RECTIFIERS CIRCUITS

INEL 4201 Electronics I

Textbook section 4.5
For positive half-cycle of input, source forces positive current through diode, diode is on, $v_o = v_s$ (assuming $v_D = 0$. Otherwise $v_o = v_S - v_D$ when $v_S > v_D$)

During negative half cycle, negative current can’t exist in diode, diode is off, current in resistor is zero and $v_o = 0$. 
Using CVD model, during on state of diode $v_o = (V_p \sin \omega t) - V_{on}$. Output voltage is zero when diode is off.

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

Time-varying components in circuit output are removed using filter capacitor.
Example: Find ripple voltage if the secondary voltage $V_{S,rms} = 9.0\text{V}$, $f = 60\text{Hz}$, $R = 15\Omega$, $C = 25,000\mu\text{F}$, and the diode’s voltage drop $V_{ON} = 1\text{V}$.
Example: Find ripple voltage if the secondary voltage $V_{S,rms} = 12.6\, V$, $f = 60\, Hz$, $R = 15\, \Omega$, $C = 25,000\, \mu F$, and the diode’s voltage drop $V_{ON} = 1\, V$.

\[ v_{L,peak} = \sqrt{2} \times 9\, V - 1\, V = 11.73\, V \]

\[ i_{L,ave} = \frac{v_{L,peak} - v_r/2}{R_L} \]

\[ \approx C \frac{\Delta v_C}{\Delta t} = C \frac{v_r}{1/f} = f C v_r \]

\[ \frac{v_{L,peak}}{R_L} = 11.73\, V/15\, \Omega = 0.78\, A \]

\[ = f C v_r + \frac{v_r/2}{R_L} = v_r(60(0.025\, F) + 1/30\, \Omega) \]

\[ = 1.53\, \Omega^{-1} v_r \]

\[ v_r = \frac{0.78}{1.53} \, V = 0.51\, V \]
In general,

Ripple voltage $V_r$: peak-to-peak value of variations of load voltage.

\[ i_C = C \frac{\Delta v_C}{\Delta t} = \frac{v_{L,dc}}{R} \]

Let $v_{L,dc} \simeq V_{L,\text{peak}} - V_r/2$ and $\Delta t = 1/f$ where $f$ is the frequency

\[ V_r \simeq \Delta v_C = \frac{v_{L,dc} \times \Delta t}{RC} \simeq \frac{v_{L,\text{peak}} - V_r/2}{fRC} \]

If $V_r \ll V_{L,\text{peak}},$

\[ V_r \simeq \frac{v_{L,\text{peak}}}{fRC} \left( 1 + \frac{1}{2fRC} \right) \]

To select $C$ to obtain a specific $V_r$, use

\[ C = \frac{v_{L,\text{peak}} - V_r/2}{fRV_r} \]
Example: Find ripple voltage if the secondary voltage $V_{S,rms} = 9.0\text{V}$, $f = 60\text{Hz}$, $R = 15\Omega$, $C = 25,000\mu\text{F}$, and the diode's voltage drop $V_{ON} = 1\text{V}$.

\[
\begin{align*}
V_{S,peak} &= \sqrt{2} \times V_{S,rms} = 12.82\text{V} \\
v_{L,peak} &= V_{S,peak} - V_{ON} = 11.82\text{V} \\
fRC &= 60 \times 15\Omega \times 25 \times 10^{-3}\text{F} = 22.5 \\
V_r &= \frac{v_{L,peak}}{fRC} \left( \frac{1}{1 + \frac{1}{2fRC}} \right) = \frac{11.82\text{V}}{22.5} \left( \frac{1}{1 + \frac{1}{2 \times 22.5}} \right) = 0.52\text{V}
\end{align*}
\]

Example: Find $C$ necessary to obtain $V_r = 0.2\text{V}$ if $V_{S,rms} = 12.6\text{V}$, $f = 60\text{Hz}$, $R = 15\Omega$, and $V_{ON} = 1\text{V}$. 

