Power Electronics Education
Electronic Book

Welcome to PEEEB

Lecture 3: Diode Rectifiers
Presenter: Dr. Firuz Zare

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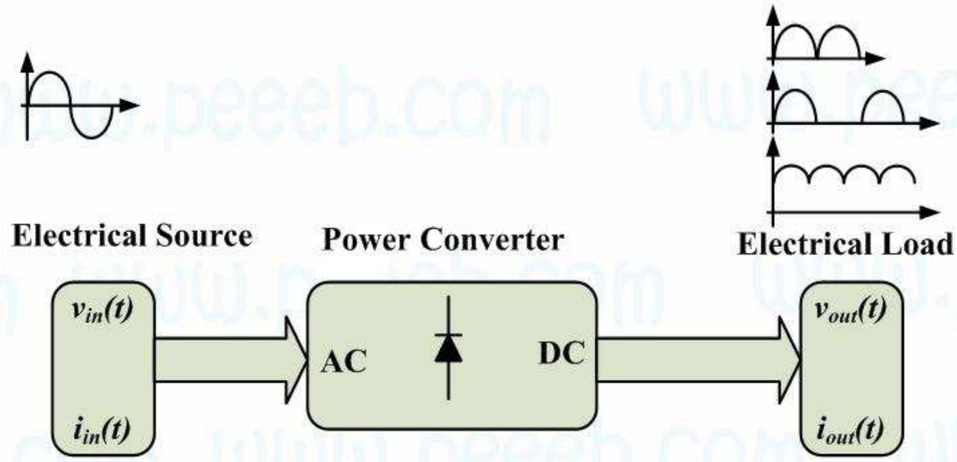
Uncontrolled AC to DC Converter



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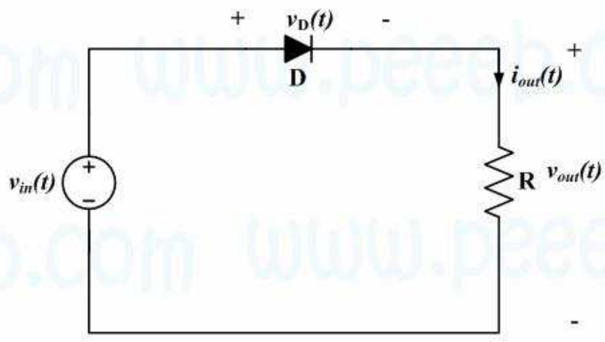
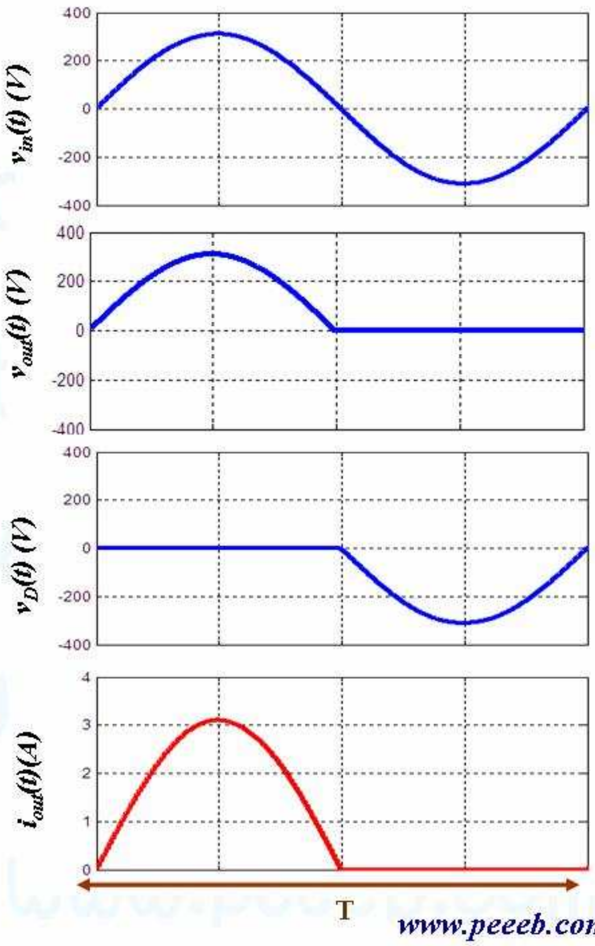
Single-phase half-wave diode-rectifier (resistive load)





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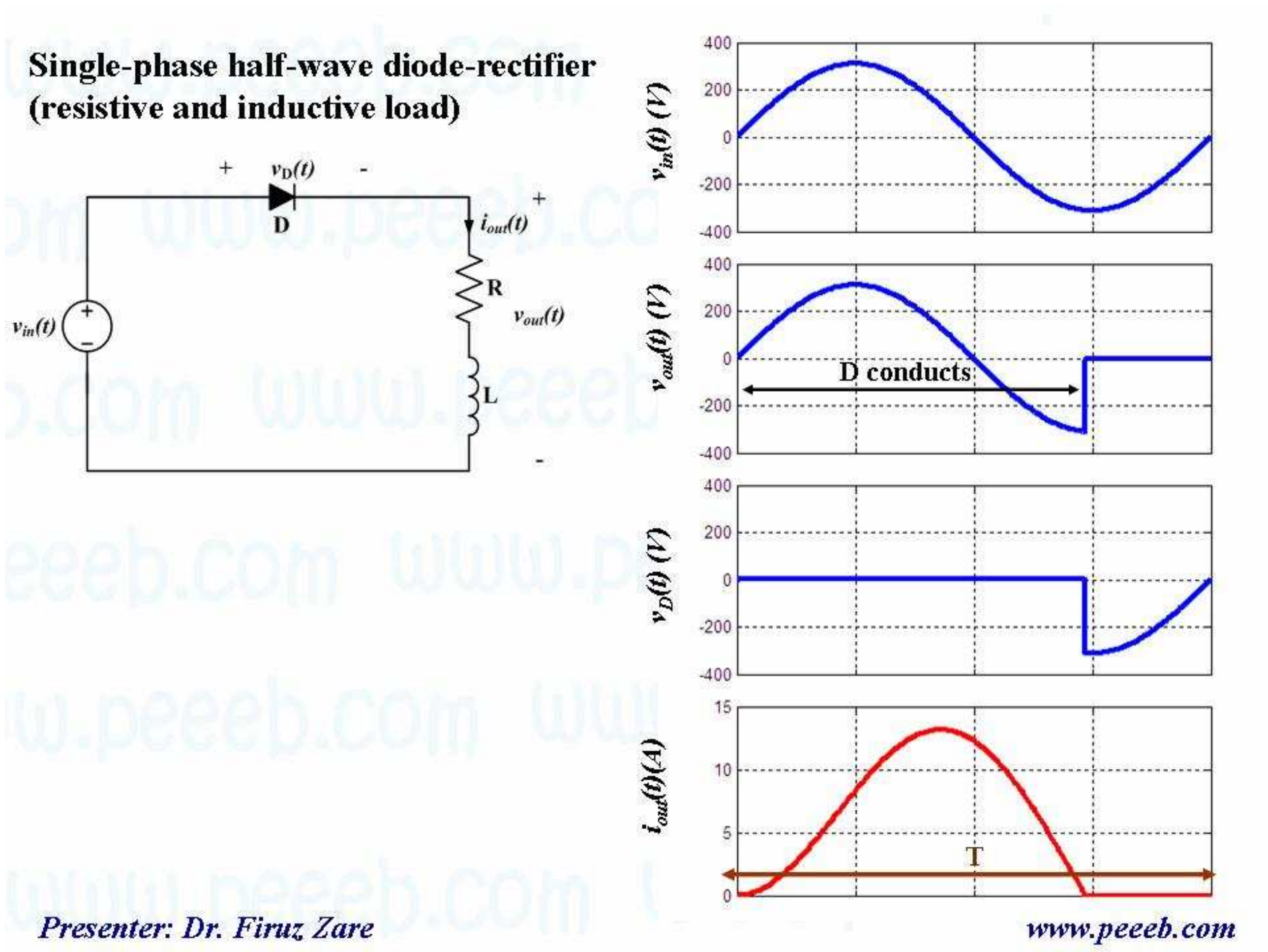
Single-phase half-wave diode-rectifier
(resistive and inductive load)
+ $v_D(t)$ -
D
$i_{out}(t)$
+
R
$v_{out}(t)$
L
-
$v_{in}(t)$
$v_{in}(t)$ (V)
$v_{out}(t)$ (V)
D conducts
$v_D(t)$ (V)
$i_{out}(t)$(A)
T
400
200
0
-200
-400
15
10
5
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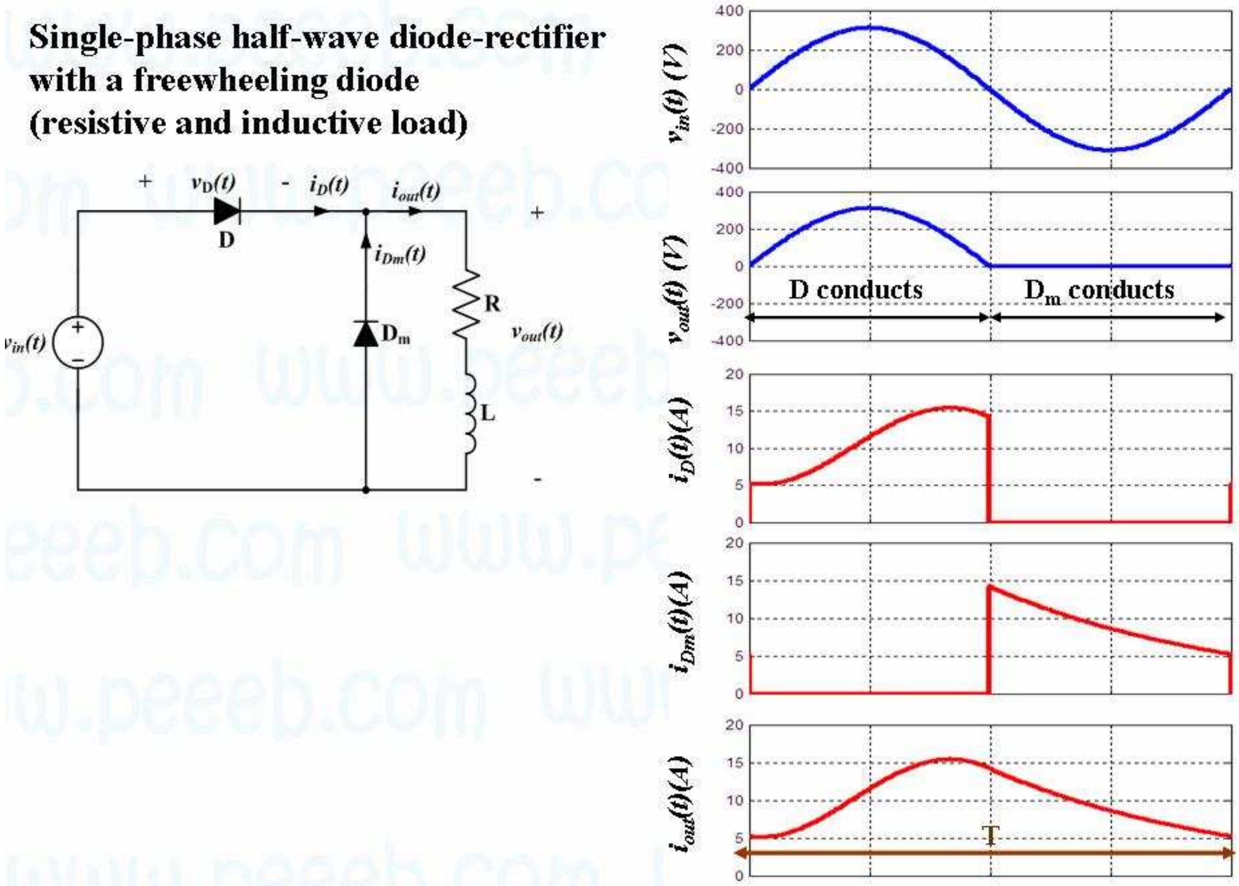
Single-phase half-wave diode-rectifier with a freewheeling diode (resistive and inductive load)



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Single-phase half-wave diode-rectifier

$$v_{out}(t)=\begin{cases} V_m \sin\left(\dfrac{2\pi t}{T}\right) & 0<t\le \dfrac{T}{2} \\ 0 & \dfrac{T}{2}<t\le T \end{cases}$$

$$V_{out} = \overline{v_{out}(t)} = \frac{1}{T}\int_0^T v_{out}(t)dt$$

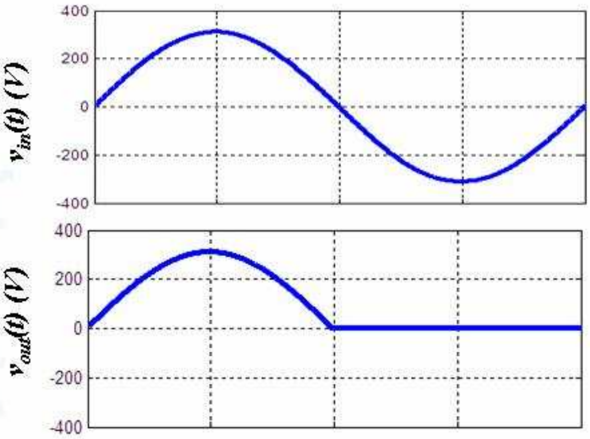
$$= \frac{1}{T}\int_0^{\frac{T}{2}} V_m \sin\left(\frac{2\pi t}{T}\right)dt + \frac{1}{T}\int_{\frac{T}{2}}^{T} 0\times dt$$

$$= \frac{V_m}{T}\left(\frac{T}{2\pi}\right)\left[-\cos\left(\frac{2\pi t}{T}\right)\Big|_0^{\frac{T}{2}}\right]$$

