Power Electronics Education
Electronic Book

Welcome to PEEEB

Lecture 4: Controlled Rectifiers

Presenter: Dr. Firuz Zare

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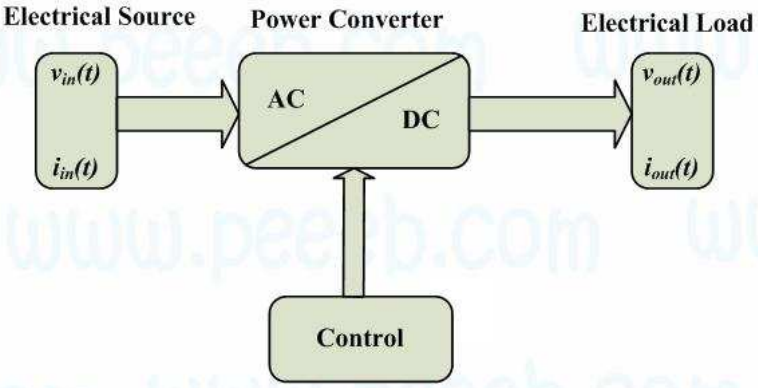
Contents:

Block Diagram of a Controlled Rectifier



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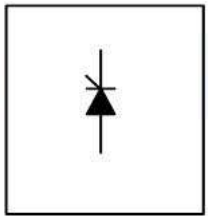
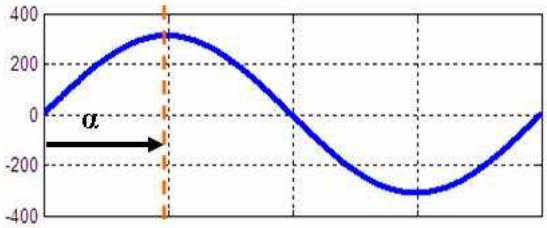
Control Circuit





