Chapter 3
Solid-State Diodes and Diode Circuits

Rectifier Circuits

- A basic rectifier converts an ac voltage to a pulsating dc voltage.
- A filter then eliminates ac components of the waveform to produce a nearly constant dc voltage output.
- Rectifier circuits are used in virtually all electronic devices to convert the 120-V 60-Hz ac power line source to the dc voltages required for operation of electronic devices.
- In rectifier circuits, the diode state changes with time and a given piecewise linear model is valid only for a certain time interval.
Half-Wave Rectifier Circuit with Resistive Load

For the positive half-cycle of the input, the source forces positive current through the diode, the diode is on, and $v_O = v_S$.

During the negative half cycle, negative current can’t exist in the diode. The diode is off, current in resistor is zero, and $v_O = 0$.

Using the constant voltage drop CVD model, during the on-state of the diode $v_O = (V_p \sin \omega t) - V_{on}$. The output voltage is zero when the diode is off.

Often a step-up or step-down transformer is used to convert the 120-V, 60-Hz voltage available from the power line to the desired ac voltage level as

Time-varying components in the rectifier output are removed using a filter capacitor.
Peak Detector Circuit

As the input voltage rises, the diode is on, and the capacitor (initially discharged) charges up to the input voltage minus the diode voltage drop.

At the peak of the input voltage, diode current tries to reverse, and the diode cuts off. The capacitor has no discharge path and retains a constant voltage providing a constant output voltage:

\[ V_{dc} = V_p - V_{on} \]

Half-Wave Rectifier Circuit with RC Load

As the input voltage rises during the first quarter cycle, the diode is on and the capacitor (initially discharged) charges up to the peak value of the input voltage.

At the peak of the input, the diode current tries to reverse, the diode cuts off, and the capacitor discharges exponentially through \( R \). Discharge continues till the input voltage exceeds the output voltage which occurs near the peak of next cycle. This process then repeats once every cycle.
Peak Diode Current

In rectifiers, nonzero current exists in the diode for only a very small fraction of period $T$, yet an almost constant dc current flows out of the filter capacitor to load. The total charge lost from the filter capacitor in each cycle is replenished by the diode during a short conduction interval causing high peak diode currents.

Peak Inverse Voltage Rating

The peak inverse voltage (PIV) rating of the rectifier diode is the diode breakdown voltage.

When the diode is off, the reverse-bias across the diode is $V_{dc} - v_S$. When $v_S$ reaches negative peak,

$$\text{PIV} \geq V_{dc} - v_{S_{\text{min}}} = V_p - V_{on} - (-V_p) \geq 2V_p$$

The PIV value corresponds to the minimum value of Zener breakdown voltage required for the rectifier diode.
Full-Wave Rectifiers (10/12)

Full-wave rectifiers cut capacitor discharge time in half and require half the filter capacitance to achieve a given ripple voltage. All specifications are the same as for half-wave rectifiers. Reversing polarity of the diodes gives a full-wave rectifier with negative output voltage.

Full-Wave Bridge Rectification

The requirement for a center-tapped transformer in the full-wave rectifier is eliminated through use of 2 extra diodes. All other specifications are the same as for a half-wave rectifier except $\text{PIV} = V_P$. 
Rectifier Topology Comparison

- Filter capacitors are a major factor in determining cost, size and weight in design of rectifiers.
- For a given ripple voltage, a full-wave rectifier requires half the filter capacitance as that in a half-wave rectifier. Reduced peak current can reduce heat dissipation in diodes. Benefits of full-wave rectification outweigh increased expenses and circuit complexity (an extra diode and center-tapped transformer).
- The bridge rectifier eliminates the center-tapped transformer, and the PIV rating of the diodes is reduced. Cost of extra diodes is negligible.

### Rectifier Topology Comparison and Design Tradeoffs

<table>
<thead>
<tr>
<th>RECTIFIER PARAMETER</th>
<th>HALF-WAVE RECTIFIER</th>
<th>FULL-WAVE RECTIFIER</th>
<th>FULL-WAVE BRIDGE RECTIFIER</th>
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<tbody>
<tr>
<td>Filter capacitor</td>
<td>$C = \frac{V_p - V_{in}}{V_t} \frac{T}{R}$</td>
<td>$C = \frac{V_p - V_{in}}{V_t} \frac{T}{2R}$</td>
<td>$C = \frac{V_p - 2V_{in}}{V_t} \frac{T}{2R}$</td>
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<tr>
<td>PIV rating</td>
<td>$2V_p$</td>
<td>$2V_p$</td>
<td>$V_p$</td>
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<tr>
<td>Peak diode current</td>
<td>Highest</td>
<td>Reduced</td>
<td>Reduced</td>
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<td>(constant $V_t$)</td>
<td>$I_p$</td>
<td>$I_p$</td>
<td>$I_p$</td>
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<tr>
<td>Surge Current</td>
<td>Highest</td>
<td>Reduced ($\alpha C$)</td>
<td>Reduced ($\alpha C$)</td>
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<tr>
<td>Comments</td>
<td>Least complexity</td>
<td>Smaller capacitor</td>
<td>Smaller capacitor</td>
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<td></td>
<td></td>
<td>Requires center-tapped transformer</td>
<td>Four diodes</td>
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<td></td>
<td></td>
<td>Two diodes</td>
<td>No center tap</td>
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<tr>
<td></td>
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<td>on transformer</td>
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