Rectifier Circuits

Rectifiers are devices that convert AC voltage to DC voltage. They use the diodes and make advantage of their characteristic that allows current to flow only in one direction.
Basic Components

**Transformer**
- Input Stepped down to a lower voltage, e.g., 15 V
- Polarity is changing

**Rectifier**
- Single polarity

**Filter**

**Zener diode**

**Regulator**
- Undesired ripples
- Ripples minimized

**Power Supply**
- 120V (rms) 60 Hz
- 15 V dc
Half-Wave Rectifier

\[ v_o = v_s - V_D \]

\[ PIV = V_s \]

(a) Half-wave rectifier circuit diagram

(b) Ideal case with diode characteristics

(c) Voltage waveform and equations
Breakdown
How or when can it occur?

Diodes are usually marked by their PIV rating. A diode with low PIV rating (i.e., one that breaks down at small negative voltage) is cheaper and easier to manufacture, while another one that has a high PIV rating can sustain a large negative voltage without breakdown.
The **PIV** for this half-wave single diode rectifier is the peak value

\[
\text{PIV} = \left| V_{\text{min}} \right| = \left| -V_S \right| = V_S
\]

In other words, to design a half-wave rectifier using a single diode, we need to use a diode whose **PIV** is higher than \( V_S \), which is the peak value of the source voltage.

For example, if \( V_S \) is 10 V, then it would be safer to choose a diode whose \( V_{ZK} \) higher than, e.g. is 40 % bigger than \( V_S \).
Full-Wave Rectifier

\[ PIV = 2V_s - V_{D0} \]
Comparison Between Half- and Full Wave Rectifier in terms of the PIV

\[
\text{PIV} \quad (\text{One-diode Half-Wave}) = V_S
\]

\[
\text{PIV} \quad (\text{Two-diode Full-Wave}) = 2V_S - V_{DO}
\]

That is bad, because it means that we will need to use a diode with a higher PIV rating.
Bridge Rectifier

The bridge rectifier acts as a full-wave rectifier. In additions it does suffer from the high PIV requirement needed in the two-diode full-wave rectifier presented earlier.
The Bridge Rectifier

\[ PIV = V_s - V_{D0} \]
PIV for the Bridge Rectifier

Consider this diode in the reverse-region

To avoid breakdown, we need to know the maximum negative voltage that $v_{D3}$ can experience.

$$v_{D3} = -(v_{D2} + v_O)$$

Since $r_D \ll v_{D2} \approx V_{D0}$

Also $v_O \approx (v_S - 2V_{DO})$

Hence $v_{D3} = -v_S + V_{D0}$
PIV for the Bridge Rectifier

\[ v_{D3} = -v_S + V_{D0} \]

Becomes the lowest negative, when \( v_S \) reaches its maximum or peak value of \( V_S \).

\[ v_{D3_{min}} = -V_S + V_{D0} \]

Hence,

\[ \text{PIV} = |v_{D3_{min}}| = V_S - V_{D0} \]
Comparison Between Rectifiers in terms of their PIV voltages

\[ PIV_{(\text{One-diode Half-Wave})} = V_S \]

\[ PIV_{(\text{Two-diode Full-Wave})} = 2V_S - V_{DO} \]

\[ PIV_{(\text{Bridge rectifier})} = V_S - V_{DO} \]

Better

Worst
The Half-Wave Peak Rectifier

\[ i_L = \frac{V_0}{R} \]

\[ i_D = i_C + i_L \]

\[ i_D = C \frac{dV_I}{dt} + i_L \]

\[ V_p - V_r = V_p e^{-T/RC} \]

\[ V_r \approx V_p \frac{T}{RC} \]

\[ V_r = \frac{V_p}{fCR} \]

\[ I_L = \frac{V_p}{R} \]

\[ V_o = V_p - \frac{1}{2} V_r \]

\[ v_o = V_p e^{-t/CR} \]

\[ i_{Dav} = I_L \left(1 + \pi \sqrt{2V_p/V_r}\right) \]

\[ i_{Dmax} = I_L \left(1 + 2\pi \sqrt{2V_p^{13}/V_r}\right) \]
We can choose $RC \gg T$.

We need to make $V_O$ Slowly Decaying, How Can we achieve that?

$$v_O = V_pe^{-t/RC}$$

This will make the discharge time longer and the output voltage will not decay quickly.
When $v_O \geq v_I$

$V_p$

$T$

$T/4$

$v_O = v_I$
We need to calculate those values.

The picture in steady-state.
The picture at Steady-State

As if the output is following the peak of the shadow of negative cycle in the input waveform
Half-wave Peak Rectifier

\[ V_r = \frac{V_p T}{RC} = \frac{V_p}{fRC} \]

\[ \omega \Delta t \simeq \sqrt{\frac{2V_r}{V_p}} \]

\[ i_{D_{ave}} = I_L \left(1 + \pi \sqrt{\frac{2V_p}{V_r}}\right) \]

\[ i_{D_{max}} = I_L \left(1 + 2\pi \sqrt{\frac{2V_p}{V_r}}\right) \]

Full-wave Peak Rectifier

\[ V_r = \frac{V_p T}{2RC} = \frac{V_p}{2fRC} \]

\[ \omega \Delta t \simeq \sqrt{\frac{2V_r}{V_p}} \]

\[ i_{D_{ave}} = I_L \left(1 + \pi \sqrt{\frac{2V_p}{V_r}}\right) \]

\[ i_{D_{max}} = I_L \left(1 + 2\pi \sqrt{\frac{2V_p}{V_r}}\right) \]