$$= \frac{V_m}{2\pi}\left[-\cos(\pi)+\cos(0)\right]$$

$$= \frac{V_m}{2\pi}\left[-(-1)+1\right]$$

$$= \frac{V_m}{2\pi}[2] = \frac{V_m}{\pi}$$



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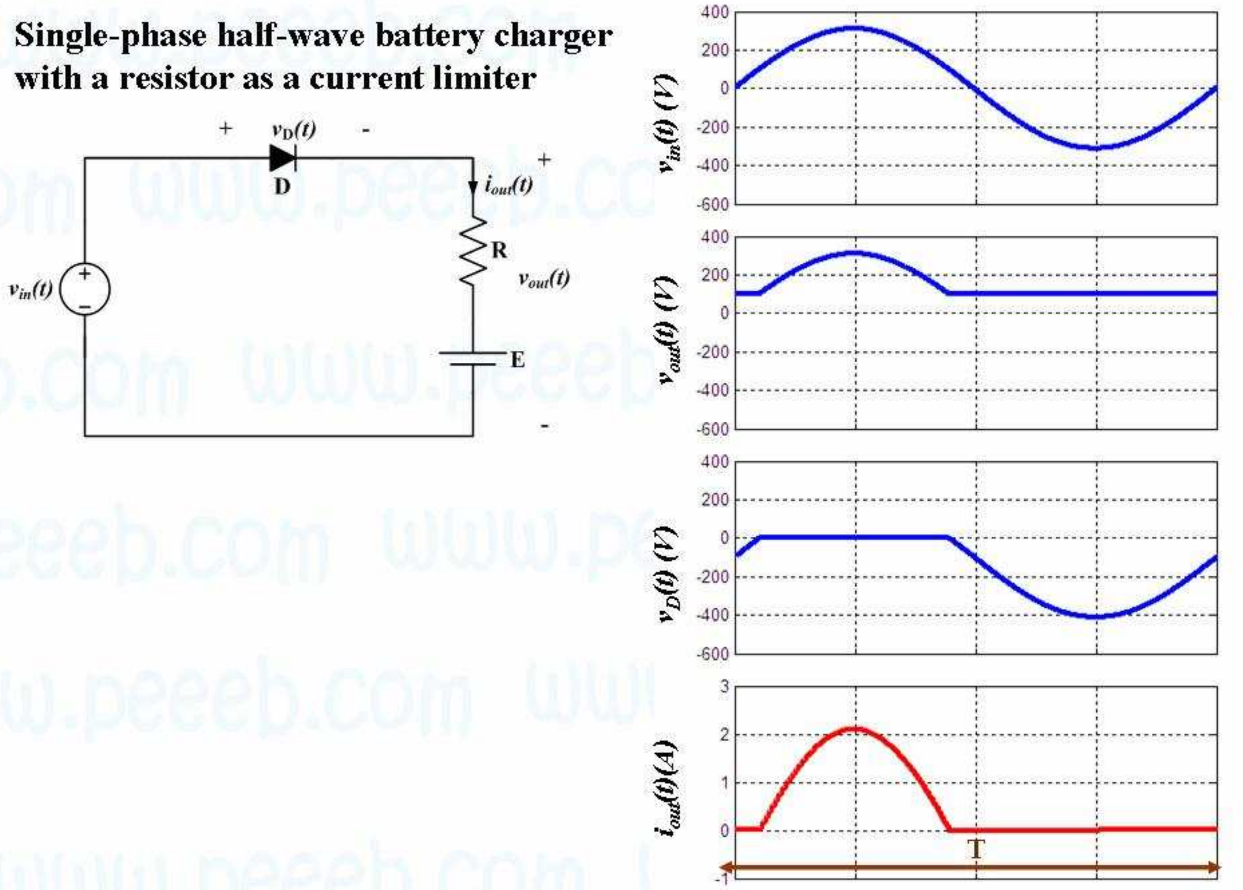
Single-phase half-wave battery charger with a resistor as a current limiter



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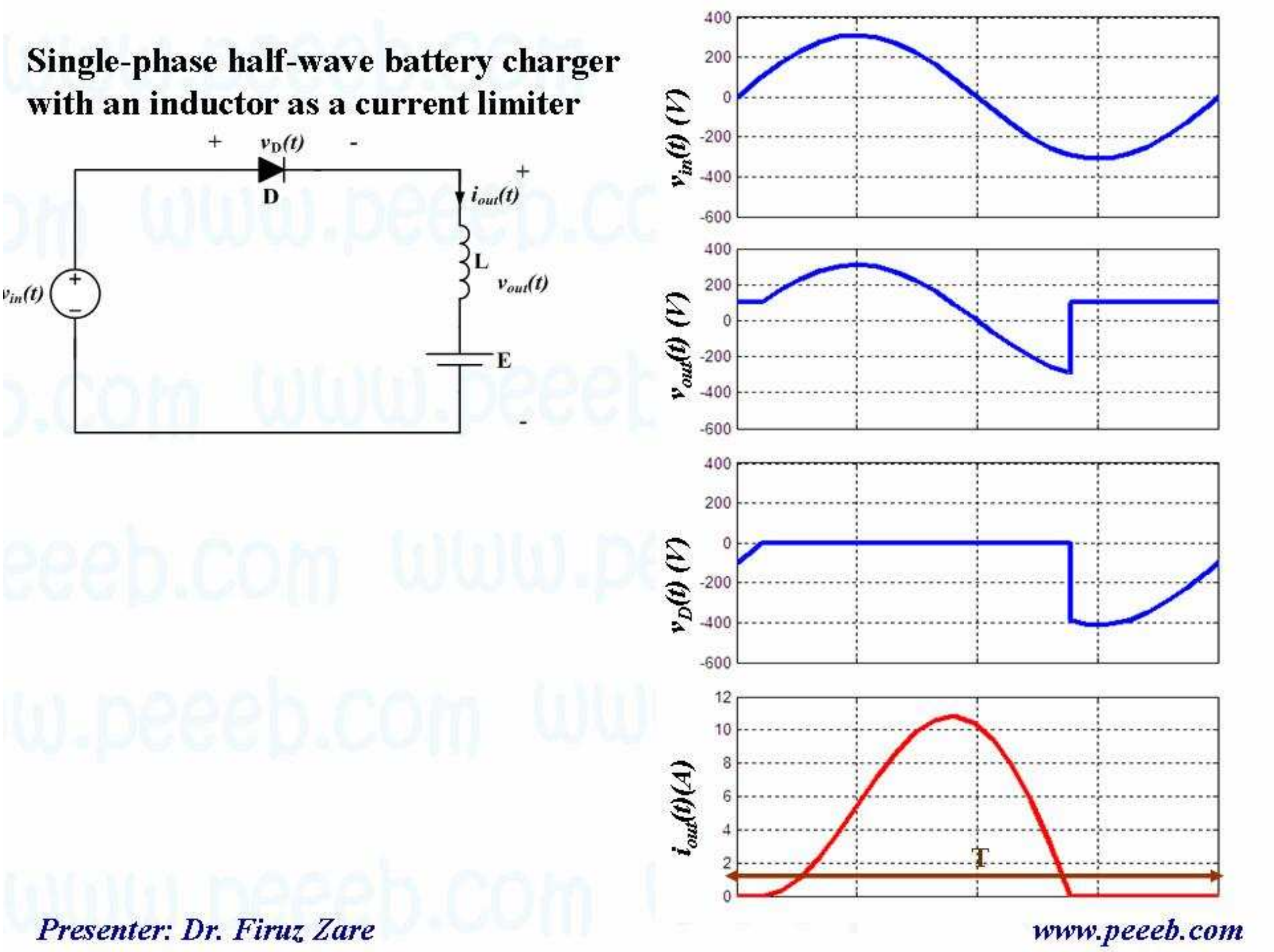
Single-phase half-wave battery charger
with an inductor as a current limiter
+ $v_D(t)$ -
D
$i_{out}(t)$
+
L
$v_{out}(t)$
$v_{in}(t)$
E
-
$v_{in}(t)$ (V)
$v_{out}(t)$ (V)
$v_D(t)$ (V)
$i_{out}(t)$(A)
T
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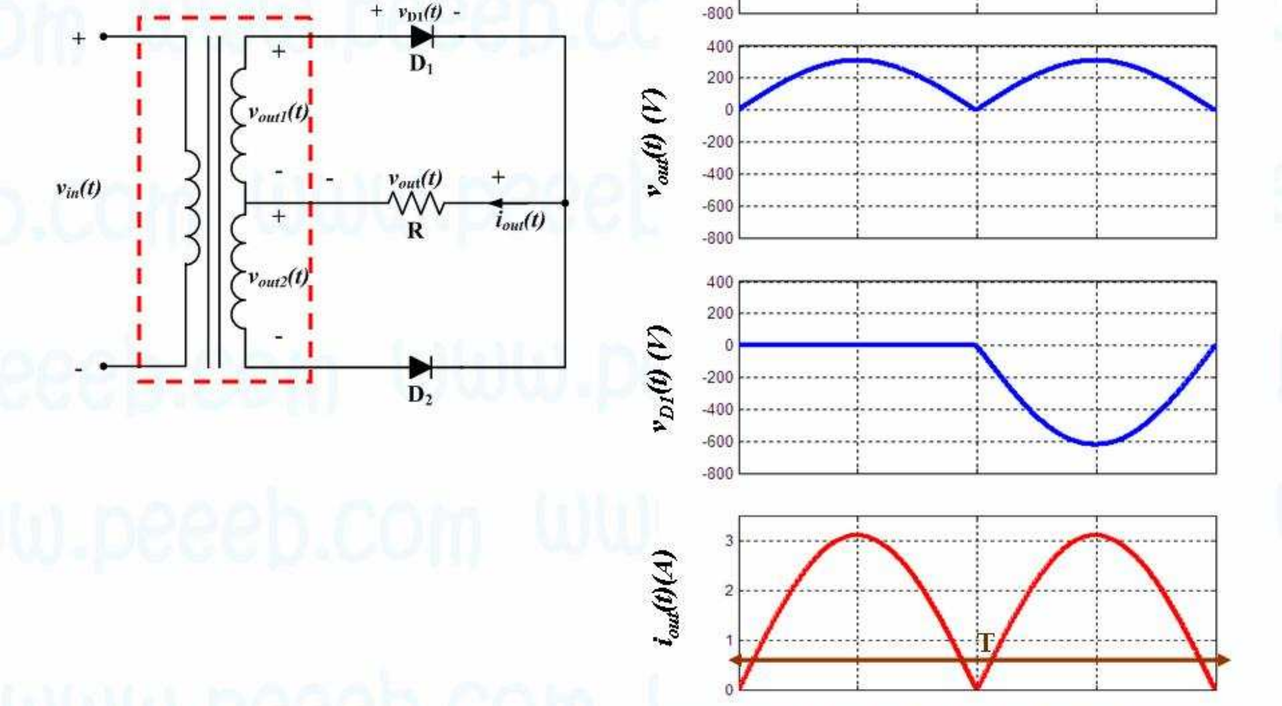
Single-phase full-wave diode rectifier with a centre-tapped transformer and a resistive load



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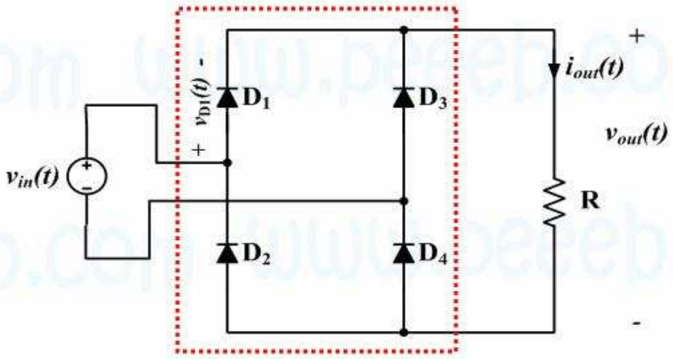
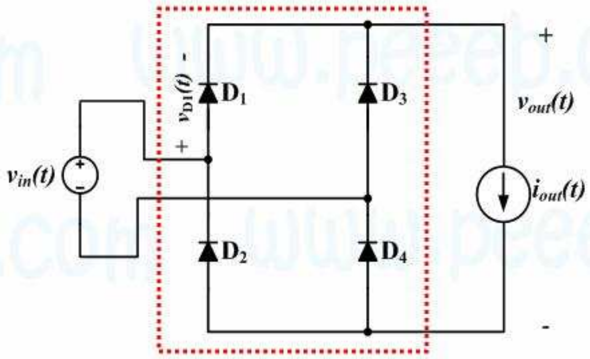
Single-phase full-wave diode rectifier (bridge rectifier)



resistive load



inductive load

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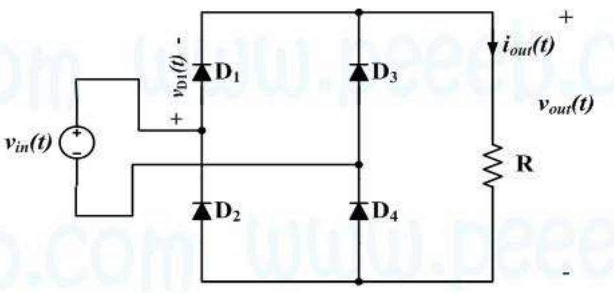
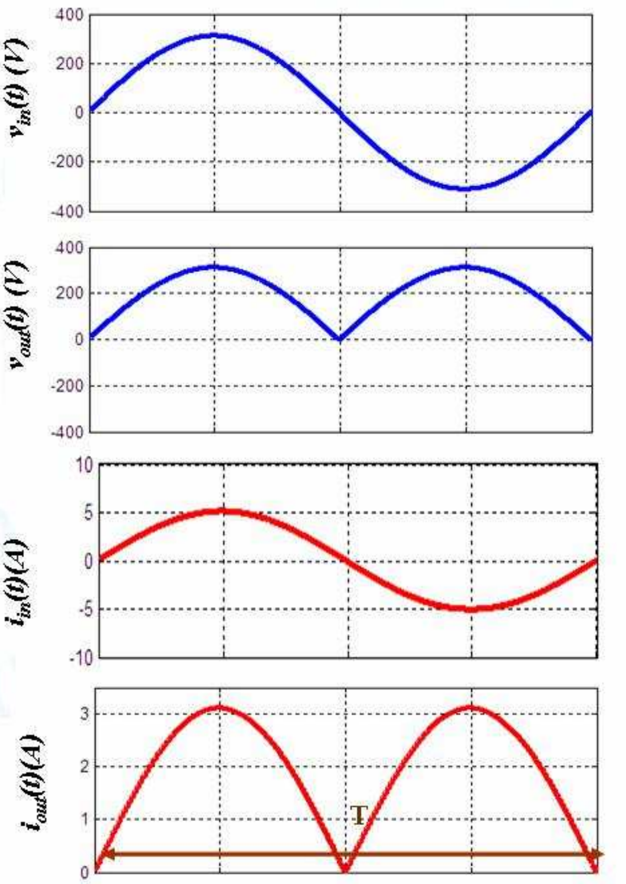
Single-phase full-wave diode rectifier with a resistive load





