ELG4139: Rectifiers and Controlled Rectifiers
AC to DC Converters

- Rectifier
  - Half-wave Rectifier
  - Full-wave Rectifier
    - Centre-tape full-wave rec.
    - Full-wave Bridge rec.

<table>
<thead>
<tr>
<th></th>
<th>Half-wave</th>
<th>Centre-tap</th>
<th>Bridge type</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of diode</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Transformer necessary</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Maximum efficiency</td>
<td>40.6%</td>
<td>81.2%</td>
<td>81.2%</td>
</tr>
</tbody>
</table>
Linear Rectifier

Consist of:

- Transformer: steps ac voltage up or down.
- Rectifier Diodes: change ac to “bumpy” dc.
- Filter Network: includes capacitors and inductors, smooths out the bumps.
- Voltage Regulator: keeps the voltage constant.
- Protection: usually a zener diode circuit.
Example: Computer Power Supply

120V, 60Hz ac
ac/dc converter (rectifier)

Controller
dc/dc converter

12V dc
5V dc
5V dc
Example: Adjustable Motor Speed Drive

- 3 phase 60Hz ac
- ac/dc converter (rectifier)
- dc/ac converter (inverter)
- DSP based control
- Motor
  - currents
  - position
Power Supply Specifics: Half Wave Rectifier

**Half-Wave Rectifier**
(Electrons flow during only one half of the cycle)

**Electron Flow - 1st Half-Cycle**
**Electron Flow - 2nd Half-Cycle**
(No Electron Flow)

Source: ARRL
Half-Wave Rectifier

High ripple factor.

Low rectification efficiency.

Low transformer utilization factor.
Power Supply Specifics
Full Wave Center-Tapped Rectifier

FULL WAVE CENTER-TAPPED RECTIFIER
(Electrons flow during both halves of the cycle)

Source: ARRL
Power Supply: Full Wave Bridge Rectifier

source: ARRL
Filtering
Capacitors are used in power supply filter networks. The capacitors smooth out the rippled AC to DC.

Source: ARRL
Rectifier Performance Parameters

\[ \eta = \frac{P_{dc}}{P_{ac}} \quad \text{Rectification Efficiency} \]

\[ V_{ac} = \sqrt{V_{rms}^2 - V_{dc}^2} \quad P_{ac} = V_{rms}I_{rms} \]

\[ FF = \frac{V_{rms}}{V_{dc}} \quad \text{Form Factor} \]

Ripple factor \[ RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \frac{V_{rms}^2}{V_{dc}^2} - 1 = \sqrt{FF^2 - 1} \]
**Example 1:** A half-wave rectifier has a pure resistive load of $R$

Determine (a) The efficiency, (b) Form factor (c) Ripple factor.

\[
V_{dc} = \frac{1}{2\pi} \int_{0}^{\pi} V_m \sin(\omega t) \, d\omega t = \frac{V_m}{2\pi} (-\cos\pi - \cos(0)) = \frac{V_m}{\pi} \\
I_{dc} = \frac{V_{dc}}{R} = \frac{V_m}{\pi R}
\]

\[
V_{rms} = \sqrt{\frac{1}{2\pi} \int_{0}^{\pi} (V_m \sin \omega t)^2 \, d\omega t} = \frac{V_m}{2} \quad I_{rms} = \frac{V_m}{2R}
\]

\[
\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc} \cdot I_{dc}}{V_{rms} \cdot I_{rms}} = \frac{\frac{V_m}{\pi} \cdot \frac{V_m}{\pi R}}{\frac{V_m}{2} \cdot \frac{V_m}{2R}} = 40.53\% \]

\[
FF = \frac{V_{rms}}{V_{dc}} = \frac{2}{\frac{V_m}{2}} = \frac{\pi}{\frac{V_m}{2}} = 1.57
\]

\[
RF = \frac{V_{ac}}{V_{dc}} = \sqrt{FF^2 - 1} = \sqrt{1.57^2 - 1} = 1.211
\]
Three-Phase Diode Bridge Rectifier
Waveforms and Conduction Times of Three-Phase Bridge Rectifier

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Three-Phase Full-Wave Rectifier
Example 2: A single-phase diode bridge rectifier has a purely resistive load of $R=15$ ohms and, $V_S=300 \sin 314 \, t$ and unity transformer ratio. Determine (a) The efficiency, (b) Form factor, (c) Ripple factor, (d) and, (d) Input power factor.

$$V_{dc} = \frac{1}{\pi} \int_{0}^{\pi} V_m \sin \omega t \, d\omega t = \frac{2V_m}{\pi} = 190.956 \, V$$

$$I_{dc} = \frac{2V_m}{\pi \, R} = 12.7324 \, A$$

$$V_{rms} = \left[ \frac{1}{\pi} \int_{0}^{\pi} (V_m \sin \omega t)^2 \, d\omega t \right]^{1/2} = \frac{V_m}{\sqrt{2}} = 212.132 \, V$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc} \, I_{dc}}{V_{rms} \, I_{rms}} = 81.06 \%$$

$$FF = \frac{V_{rms}}{V_{dc}} = 1.11$$

$$RF = \frac{V_{ac}}{V_{dc}} = \sqrt{\frac{V_{rms}^2 - V_{dc}^2}{V_{dc}^2}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{FF^2 - 1} = 0.482$$

Input power factor = $\frac{\text{Real Power}}{\text{Apperant Power}} = \frac{V_S \, I_S \cos \phi}{V_S \, I_S} = 1$
Alternative! Controlled Switching Mode

- By using linear regulator, the AC to DC converter is not efficient and of large size and weight!
- Using Switching-Mode
- High efficiency
- Small size and light weight
- For high power (density) applications.
- **Use Power Electronics!**
Thyristors and Controlled Rectifiers

A (anode)

G (gate)

K (cathode)

$i_A$

$v_{AK}$

Holding current
Latching current
Holding current
$i_L$
$i_H$

Reverse breakdown voltage
Forward leakage current
Reverse leakage current

Gate triggered
Controlled Rectifier Circuit

\[ V_{dc} = \frac{1}{2\pi} \int_{\alpha}^{\pi} V_p \sin(\omega t) \, d\omega = \frac{V_p}{2\pi} (1 + \cos \alpha) \]

\[ V_{rms} = \left[ \frac{1}{2\pi} \int_{\alpha}^{\pi} V_p^2 \sin^2(\omega t) \, d\omega \right]^{1/2} \]

\[ = \frac{V_p}{2} \left[ \frac{1}{\pi} \left( \pi - \alpha + \frac{\sin 2\alpha}{2} \right) \right]^{1/2} \]
**Example:** Consider the following SCR-based variable voltage supply. For \( RL = 240 \) Ohm, derive the RMS value of the load voltage as a function of the firing angle, and then calculate the load power when the firing angle \( \alpha \) is 0, \( \pi/2 \), and \( \pi \).
Full-Wave Rectifiers Using SCR

\[ V_{dc} = \frac{2}{2\pi} \int_{\alpha}^{\pi+\alpha} V_p \sin \omega t \, d\omega t = \frac{2V_p}{\pi} (\cos \alpha) \]

\[ V_{rms} = \left[ \frac{2}{2\pi} \int_{\alpha}^{\pi+\alpha} V_p^2 \sin^2 \omega t \, d\omega t \right]^{1/2} \]

\[ = \frac{V_p}{\sqrt{2}} = V_s \]

With a purely resistive load, SCRs S_1 and S_2 can conduct from \( \alpha \) to \( \pi \), and SCRs S_3 and S_4 can conduct from \( \alpha + \pi \) to \( 2\pi \).