Welcome to PEEEB

Lecture 3: Diode Rectifiers
Presenter: Dr. Firuz Zare

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Contents:

- Single phase half-wave diode rectifier
- Single phase half-wave diode rectifier with freewheeling diode (R-L load)
- Battery charger (with R or L component as a current limiter)
- Single phase full wave diode rectifier with centre-tapped transformer
- Single phase full wave diode rectifier (different loads)
- Six-phase diode rectifier
- Three-phase diode rectifier
- Three-phase full-wave diode rectifier
- Line impedance effects
- Examples

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Uncontrolled AC to DC Converter

Electrical Source  Power Converter  Electrical Load

$v_{in}(t)$  $i_{in}(t)$  $v_{out}(t)$  $i_{out}(t)$

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Single-phase half-wave diode-rectifier
(resistive load)

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Single-phase half-wave diode-rectifier (resistive and inductive load)

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Single-phase half-wave diode-rectifier with a freewheeling diode (resistive and inductive load)

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Single-phase half-wave diode-rectifier

\[ v_{ou}(t) = \begin{cases} 
V_m \sin \left( \frac{2\pi t}{T} \right) & 0 < t \leq \frac{T}{2} \\
0 & \frac{T}{2} < t \leq T 
\end{cases} \]

\[ V_{ou} = \int_{0}^{T/2} v_{ou}(t) \, dt \]

\[ V_{ou} = \frac{1}{T} \int_{0}^{T/2} V_m \sin \left( \frac{2\pi t}{T} \right) \, dt + \frac{1}{T} \int_{T/2}^{T} 0 \, dt \]

\[ V_{ou} = \frac{V_m}{2\pi} \left[ -\cos \left( \frac{2\pi t}{T} \right) \right]_{0}^{T/2} \]

\[ V_{ou} = \frac{V_m}{2\pi} \left[ -\cos(\pi) + \cos(\theta) \right] \]

\[ V_{ou} = \frac{V_m}{2\pi} \left[ 0 + 1 \right] \]

\[ V_{ou} = \frac{V_m}{2\pi} \left[ 2 \right] = \frac{V_m}{\pi} \]

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Single-phase half-wave battery charger with a resistor as a current limiter
Single-phase half-wave battery charger with an inductor as a current limiter

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Single-phase full-wave diode rectifier with a centre-tapped transformer and a resistive load

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Single-phase full-wave diode rectifier (bridge rectifier)

resistive load

inductive load

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Single-phase full-wave diode rectifier with a resistive load

**Diagram:**

- Input voltage $v_{in}(t)$
- Output voltage $v_{out}(t)$
- Load current $i_{load}(t)$
- Rectifier diodes $D_1, D_2, D_3, D_4$
- Resistor $R$

**Graphs:**

- $v_{in}(t)$ vs. $t$
- $v_{out}(t)$ vs. $t$
- $i_{load}(t)$ vs. $t$

**Presentation Note:**

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Single-phase full-wave diode rectifier with an inductive load

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Single-phase full-wave diode-rectifier

\[ v_{out}(t) = \begin{cases} 
V_m \sin \left( \frac{2\pi t}{T} \right) & 0 < t \leq \frac{T}{2} \\
V_m \sin \left( \frac{2\pi t}{T} \right) & \frac{T}{2} < t \leq T
\end{cases} \]

\[ V_{out} = \frac{1}{T} \int_0^T v_{out}(t) \, dt \]

\[ = \frac{1}{T} \int_0^{T/2} V_m \sin \left( \frac{2\pi t}{T} \right) \, dt + \frac{1}{T} \int_{T/2}^T V_m \sin \left( \frac{2\pi t}{T} \right) \, dt \]

\[ = 2 \left( \frac{1}{T} \int_0^{T/2} V_m \sin \left( \frac{2\pi t}{T} \right) \, dt \right) \]

\[ = 2 \left( \frac{V_m}{\pi} \right) = \frac{2V_m}{\pi} \]

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Single-phase full-wave diode rectifier as a DC power supply

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Single-phase full-wave battery charger with an inductor at the input side

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Single-phase full-wave battery charger with an inductor at the output side

![Diagram of a single-phase full-wave battery charger with an inductor at the output side]

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Single-phase full-wave battery charger with an inductor at both sides

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The capacitor C1 is charged through the diode D1 during the positive half-cycle of the input AC voltage and C2 is charged through D2 during the negative half-cycle.

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Doubling Output Voltage

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Six-phase half-wave diode rectifier with star connection and resistive load

\[ v_1(t) \]

\[ v_2(t) \]

\[ v_3(t) \]

\[ v_4(t) \]

\[ v_5(t) \]

\[ v_6(t) \]

\[ i_{\text{out}}(t) \]

\[ v_{\text{out}}(t) \]

\[ R \]

\[ T \]

\[ V_1 \] has the highest magnitude compared to other phases. Thus during this period \( D_1 \) conducts and the rest of the diodes are reverse biased.

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Six-phase half-wave diode rectifier with star connection and resistive load

Now, \( V_2 > V_1 \) and other phases, thus during this period, \( D_1 \) is turned off and \( D_2 \) is turned on.

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Three-phase half-wave diode rectifier with star connection

When $D_1$ is off, $V_{D1} = V_a - V_b$ or $V_a - V_c$ which is a line voltage.