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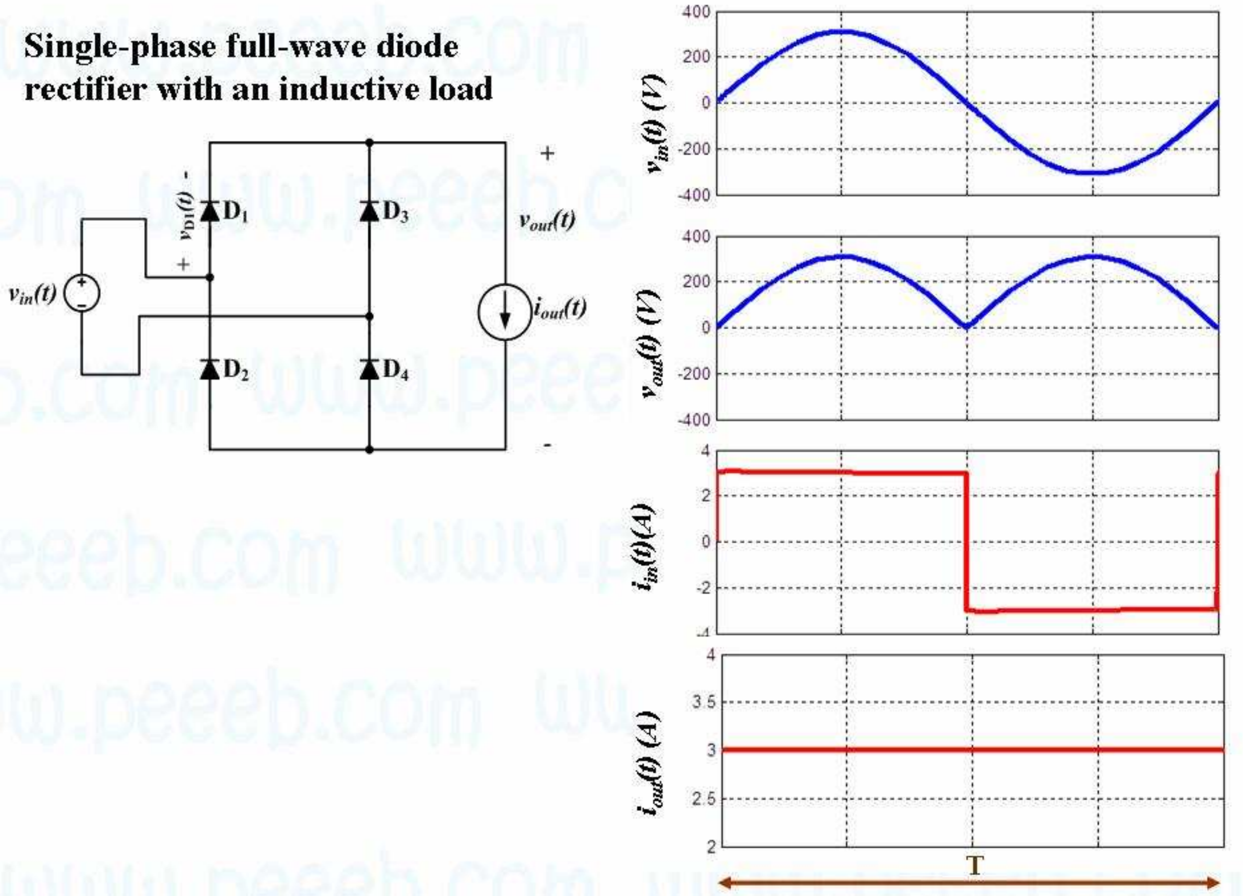
Single-phase full-wave diode rectifier with an inductive load



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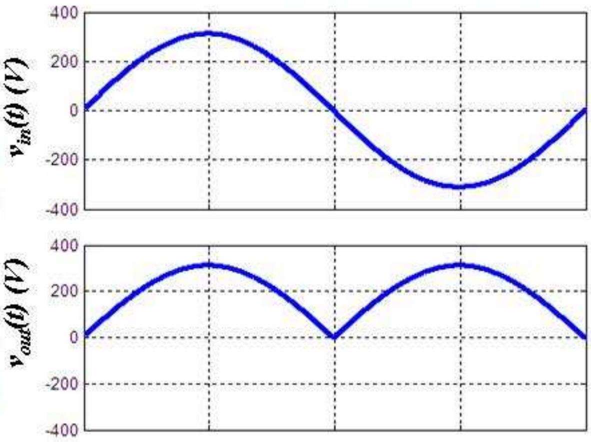
Single-phase full-wave diode-rectifier

$$v_{out}(t) = \begin{cases} V_m \sin\left(\dfrac{2\pi t}{T}\right) & 0 < t \le \dfrac{T}{2} \\ V_m \sin\left(\dfrac{2\pi t}{T}\right) & \dfrac{T}{2} < t \le T \end{cases}$$



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

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

$$= 2\left(\frac{1}{T}\int_0^{\frac{T}{2}} V_m \sin\left(\frac{2\pi t}{T}\right)dt\right)$$

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

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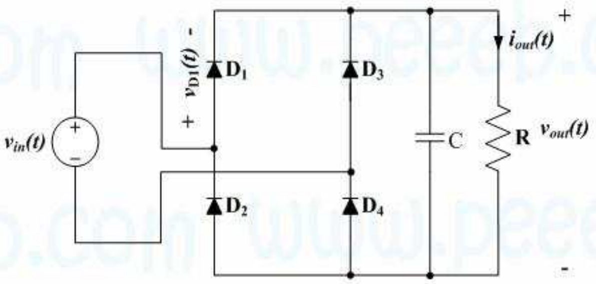
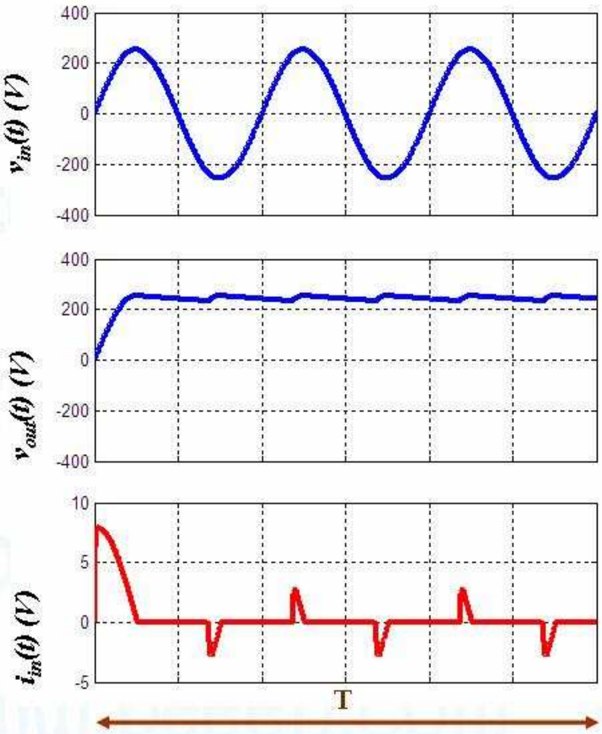
Single-phase full-wave diode rectifier as a DC power supply





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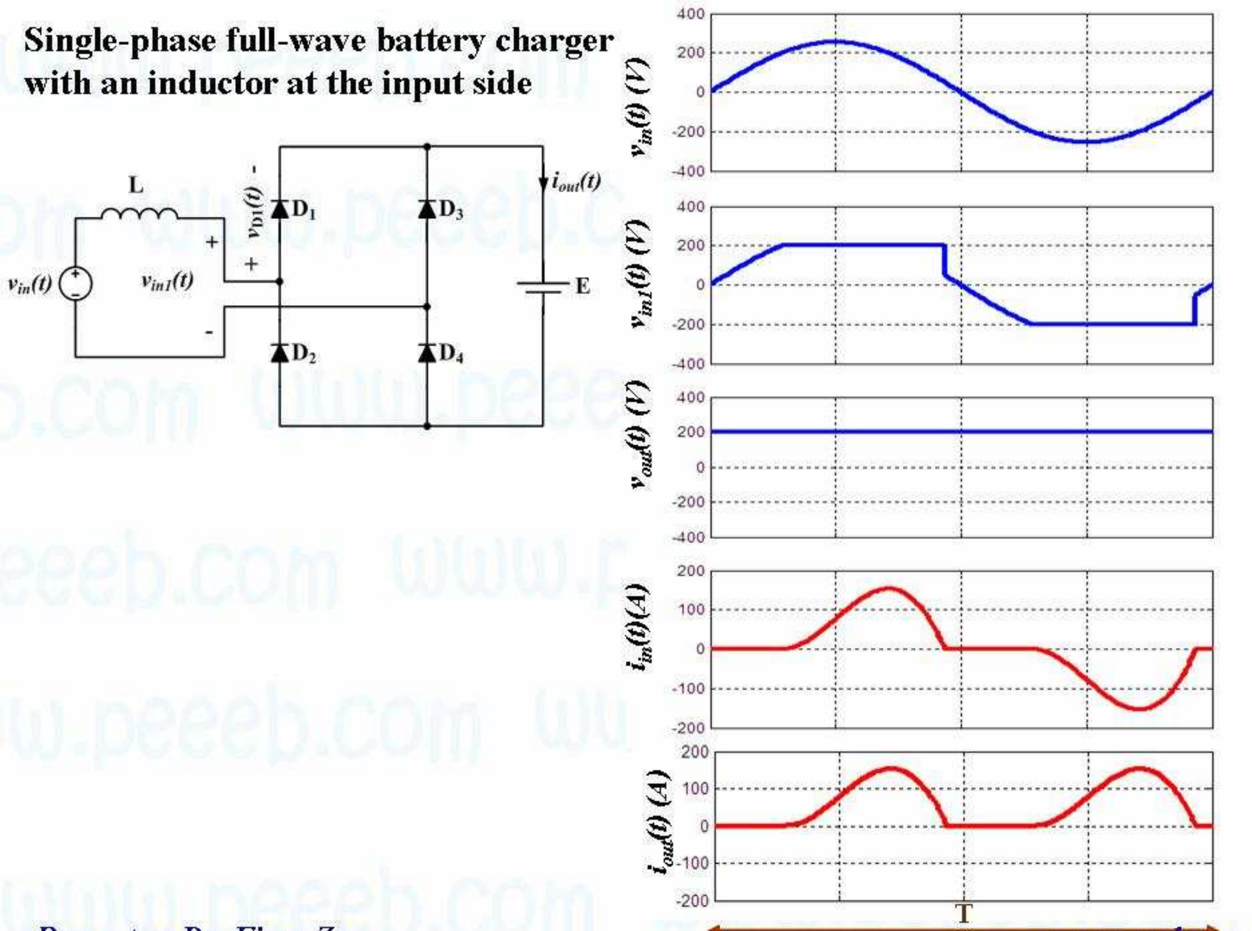
Single-phase full-wave battery charger with an inductor at the input side



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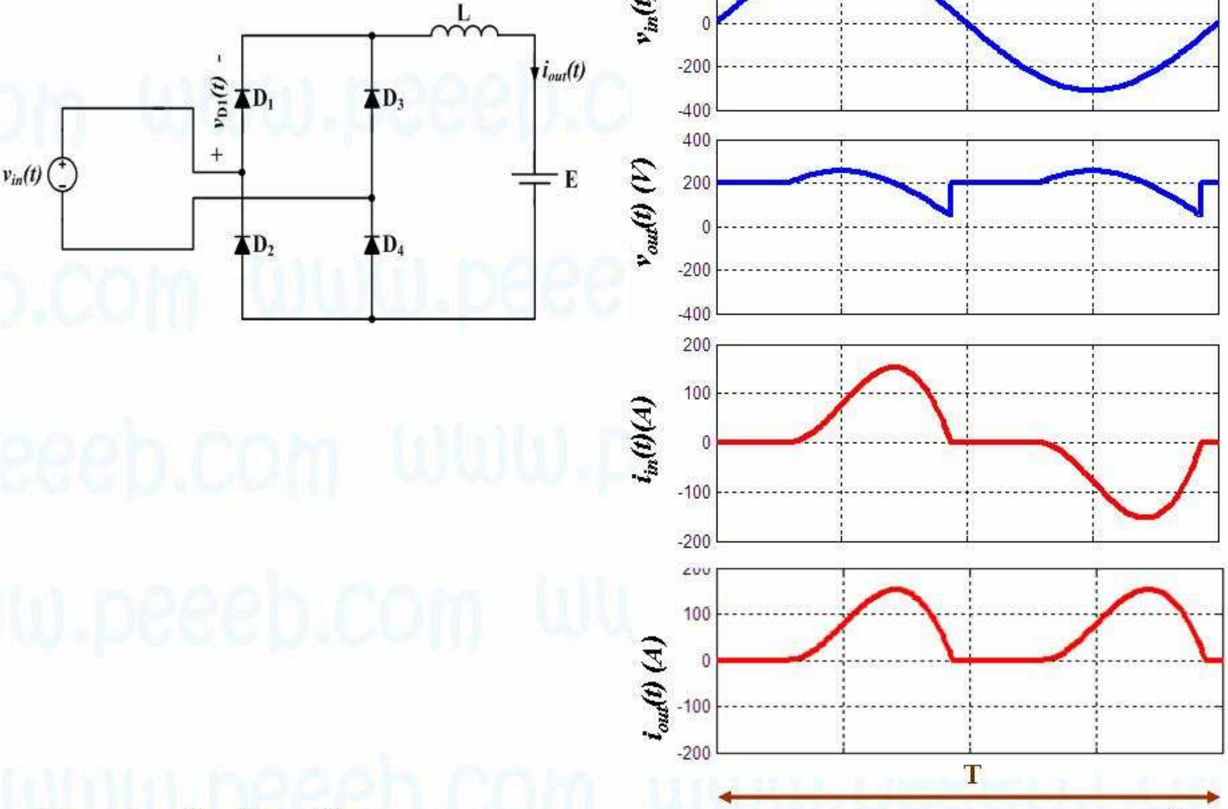
Single-phase full-wave battery charger with an inductor at the output side



