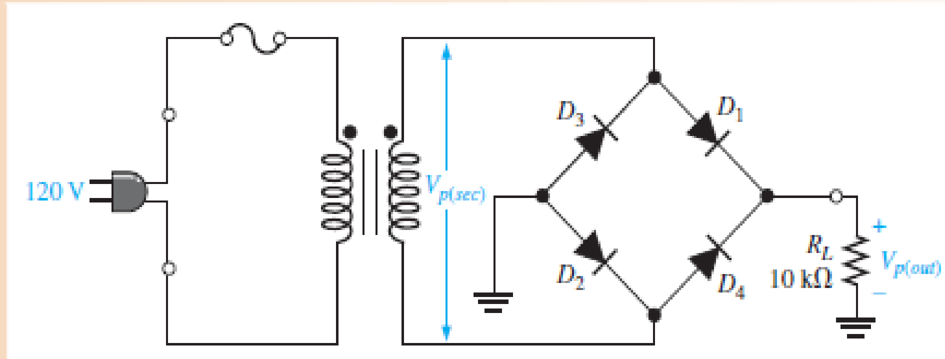


(b) Practical diodes (Diode drops included)

EXAMPLE 2–7

Determine the peak output voltage for the bridge rectifier in Figure 2–41. Assuming the practical model, what PIV rating is required for the diodes? The transformer is specified to have a 12 V rms secondary voltage for the standard 120 V across the primary.

▶ FIGURE 2–41



Solution The peak output voltage (taking into account the two diode drops) is

$$V_{p(sec)} = 1.414V_{rms} = 1.414(12\text{ V}) \cong 17\text{ V}$$

$$V_{p(out)} = V_{p(sec)} - 1.4\text{ V} = 17\text{ V} - 1.4\text{ V} = \mathbf{15.6\text{ V}}$$

The PIV rating for each diode is

$$\text{PIV} = V_{p(out)} + 0.7\text{ V} = 15.6\text{ V} + 0.7\text{ V} = \mathbf{16.3\text{ V}}$$

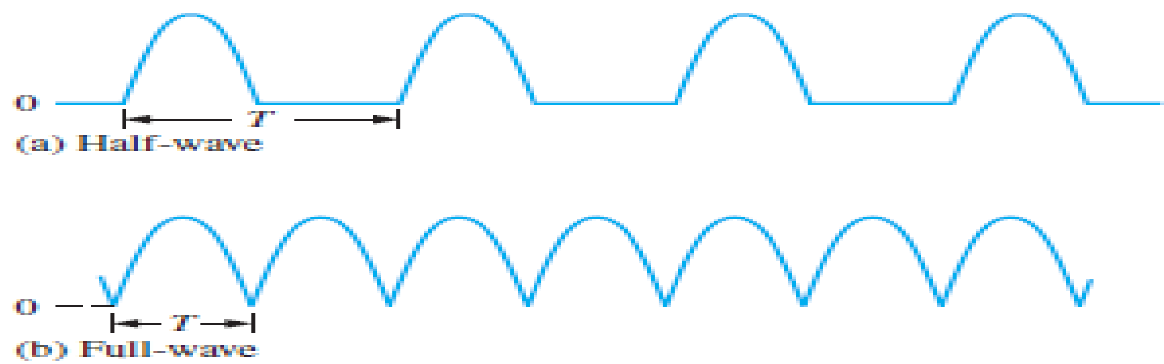
Related Problem Determine the peak output voltage for the bridge rectifier in Figure 2–41 if the transformer produces an rms secondary voltage of 30 V. What is the PIV rating for the diodes?

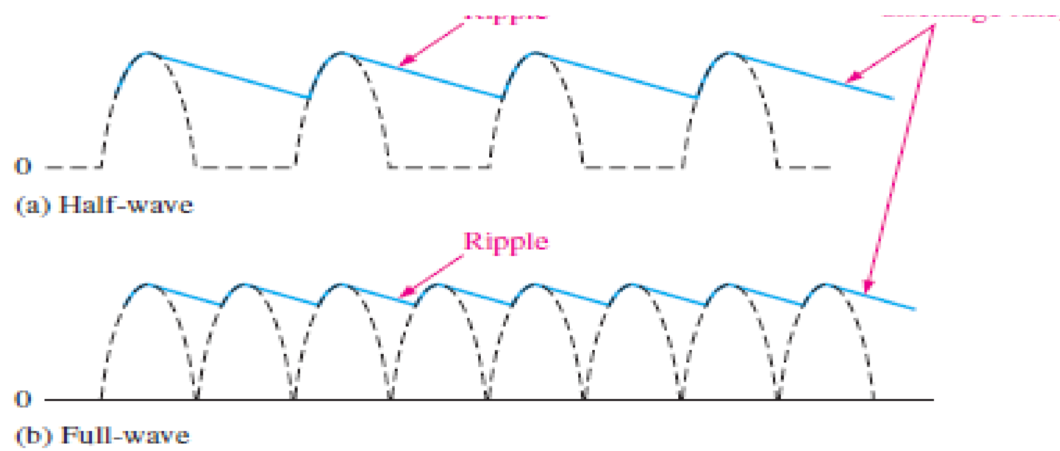
Open the Multisim file E02-07 in the Examples folder on the companion website. Measure the output voltage and compare to the calculated value.