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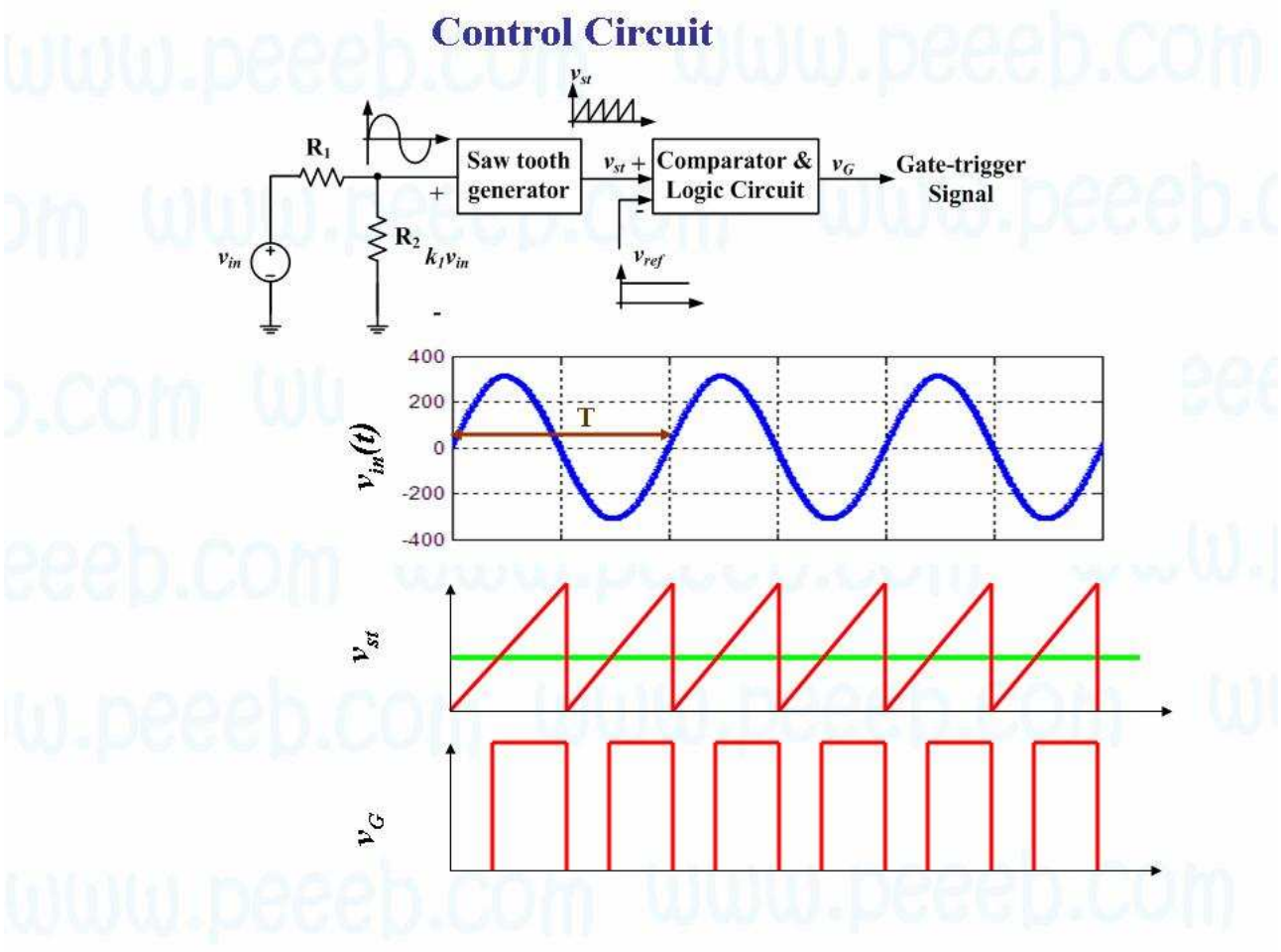
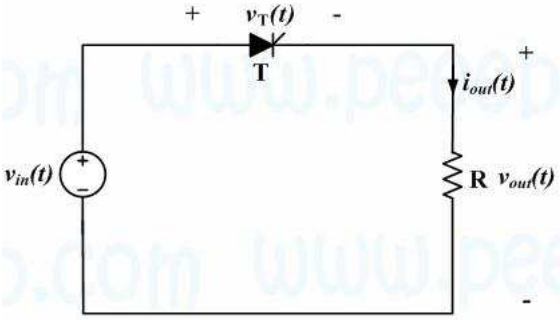
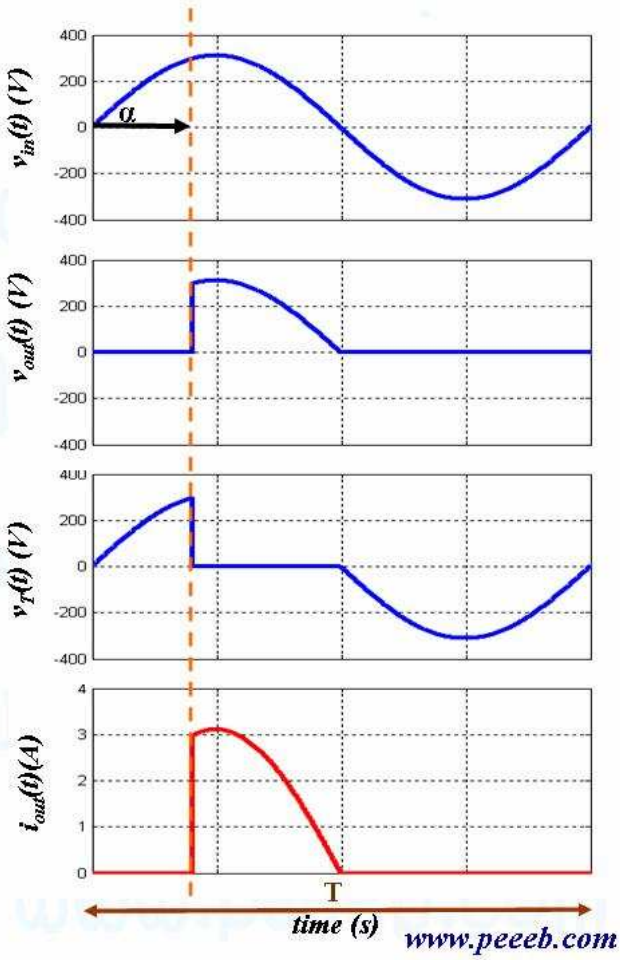

Control Circuit
v_{st}
R1
Saw tooth generator
v_{st} +
Comparator & Logic Circuit
v_G
Gate-trigger Signal
+
R2
$k_1 v_{in}$
v_{in}
v_{ref}
-
400
200
0
-200
-400
T
$v_{in}(t)$
v_{st}
v_G

Single phase half wave rectifier (Resistive load)





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Single phase half wave rectifier (Resistive load)

$$v_{out}(t)=\begin{cases}0 & 0<t\le t_1\\ V_m \sin\left(\frac{2\pi t}{T}\right) & t_1<t\le T/2\\ 0 & T/2<t\le T\end{cases}$$