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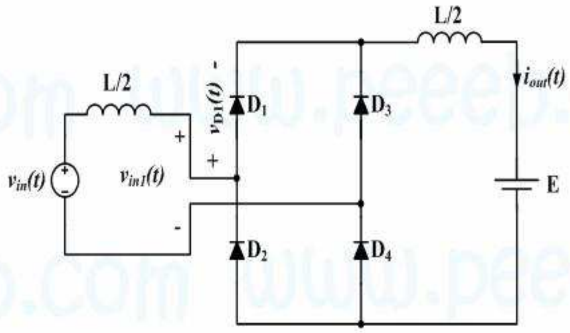
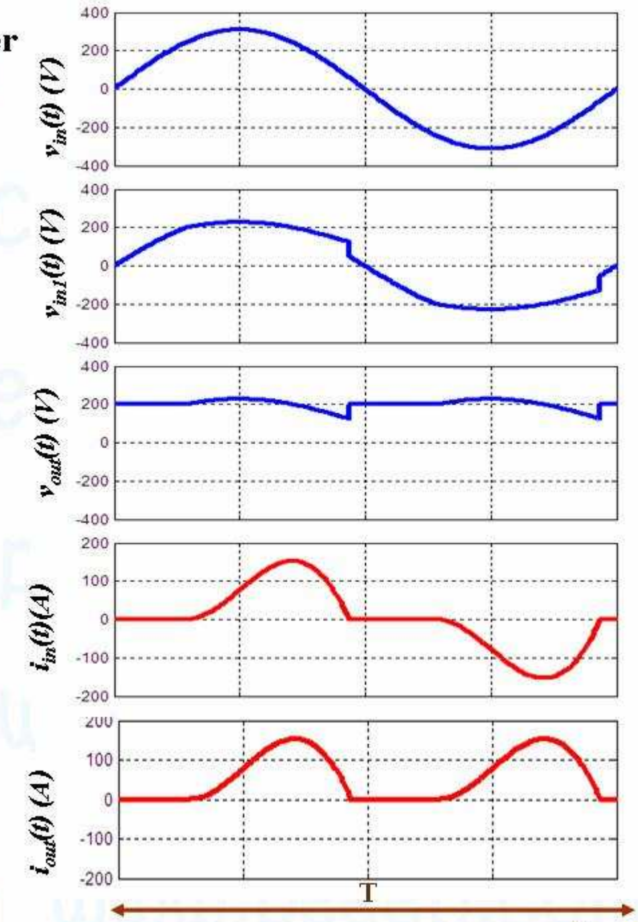
Single-phase full-wave battery charger with an inductor at the both sides





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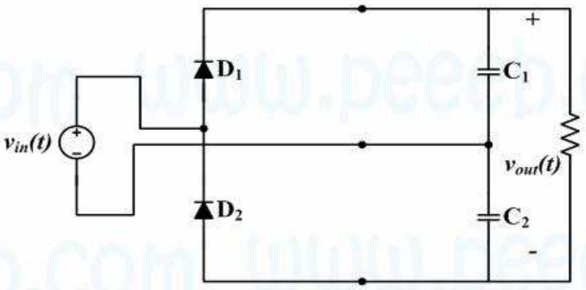
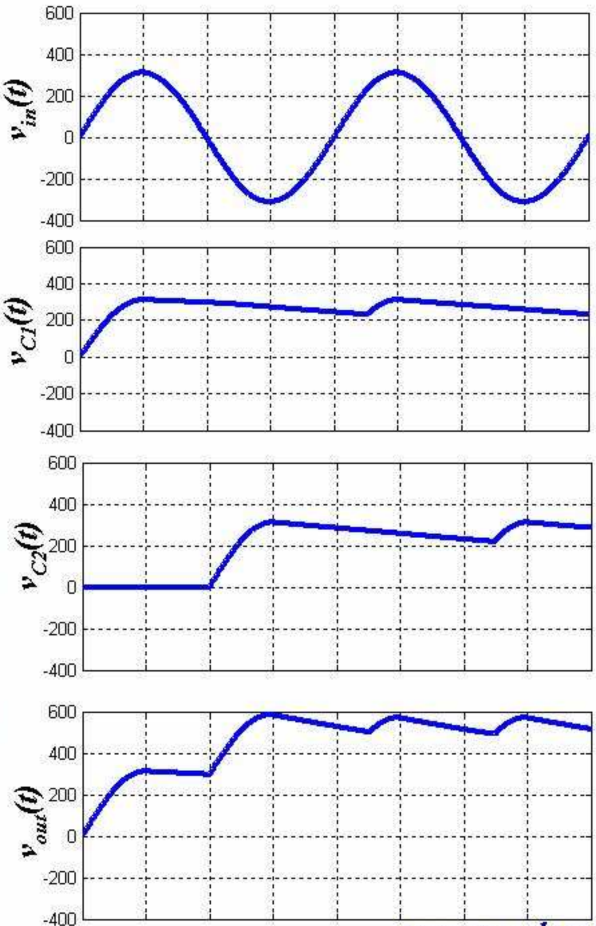
Doubling Output Voltage



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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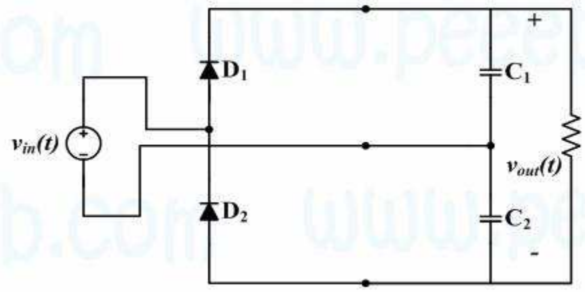
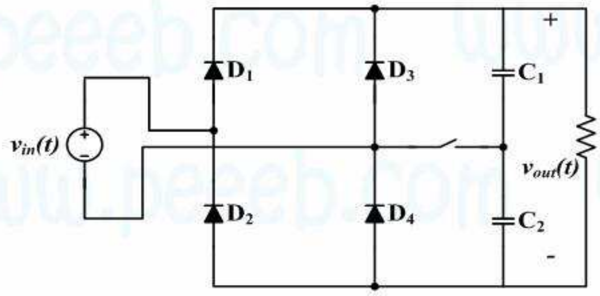
Doubling Output Voltage





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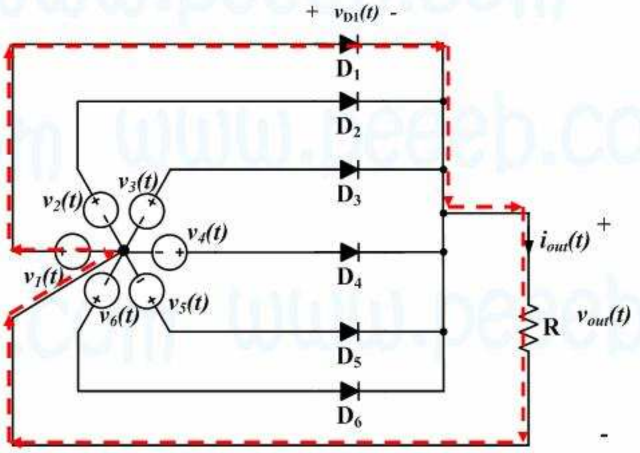
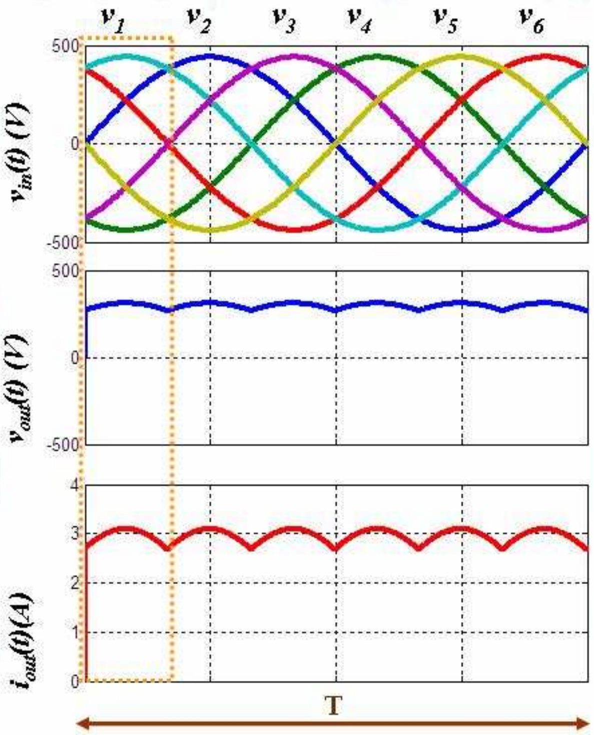
Six-phase half-wave diode rectifier with star connection and resistive load





V_1 has the highest magnitude compare to other phases. Thus during this period D_1 conducts and the rest of diodes are reverse biased.

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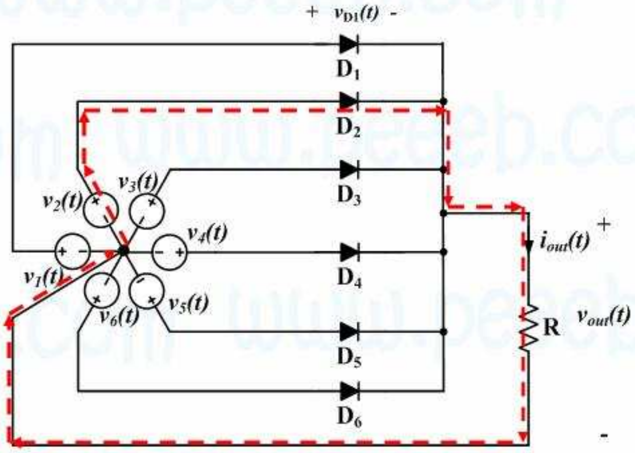
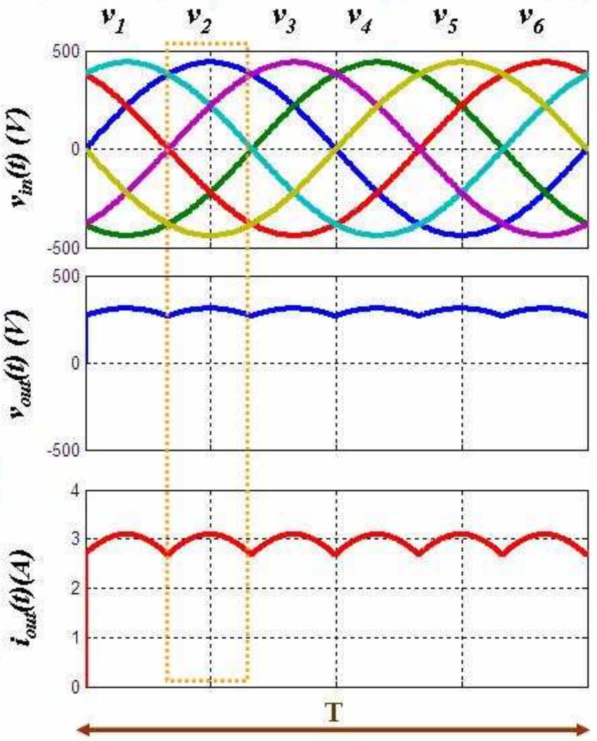
Six-phase half-wave diode rectifier with star connection and resistive load





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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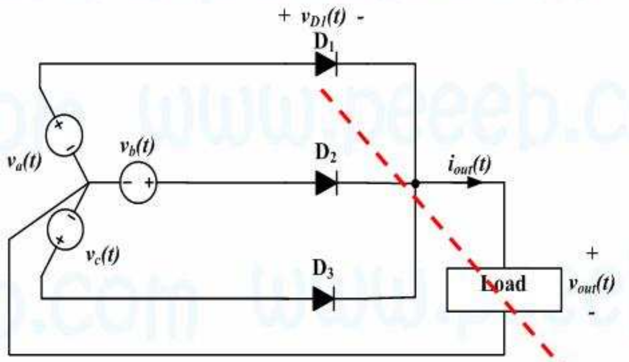
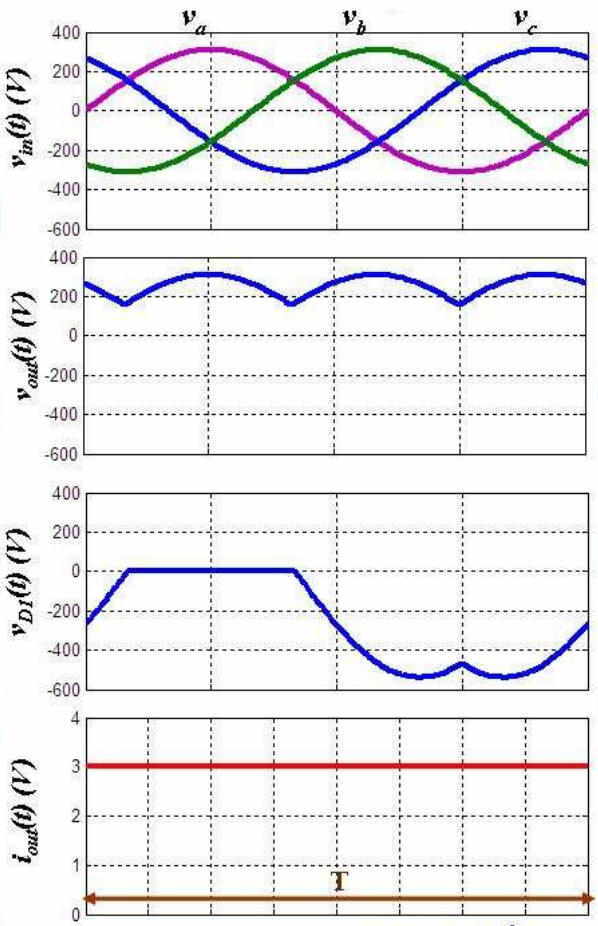
Three-phase half-wave diode rectifier with star connection





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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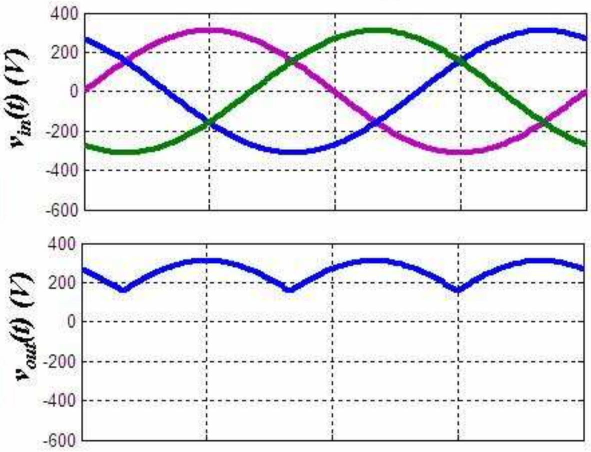
Three-phase half-wave diode-rectifier



$$v_{out}(t) = V_m \cos\left(\frac{2\pi t}{T}\right) \qquad -\frac{T}{6} < t \le \frac{T}{6}$$

$$V_{out} = \frac{1}{\frac{T}{3}} \int_{-\frac{T}{6}}^{\frac{T}{6}} V_m \cos\left(\frac{2\pi t}{T}\right) dt$$

$$= \frac{3V_m}{T}\left(\frac{T}{2\pi}\right)\left[\sin\left(\frac{2\pi t}{T}\right)\Big|_{-\frac{T}{6}}^{\frac{T}{6}}\right]$$