Full-Wave Rectifier with a Capacitor Filter

– For a given input frequency, the output frequency of a full-wave rectifier is twice that of a half-wave rectifier, as illustrated. This makes a full-wave rectifier easier to filter because of the shorter time between peaks.

– When filtered, the full-wave rectified voltage has a smaller ripple than does a half-wave voltage for the same load resistance and capacitor values. The capacitor discharges less during the shorter interval between full-wave pulses, as shown in Figure


0
T
(a) Half-wave
0
T
(b) Full-wave


0
(a) Half-wave
Ripple
0
(b) Full-wave

– ***Ripple Factor*** The **ripple factor (*r*)** is an indication of the effectiveness of the filter and is defined as

$$r = \frac{V_{r(pp)}}{V_{DC}}$$

– For a full-wave rectifier with a capacitor-input filter, approximations for the peak-topeak ripple voltage, $V_r(pp)$, and the dc value of the filter output voltage, V_{DC}, are given in the following equations.

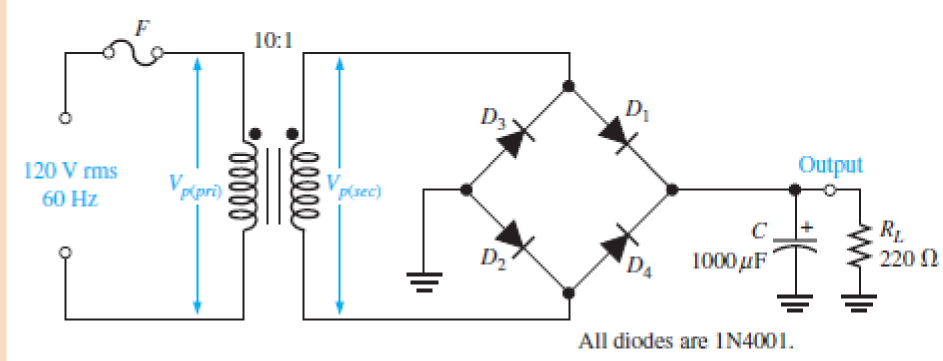
– The variable *Vp*(*rect*) is the unfiltered peak rectified voltage. Noticethat if *RL* or *C* increases, the ripple voltage decreases and the dc voltage increases.

$$V_{r(pp)} \cong \left(\frac{1}{fR_LC}\right)V_{p(rect)}$$

$$V_{DC} \cong \left(1 - \frac{1}{2fR_LC}\right)V_{p(rect)}$$

EXAMPLE 2–8 Determine the ripple factor for the filtered bridge rectifier with a load as indicated in Figure 2–48.

▶ FIGURE 2–48



Solution The transformer turns ratio is $n = 0.1$. The peak primary voltage is

$$V_{p(pri)} = 1.414V_{rms} = 1.414(120\text{ V}) = 170\text{ V}$$

The peak secondary voltage is

$$V_{p(sec)} = nV_{p(pri)} = 0.1(170\text{ V}) = 17.0\text{ V}$$

The unfiltered peak full-wave rectified voltage is

$$V_{p(rect)} = V_{p(sec)} - 1.4\text{ V} = 17.0\text{ V} - 1.4\text{ V} = 15.6\text{ V}$$

The frequency of a full-wave rectified voltage is 120 Hz. The approximate peak-to-peak ripple voltage at the output is

$$V_{r(pp)} \cong \left(\frac{1}{fR_LC}\right)V_{p(rect)} = \left(\frac{1}{(120\text{ Hz})(220\ \Omega)(1000\ \mu\text{F})}\right)15.6\text{ V} = 0.591\text{ V}$$

The approximate dc value of the output voltage is determined as follows:

$$V_{DC} = \left(1 - \frac{1}{2fR_LC}\right)V_{p(rect)} = \left(1 - \frac{1}{(240\text{ Hz})(220\ \Omega)(1000\ \mu\text{F})}\right)15.6\text{ V} = 15.3\text{ V}$$

The resulting ripple factor is

$$r = \frac{V_{r(pp)}}{V_{DC}} = \frac{0.591\text{ V}}{15.3\text{ V}} = \mathbf{0.039}$$

The percent ripple is 3.9%.

Thank You