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Three-phase half-wave diode-rectifier

\[ v_{out}(t) = V_m \cos\left(\frac{2\pi t}{T}\right) \quad -\frac{T}{6} < t \leq \frac{T}{6} \]

\[ V_{out} = \frac{1}{T} \int_{-\frac{T}{3}}^{\frac{T}{3}} V_m \cos\left(\frac{2\pi t}{T}\right) dt \]

\[ = \frac{3V_m}{2\pi} \left[ \sin\left(\frac{\pi}{3}\right) - \sin\left(-\frac{\pi}{3}\right) \right] \]

\[ = \frac{3V_m}{2\pi} \left[ \sin\left(\frac{\pi}{3}\right) + \sin\left(\frac{\pi}{3}\right) \right] = \frac{3V_m}{2\pi} \left[ 2 \sin\left(\frac{\pi}{3}\right) \right] \]

\[ = \frac{3V_m}{\pi} \frac{\sqrt{3}}{2} = \frac{3\sqrt{3}V_m}{2\pi} \]

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Three-phase full-wave diode rectifier with resistive load

Diodes which are turned on

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Three-phase full-wave diode rectifier with resistive load

Diodes which are turned on

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Diodes which are turned on

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Diodes which are turned on

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Diodes which are turned on

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Diodes which are turned on

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Three-phase full-wave diode rectifier with resistive load

Diodes which are turned on

$v_{cb}(t)$ $v_{ab}(t)$ $v_{ac}(t)$ $v_{bc}(t)$ $v_{ba}(t)$ $v_{ca}(t)$

$v_{m}(t)$ (V)

$v_{m}(t)$ (V)

$i(t)$ (A)

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Three-phase full-wave diode-rectifier

\[ v_{ou}(t) = \sqrt{3}V_m \cos \left( \frac{2\pi t}{T} \right) \]

\[ V_{ou} = \frac{1}{T} \int_{-T/12}^{T/12} \sqrt{3}V_m \cos \left( \frac{2\pi t}{T} \right) dt \]

\[ = \frac{6 \sqrt{3}V_m}{T} \left[ \sin \left( \frac{2\pi t}{T} \right) \right]_{-T/12}^{T/12} \]

\[ = \frac{3 \sqrt{3}V_m}{\pi} \left[ \sin \left( \frac{\pi}{6} \right) - \sin \left( -\frac{\pi}{6} \right) \right] \]

\[ = \frac{3 \sqrt{3}V_m}{\pi} \left[ \frac{1}{2} + \frac{1}{2} \right] = \frac{3 \sqrt{3}V_m}{\pi} \]

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Effects of line impedance on output voltage

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Effects of line impedance on output voltage

\[ L \frac{di(t)}{dt} = v_i(t) = V_m \sin \left( \frac{2\pi t}{T} \right) \]

\[ di(t) = \frac{V_m}{L} \sin \left( \frac{2\pi t}{T} \right) dt \]

\[ \int_{0}^{t} di(t) dt = \frac{V_m}{L} \int_{0}^{t} \sin \left( \frac{2\pi t}{T} \right) dt \]

\[ I = \frac{V_m}{L} \left( \frac{T}{2\pi} \right) \left[ -\cos \left( \frac{2\pi t}{T} \right) \right]_{0}^{t_1} \]

\[ I = \frac{V_m T}{2\pi L} \left[ -\cos \left( \frac{2\pi t_1}{T} \right) + 1 \right] \]

\[ \frac{2\pi L I}{V_m T} = 1 - \cos \left( \frac{2\pi t_1}{T} \right) \]

\[ \cos \left( \frac{2\pi t_1}{T} \right) = 1 - \frac{2\pi L I}{V_m T} \]

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Effects of line impedance on output voltage

\[ V_{\text{out}} = \frac{1}{T} \int_{0}^{T} v_{\text{out}}(t) \, dt \]
\[ = \frac{1}{T} \int_{0}^{T} v_{\text{m}} \sin \left( \frac{2\pi t}{T} \right) \, dt \]
\[ = \frac{V_{\text{m}}}{T} \left[ -\cos \left( \frac{2\pi t}{T} \right) \right]_{0}^{T/2} \]
\[ = \frac{V_{\text{m}}}{2\pi} \left[ -\cos(\pi) + \cos \left( \frac{2\pi t}{T} \right) \right] \]
\[ = \frac{V_{\text{m}}}{2\pi} \left[ -\cos(\pi) + 1 \right] \]
\[ = \frac{V_{\text{m}}}{2\pi} \left[ 1 + \frac{2\pi L I}{V_{\text{m}} T} \right] \]
\[ = \frac{V_{\text{m}}}{\pi} \left( \frac{L I}{T} \right) \]

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Effects of line impedance on output voltage in a single phase full-wave rectifier

When the input voltage has gone positive, the voltage across D1 and D2 are positive and they are forward biased. There are short circuits in the upper loop (D1, D2 and input supply) and the lower loop (D3, D4 and the input supply). The diode currents (D2 and D3) are commutated to the other legs (D1 and D4).

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Effects of line impedance on output voltage in a three-phase full-wave rectifier

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How a diode rectifier with an inductive load affects other loads in a network

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How a diode rectifier with capacitive load affects other loads in a network

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