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

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

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

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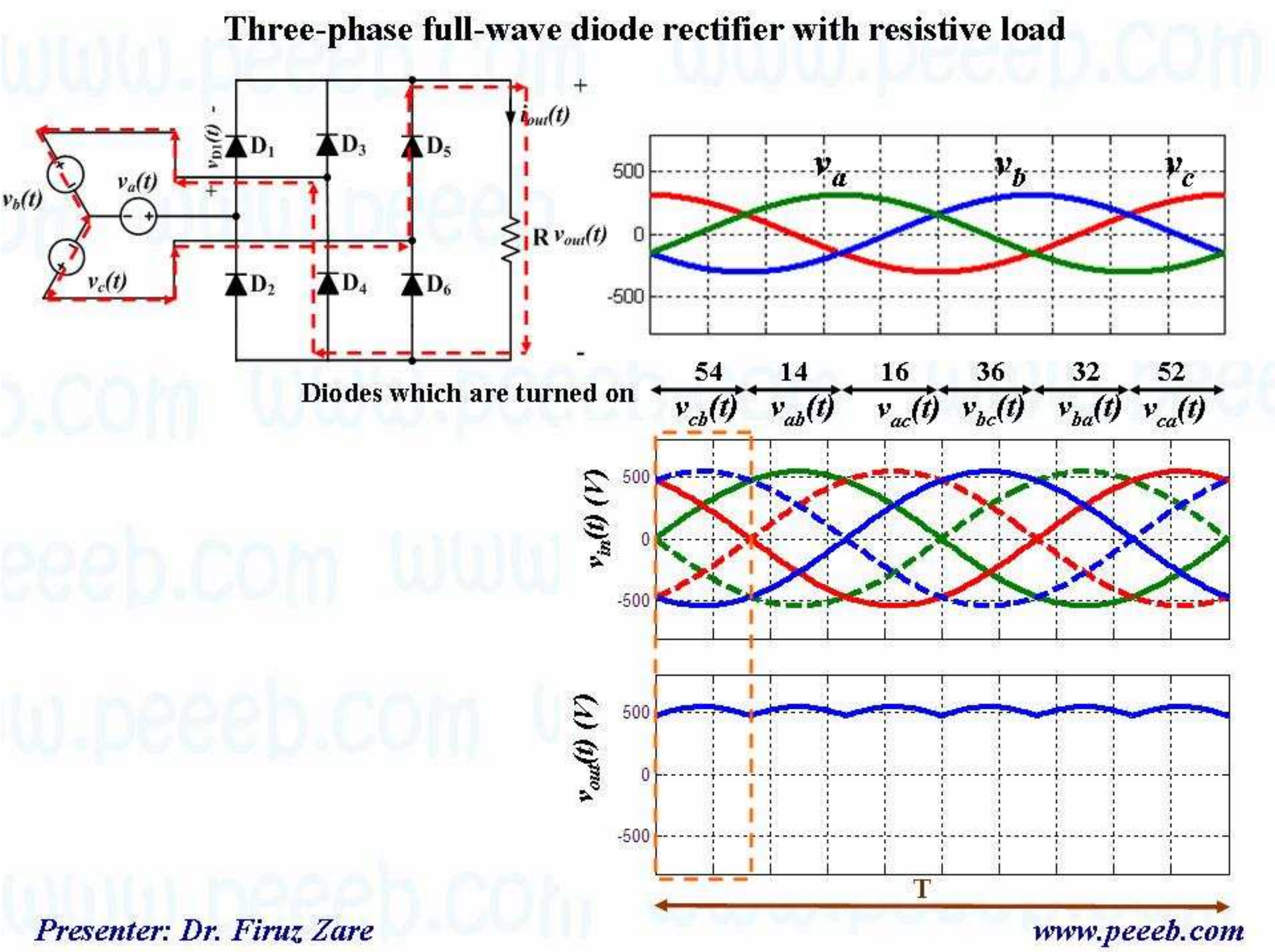

Three-phase full-wave diode rectifier with resistive load
D1
D3
D5
D2
D4
D6
$v_a(t)$
$v_b(t)$
$v_c(t)$
$v_{D1}(t)$
$i_{out}(t)$
R $v_{out}(t)$
v_a
v_b
v_c
500
0
-500
Diodes which are turned on
54
14
16
36
32
52
$v_{cb}(t)$
$v_{ab}(t)$
$v_{ac}(t)$
$v_{bc}(t)$
$v_{ba}(t)$
$v_{ca}(t)$
$v_{in}(t)$ (V)
$v_{out}(t)$ (V)
T
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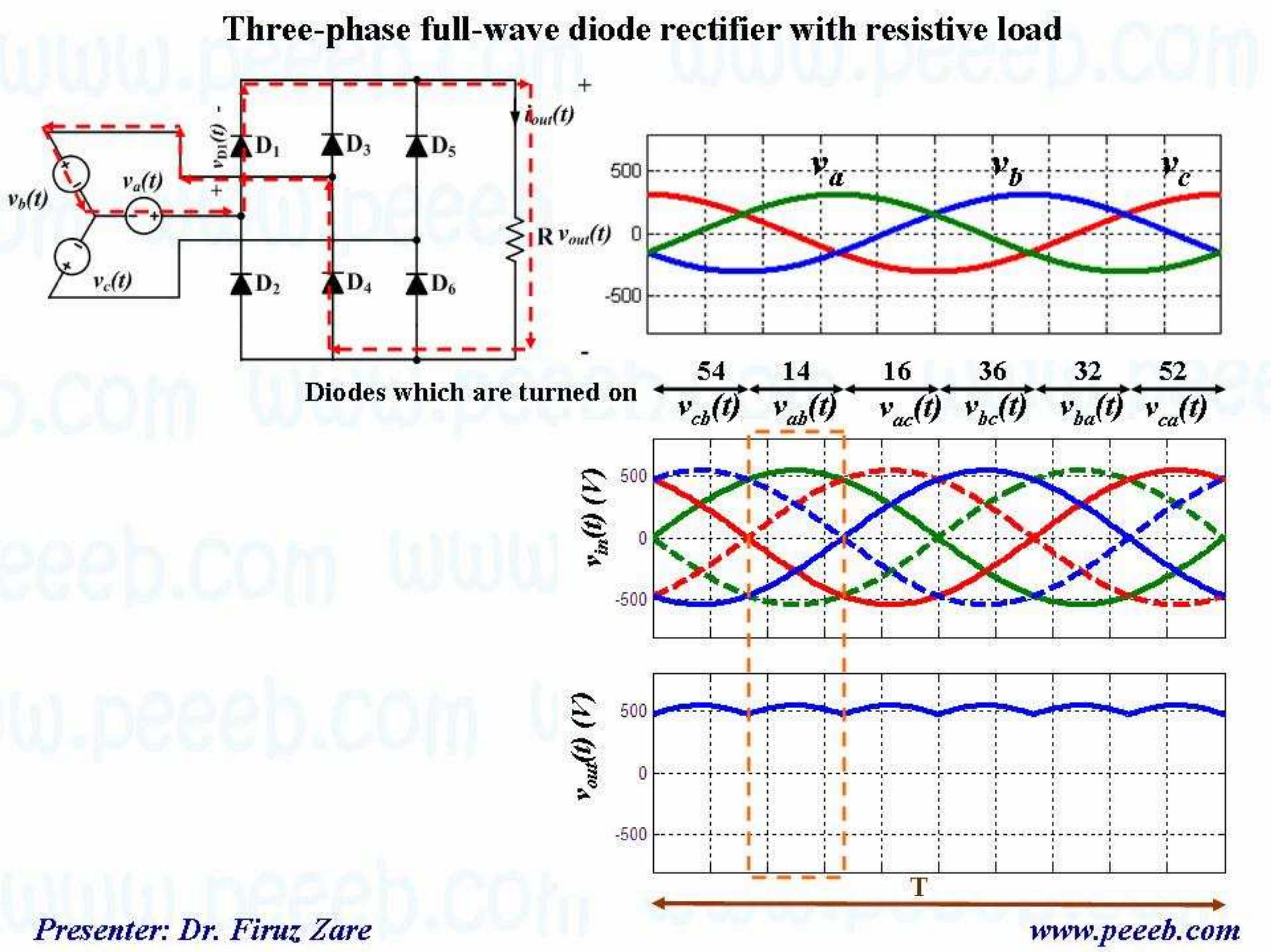
Three-phase full-wave diode rectifier with resistive load
D1
D3
D5
D2
D4
D6
$v_a(t)$
$v_b(t)$
$v_c(t)$
$v_{D1}(t)$
$i_{out}(t)$
R $v_{out}(t)$
v_a
v_b
v_c
Diodes which are turned on
54 $v_{cb}(t)$
14 $v_{ab}(t)$
16 $v_{ac}(t)$
36 $v_{bc}(t)$
32 $v_{ba}(t)$
52 $v_{ca}(t)$
$v_{in}(t)$ (V)
$v_{out}(t)$ (V)
T
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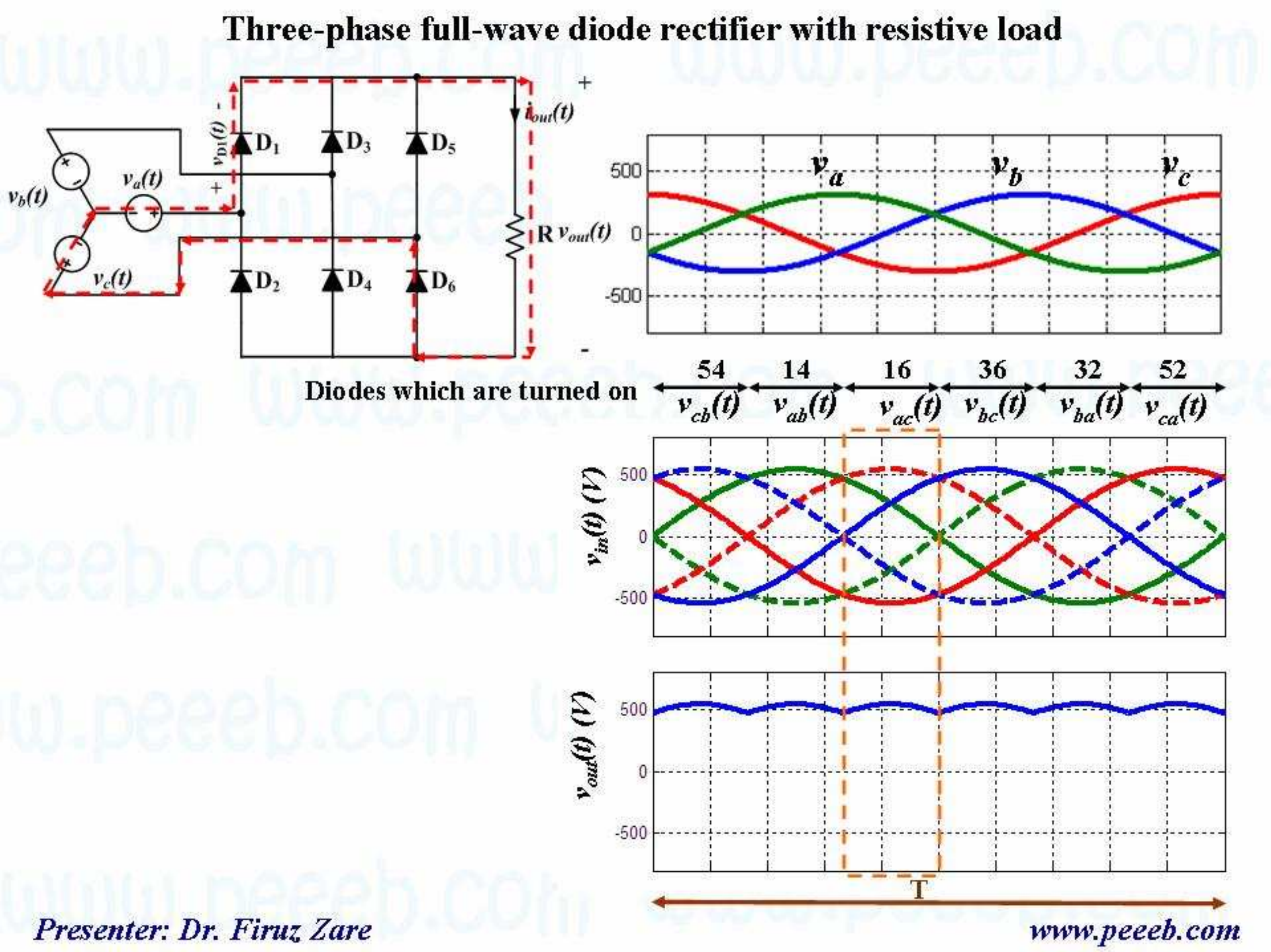