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

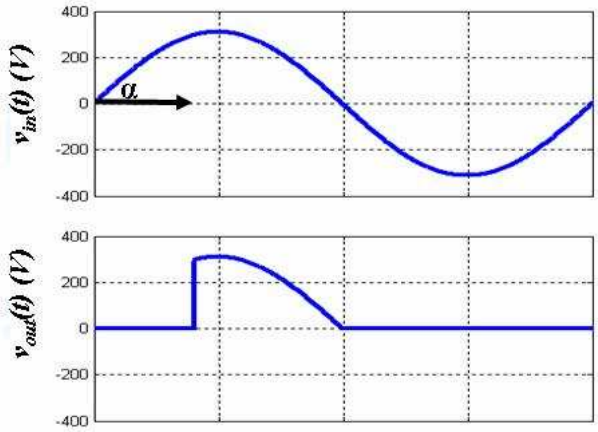
$$=\frac{1}{T}\int_{t_1}^{\frac{T}{2}} V_m \sin\left(\frac{2\pi t}{T}\right)dt$$

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

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

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

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



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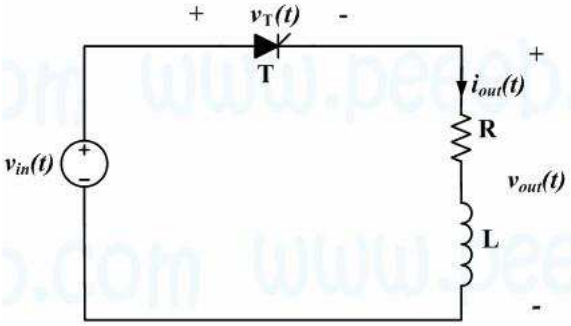
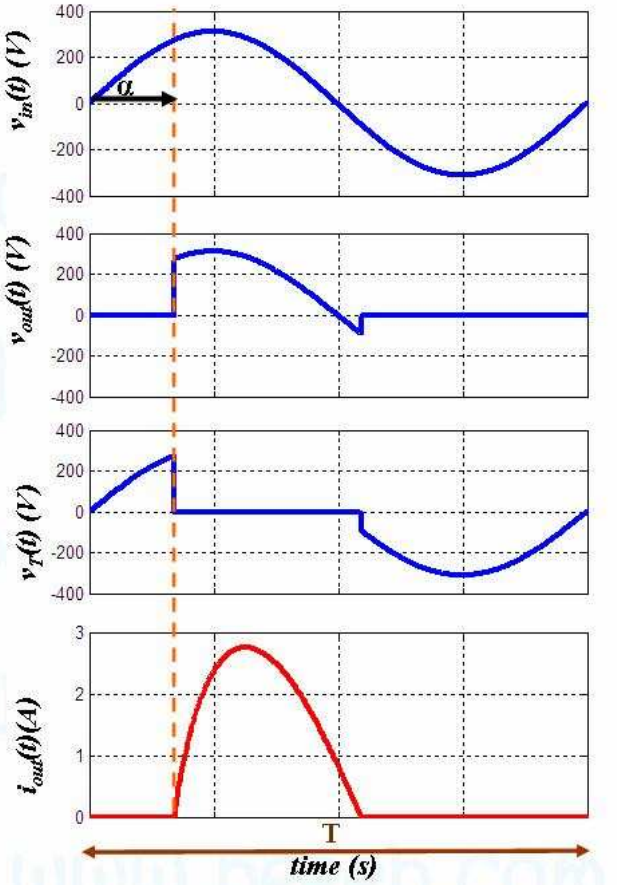
Single phase half wave rectifier (R-L load)