\[
C = \frac{v_{L,peak}}{fR} = \frac{11.82\text{V}}{60 \times 15\Omega} = \frac{1}{900}\text{F} \\
C = 1000\mu\text{F}
\]
Example: Find ripple voltage if the secondary voltage $V_{S,rms} = 12.6\,\text{V}$, $f = 60\,\text{Hz}$, $R = 15\,\Omega$, $C = 25,000\,\mu\text{F}$, and the diode’s voltage drop $V_{ON} = 1\,\text{V}$.

\[
\begin{align*}
V_{S,peak} &= \sqrt{2} \times V_{S,rms} = 12.82\,\text{V} \\
v_{L,peak} &= V_{S,peak} - V_{ON} = 11.82\,\text{V} \\
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V_r &= \frac{v_{L,peak}}{fRC} \frac{1}{1 + \frac{1}{2fRC}} = \frac{11.82\,\text{V}}{22.5} \frac{1}{1 + \frac{1}{2 \times 22.5}} = 0.52\,\text{V}
\end{align*}
\]

Example: Find $C$ necessary to obtain $V_r = 0.2\,\text{V}$ if $V_{S,rms} = 12.6\,\text{V}$, $f = 60\,\text{Hz}$, $R = 15\,\Omega$, and $V_{ON} = 1\,\text{V}$.

\[
C = \frac{V_{L,peak} - V_r/2}{fRV_r} = \frac{11.82\,\text{V} - 0.1\,\text{V}}{60 \times 15\,\Omega \times 0.2\,\text{V}} \approx 65000\,\mu\text{F}
\]

Example: Find $C$ necessary to obtain $V_r = 0.2\,\text{V}$ if $V_{S,rms} = 12.6\,\text{V}$, $f = 60\,\text{Hz}$, $R = 1\,k\,\Omega$, and $V_{ON} = 1\,\text{V}$.

\[
C = \frac{V_{L,peak} - V_r/2}{fRV_r} = \frac{11.82\,\text{V} - 0.1\,\text{V}}{60 \times 1\,k\,\Omega \times 0.2\,\text{V}} \approx 1000\,\mu\text{F}
\]
Peak inverse voltage (PIV) rating of the rectifier diode gives the breakdown voltage.

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

$$\text{PIV} \approx 2 V_{S, \text{PEAK}}$$

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

To find $C$ or $V_r$, use same formula with $f = 120\text{Hz}$

$$\text{PIV} \approx 2V_{S, \text{PEAK}}$$
Requirement for a center-tapped transformer in the full-wave rectifier is eliminated through use of 2 extra diodes. All other specifications are same as for a half-wave rectifier except PIV=$V_p$. 

Full-wave rectifier with bridge circuit
DIODE CURRENT SPECS

Repetitive diode current
(after first cycle)

\[ I_{D,av} = I_L \left(1 + \pi \sqrt{\frac{V_p}{2V_r}}\right) \]
\[ I_{D,max} = I_L \left(1 + 2\pi \sqrt{\frac{V_p}{2V_r}}\right) \]

Diode surge current: can flow initially, when power is first applied.
- cap is discharged
- Sec. voltage can be the peak

\[ I_{SC} = 2\pi fCV_p \]
Rectifier Topology Comparison

- Filter capacitor is a major factor in determining cost, size and weight in design of rectifiers.

- For given ripple voltage, full-wave rectifier requires half the filter capacitance as that in half-wave rectifier. Reduced peak current can reduce heat dissipation in diodes. Benefits of full-wave rectification outweigh increased expenses and circuit complexity (a extra diode and center-tapped transformer).

- Bridge rectifier eliminates center-tapped transformer, PIV rating of diodes is reduced. Cost of extra diodes is negligible.
SIM 4.67 Consider a half-wave rectifier circuit with a triangular-wave input of 5-V peak-to-peak amplitude and zero average, and with $R = 1 \, \text{k}\Omega$. Assume that the diode can be represented by the constant-voltage-drop model with $V_D = 0.7 \, \text{V}$. Find the average value of $v_O$. 
4.70 A full-wave bridge rectifier circuit with a 1-kΩ load operates from a 120-V (rms) 60-Hz household supply through a 10-to-1 step-down transformer having a single secondary winding. It uses four diodes, each of which can be modeled to have a 0.7-V drop for any current. What is the peak value of the rectified voltage across the load? For what fraction of a cycle does each diode conduct? What is the average voltage across the load? What is the average current through the load?