Three-phase full-wave diode rectifier with resistive load
Diodes which are turned on
54
14
16
36
32
52
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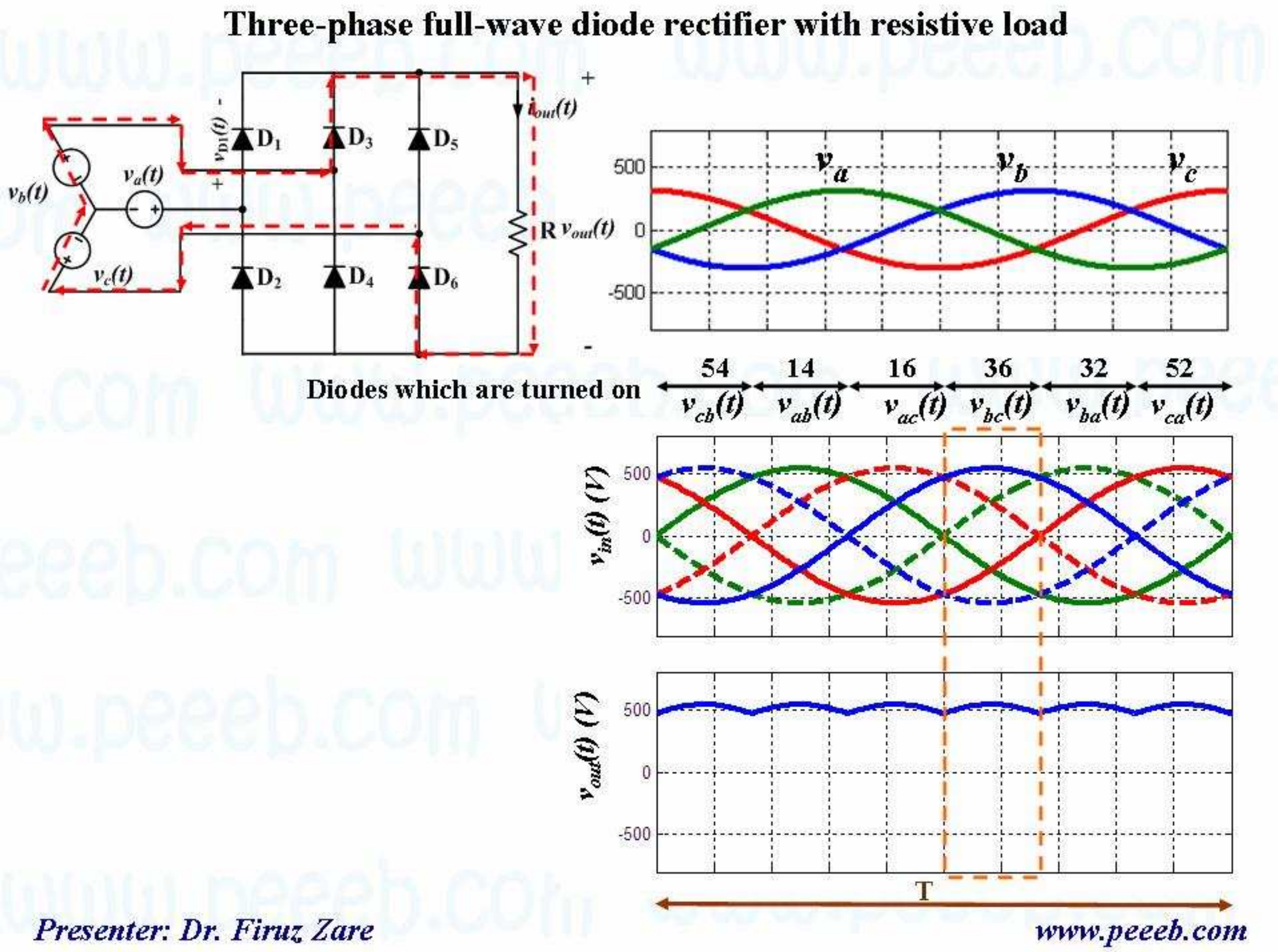
Three-phase full-wave diode rectifier with resistive load
Diodes which are turned on
54
14
16
36
32
52
$v_{cb}(t)$ $v_{ab}(t)$ $v_{ac}(t)$ $v_{bc}(t)$ $v_{ba}(t)$ $v_{ca}(t)$
v_a v_b v_c
$v_{in}(t)$ (V)
$v_{out}(t)$ (V)
T
D1 D2 D3 D4 D5 D6
R $v_{out}(t)$
$i_{out}(t)$
$v_{D1}(t)$
$v_a(t)$ $v_b(t)$ $v_c(t)$
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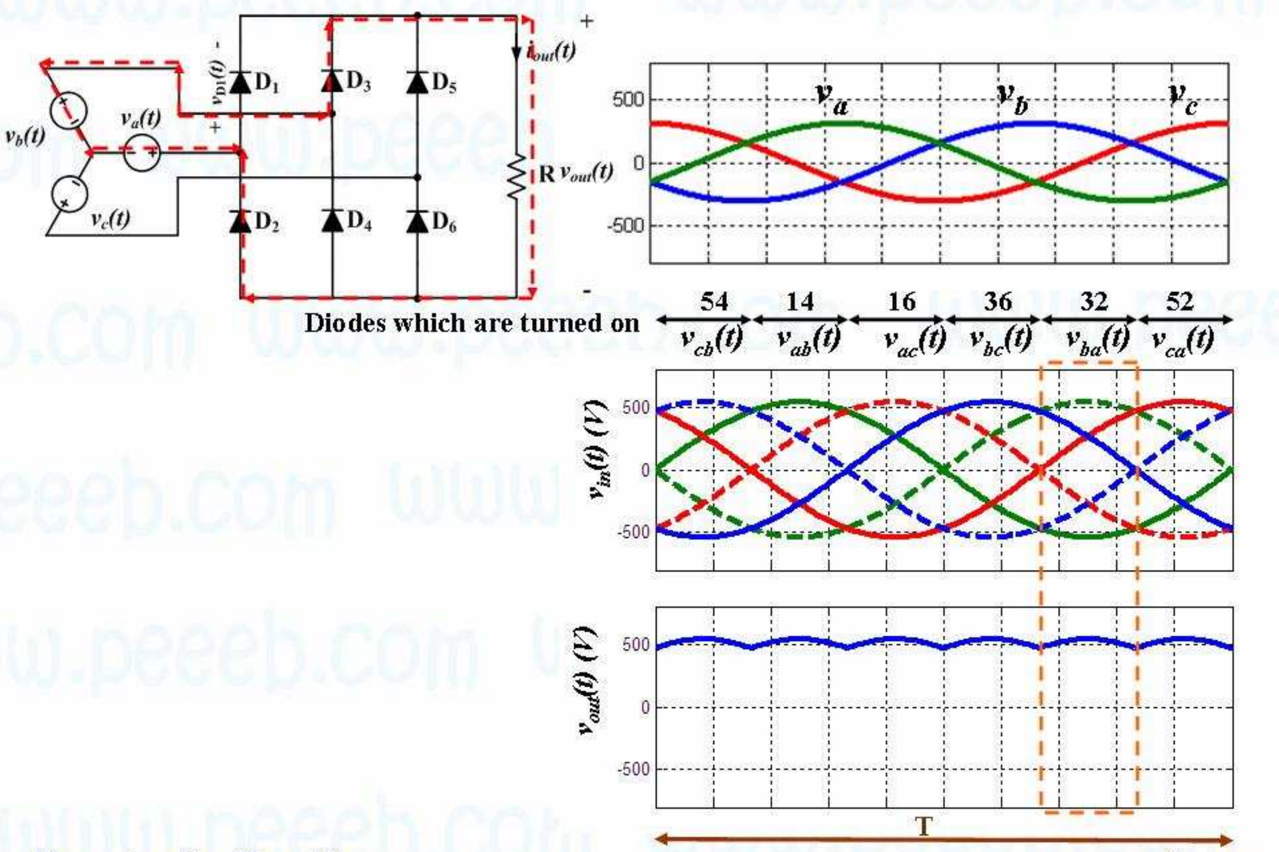
Three-phase full-wave diode rectifier with resistive load



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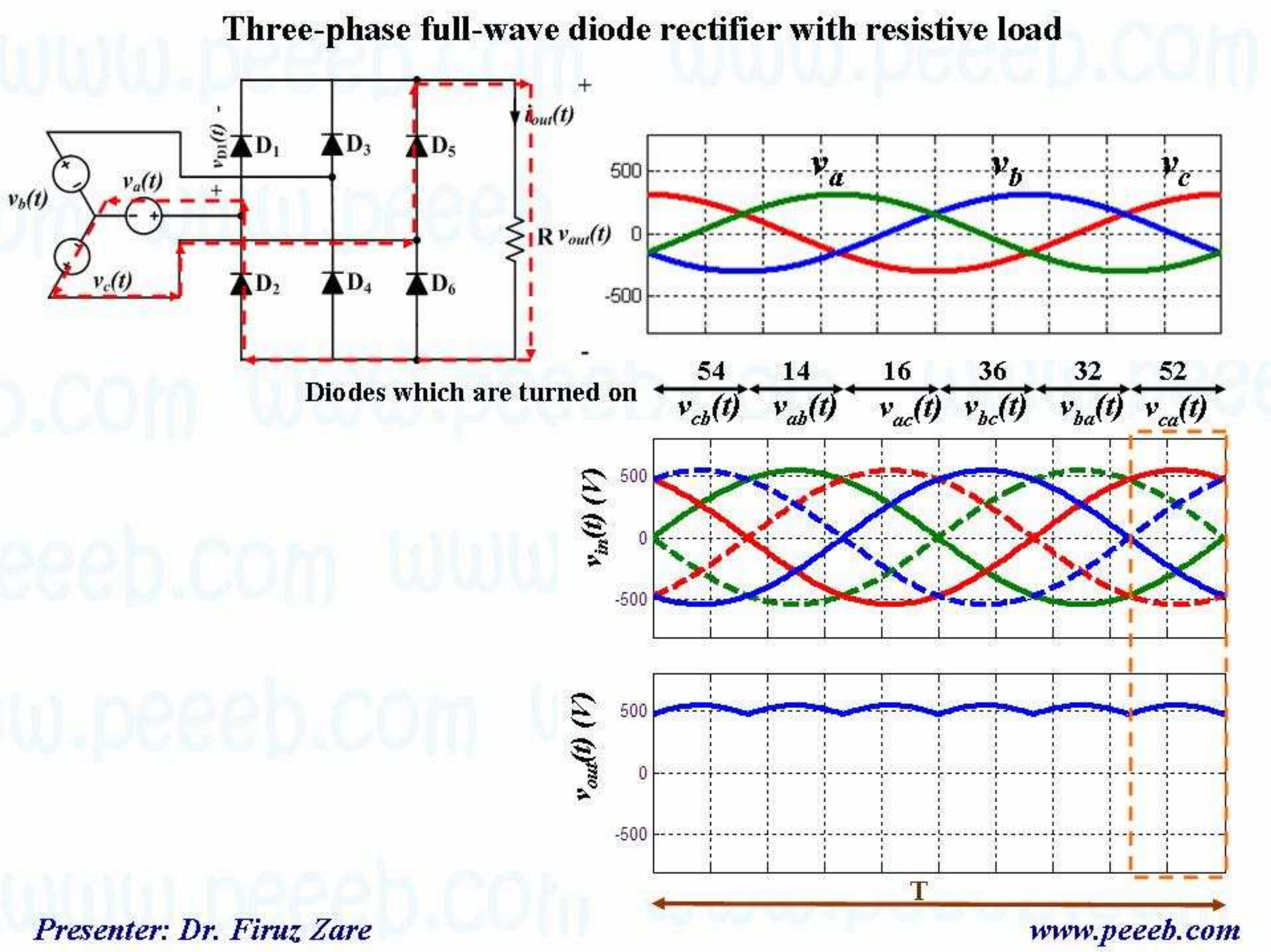

Three-phase full-wave diode rectifier with resistive load
D1
D2
D3
D4
D5
D6
R
Diodes which are turned on
54
14
16
36
32
52
T
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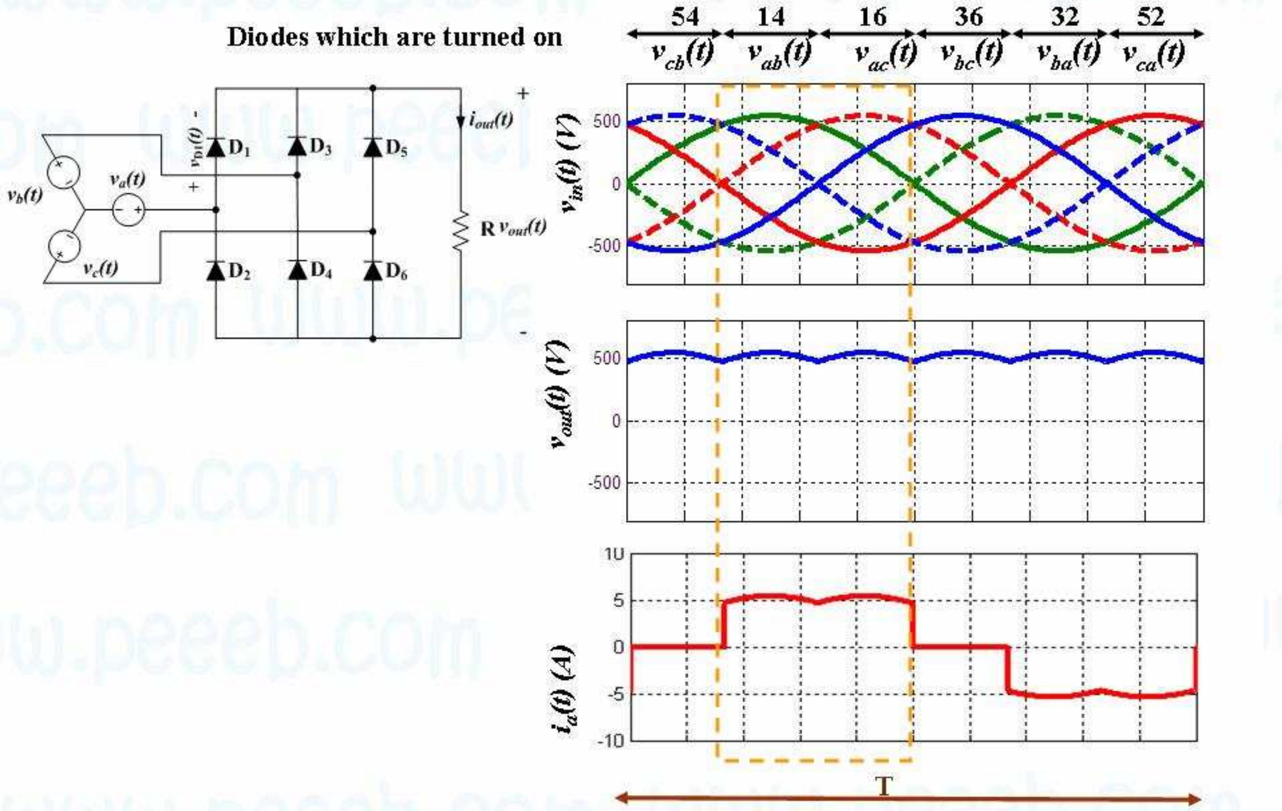
Three-phase full-wave diode rectifier with resistive load



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Three-phase full-wave diode-rectifier

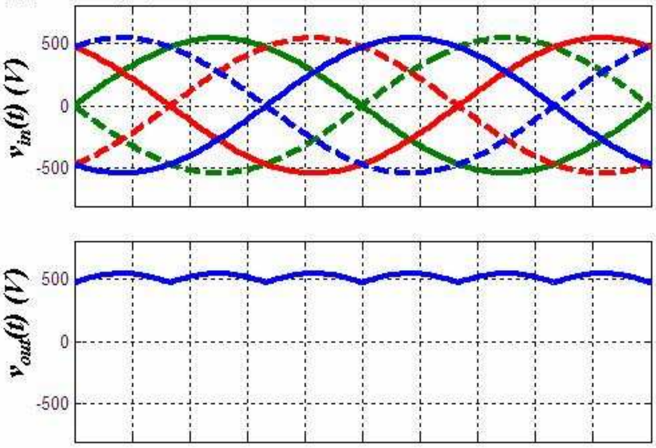
$$v_{out}(t) = \sqrt{3}V_m \cos\left(\frac{2\pi t}{T}\right) \qquad -\frac{T}{12} < t \le \frac{T}{12}$$

$$V_{out} = \frac{1}{\frac{T}{6}} \int_{-\frac{T}{12}}^{\frac{T}{12}} \sqrt{3}V_m \cos\left(\frac{2\pi t}{T}\right) dt$$

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

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

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



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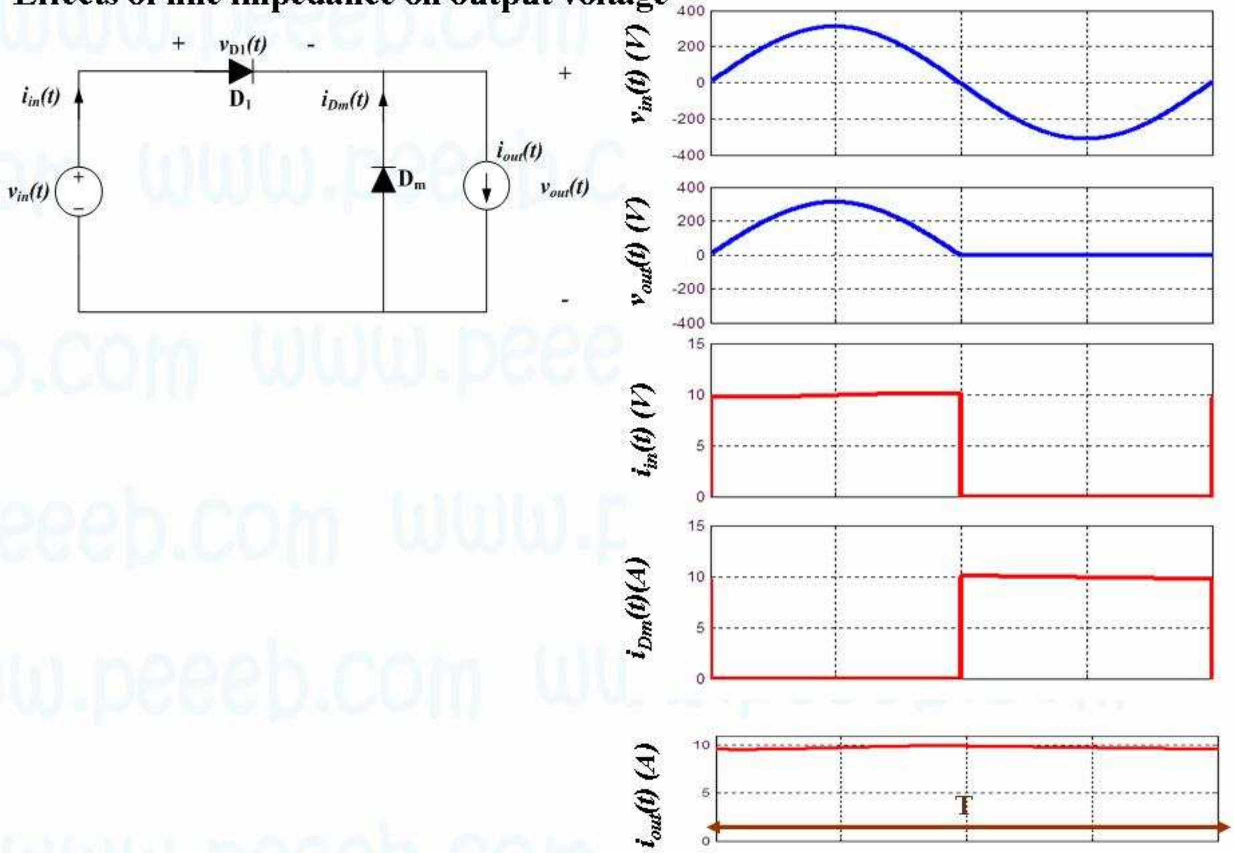
Effects of line impedance on output voltage



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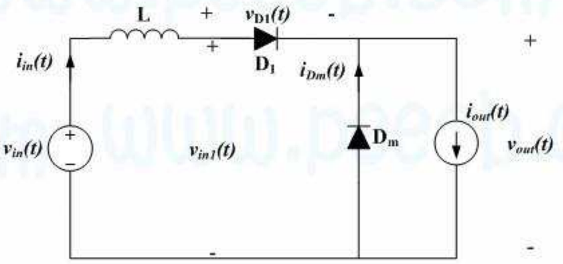
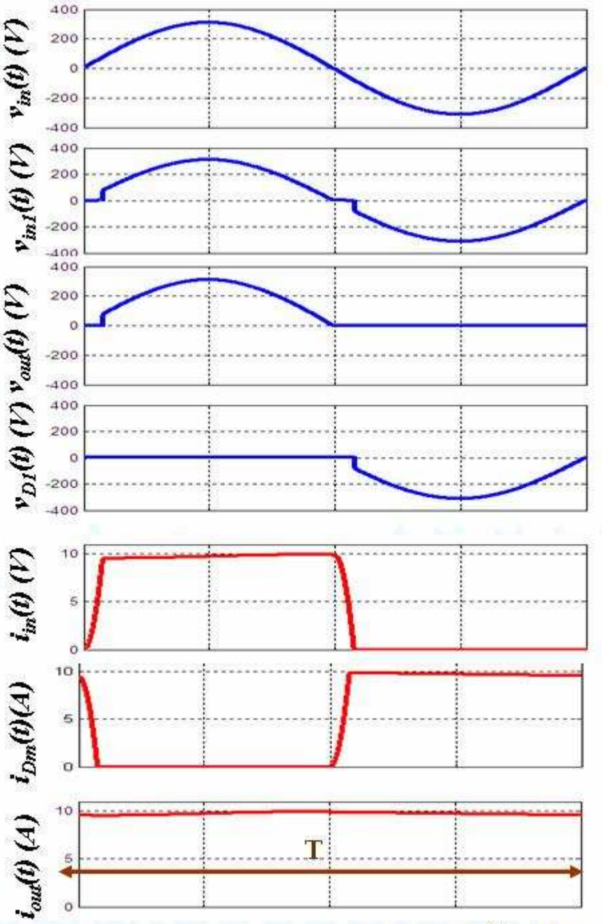
Effects of line impedance on output voltage





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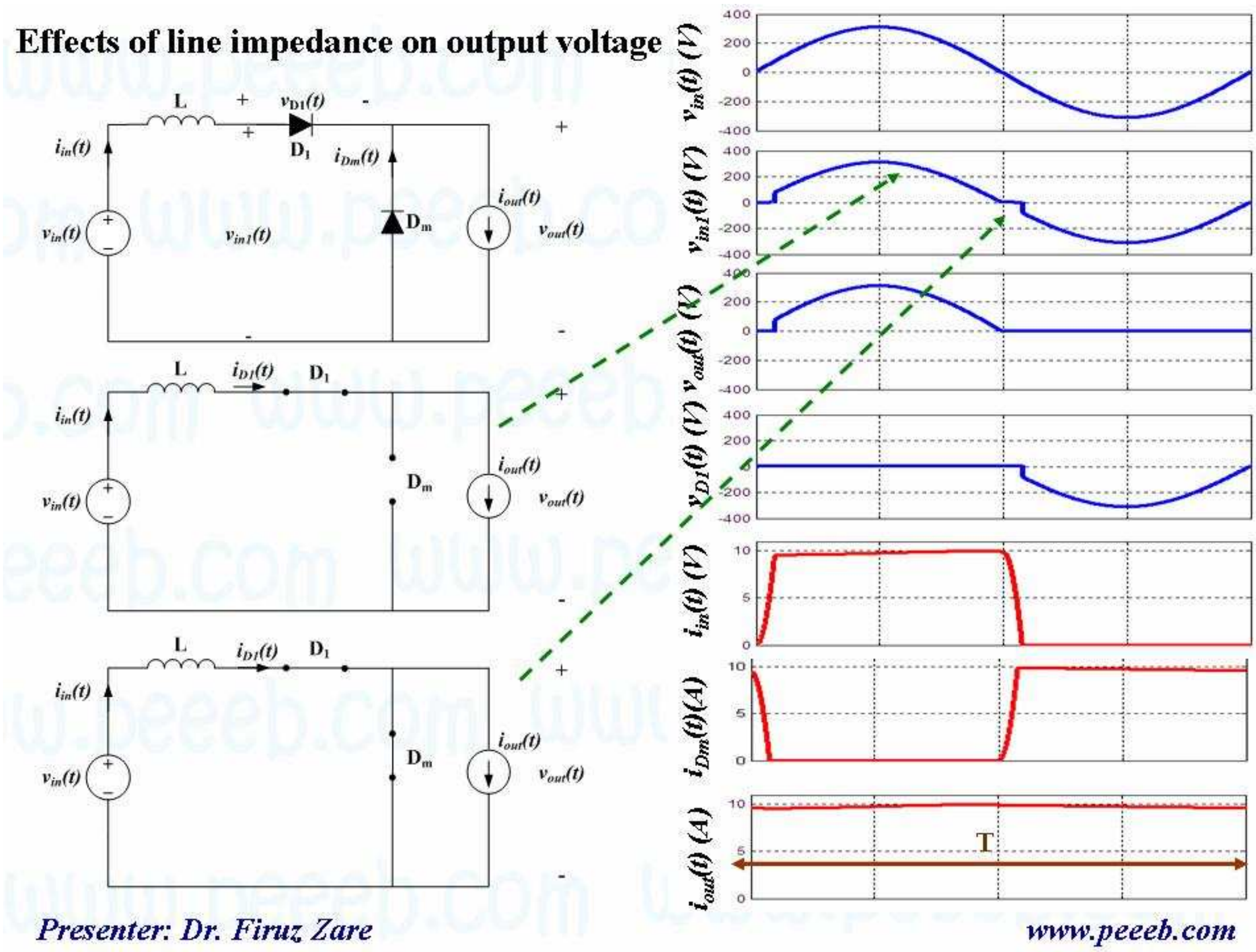

Effects of line impedance on output voltage
L
$v_{D1}(t)$
D_1
$i_{Dm}(t)$
$i_{in}(t)$
$v_{in}(t)$
$v_{in1}(t)$
D_m
$i_{out}(t)$
$v_{out}(t)$
$i_{D1}(t)$
$v_{in}(t)$ (V)
$v_{in1}(t)$ (V)
$v_{out}(t)$ (V)
$v_{D1}(t)$ (V)
$i_{in}(t)$ (V)
$i_{Dm}(t)$(A)
$i_{out}(t)$ (A)
T
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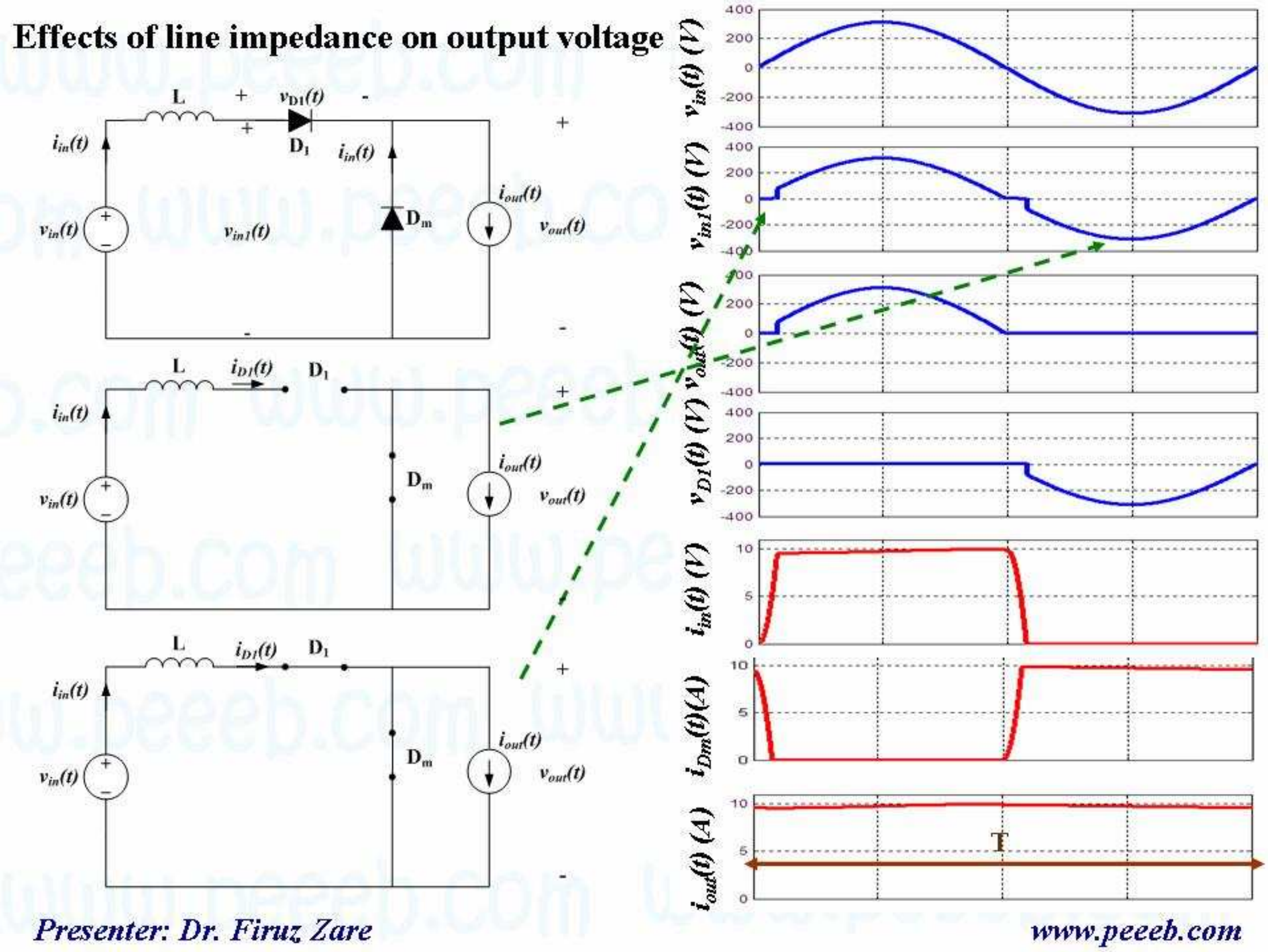

Effects of line impedance on output voltage
L
$v_{D1}(t)$
D_1
$i_{in}(t)$
D_m
$i_{out}(t)$
$v_{in}(t)$
$v_{in1}(t)$
$v_{out}(t)$
$i_{D1}(t)$
$v_{in}(t)$ (V)
$v_{in1}(t)$ (V)
$v_{out}(t)$ (V)
$v_{D1}(t)$ (V)
$i_{in}(t)$ (V)
$i_{Dm}(t)$(A)
$i_{out}(t)$ (A)
T
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Effects of line impedance on output voltage

$$L\frac{di_L(t)}{dt} = v_L(t) = V_m \sin\left(\frac{2\pi t}{T}\right)$$

$$di_L(t) = \frac{V_m}{L}\sin\left(\frac{2\pi t}{T}\right)dt$$

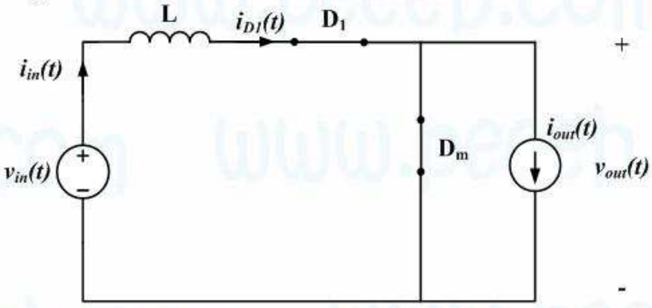
$$\int_0^I di_L(t)dt = \frac{V_m}{L}\int_0^{t_1}\sin\left(\frac{2\pi t}{T}\right)dt$$

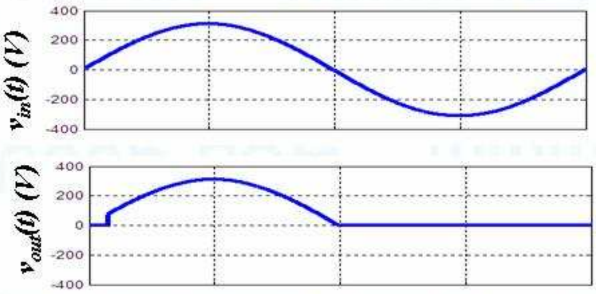
$$I = \frac{V_m}{L}\left(\frac{T}{2\pi}\right)\left[-\cos\left(\frac{2\pi t}{T}\right)\Bigg|_0^{t_1}\right]$$

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

$$\frac{2\pi LI}{V_m T} = 1-\cos\left(\frac{2\pi t_1}{T}\right)$$

$$\cos\left(\frac{2\pi t_1}{T}\right) = 1-\frac{2\pi LI}{V_m T}$$





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Effects of line impedance on output voltage

$$V_{out} = \frac{1}{T}\int_{0}^{T} v_{out}(t)dt$$

$$= \frac{1}{T}\int_{t_1}^{\frac{T}{2}} V_m \sin\left(\frac{2\pi t}{T}\right)dt$$

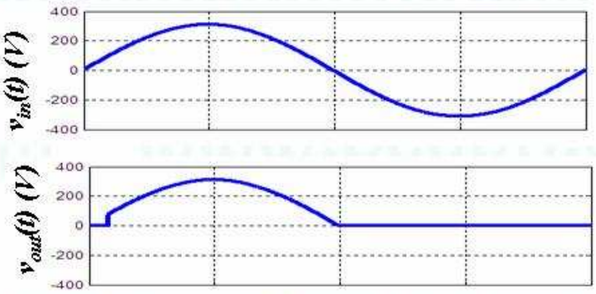
$$= \frac{V_m}{T}\left(\frac{T}{2\pi}\right)\left[-\cos\left(\frac{2\pi t}{T}\right)\Bigg|_{t_1}^{\frac{T}{2}}\right]$$

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

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

$$= \frac{V_m}{2\pi}\left[1 + 1 - \frac{2\pi LI}{V_m T}\right]$$

$$= \frac{V_m}{\pi} - \frac{LI}{T}$$



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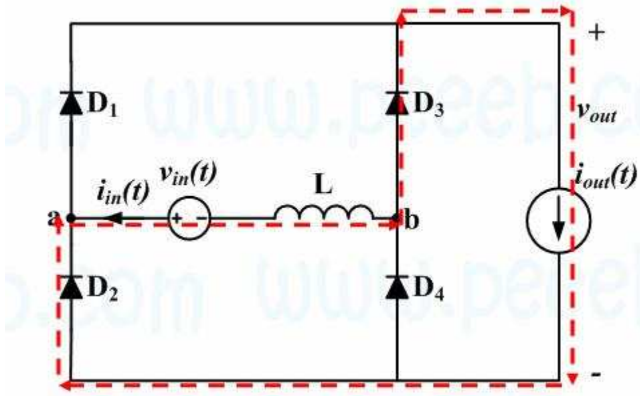
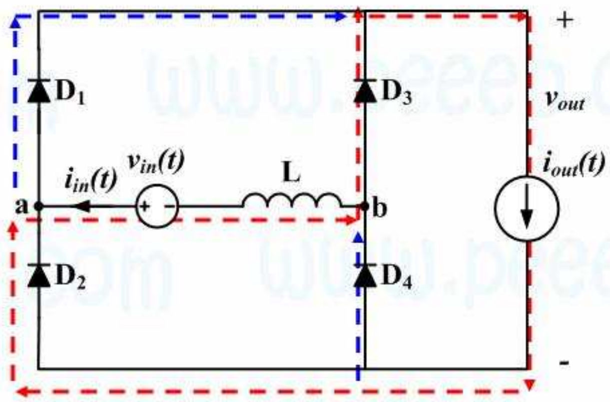
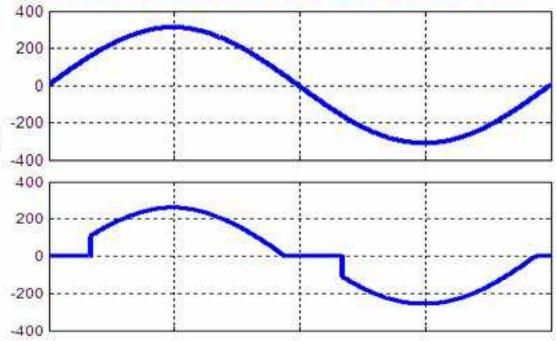
Effects of line impedance on output voltage in a single phase full-wave rectifier





When the input voltage has gone positive, the voltage across D_1 and D_2 are positive and they are forward biased. There are short circuits in the upper loop (D_1, D_2 and input supply) and the lower loop (D_3, D_4 and the input supply). The diode currents (D_2 and D_3) are commutated to the other legs (D_1 and D_4).



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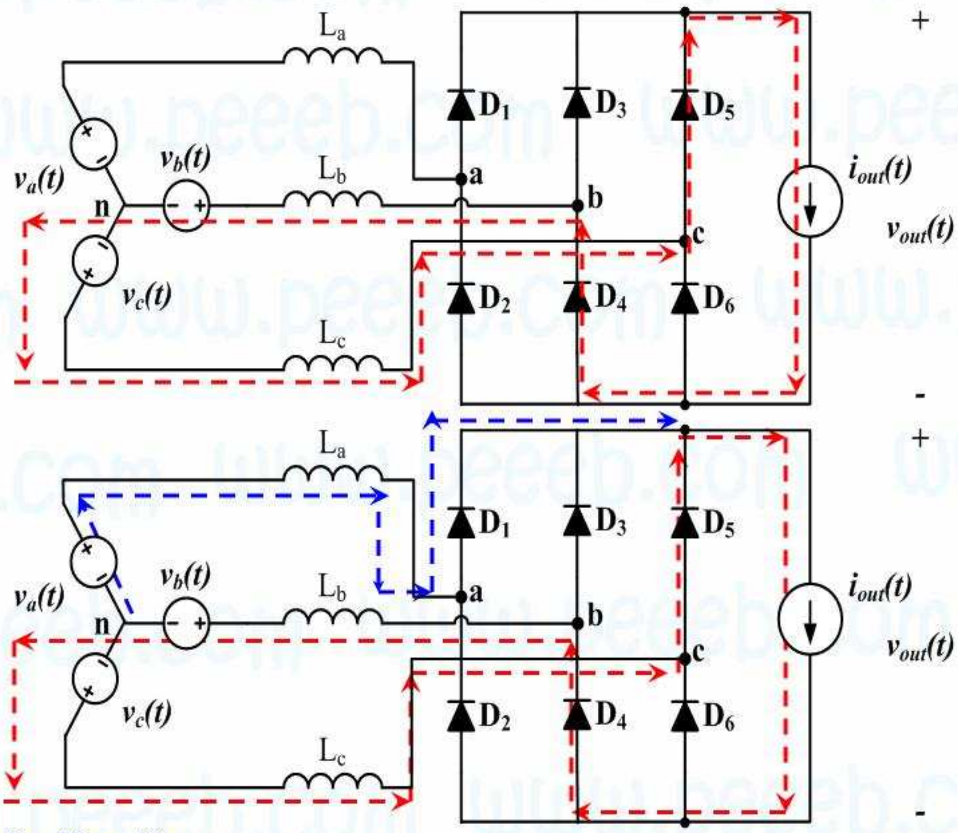
Effects of line impedance on output voltage in a three-phase full-wave rectifier



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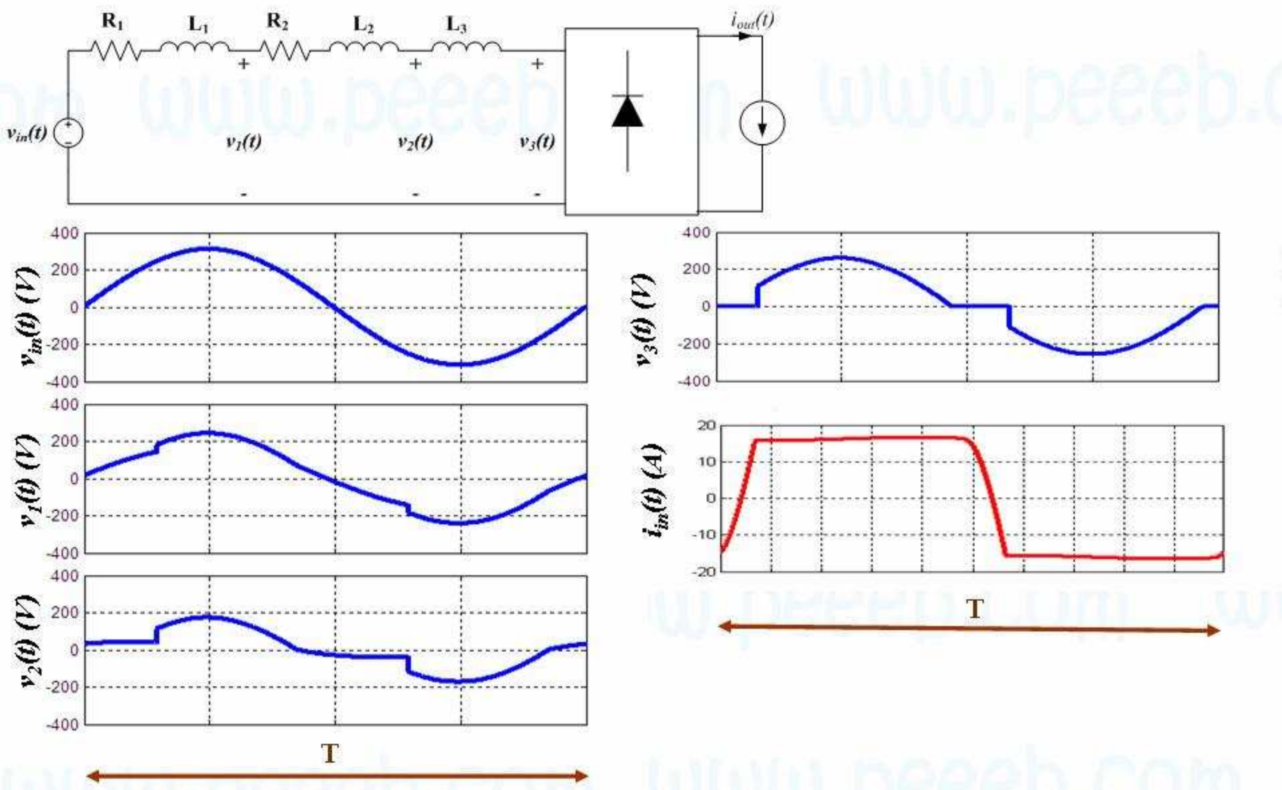
How a diode rectifier with an inductive load affects other loads in a network



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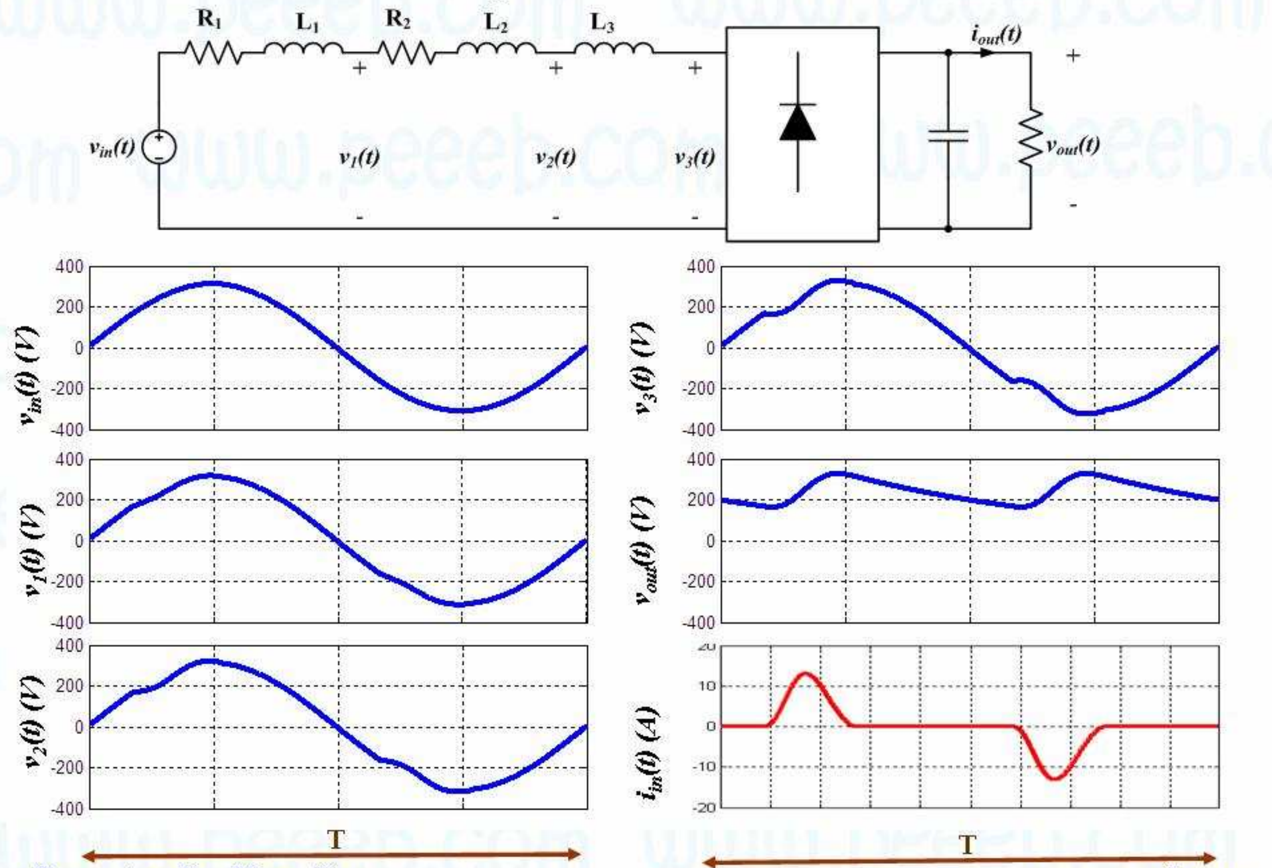
How a diode rectifier with capacitive load affects other loads in a network



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