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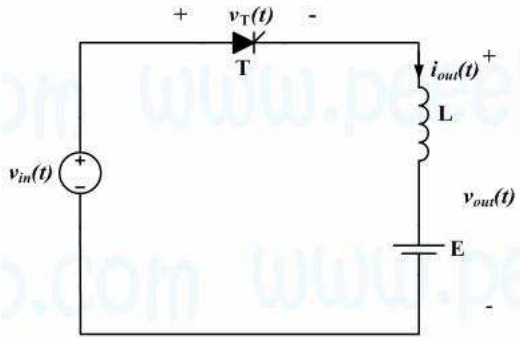
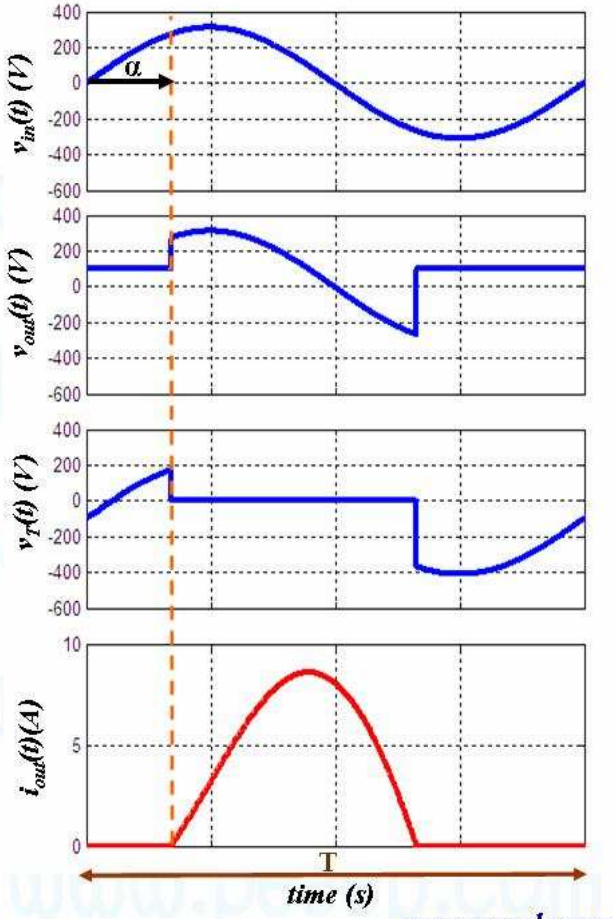
Single phase half wave rectifier (L-E load)





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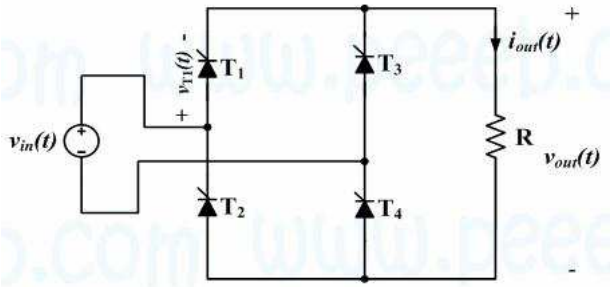
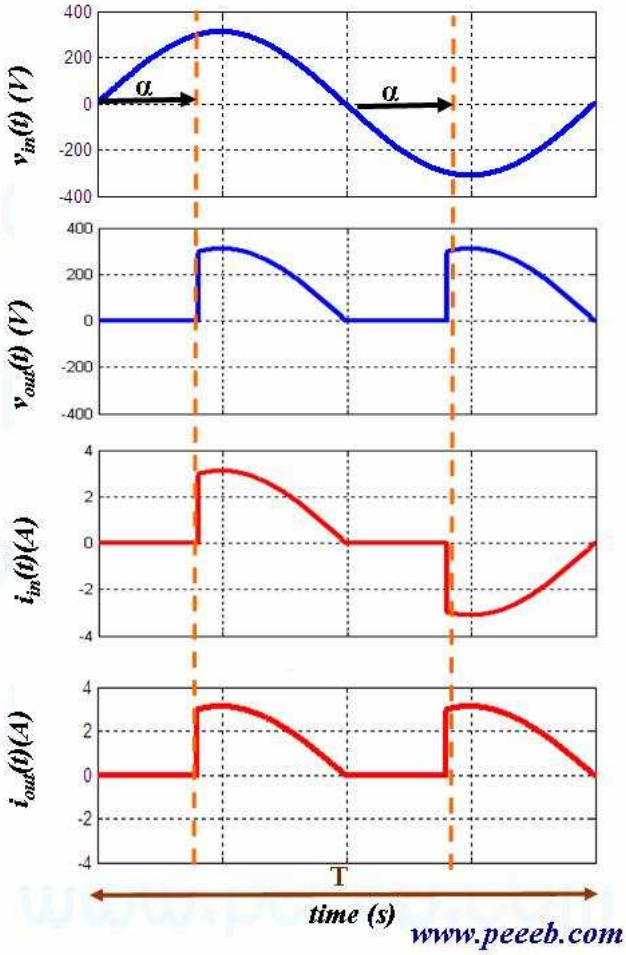
Single phase full wave bridge rectifier (Resistive load)





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Single phase full wave bridge rectifier (Resistive load)

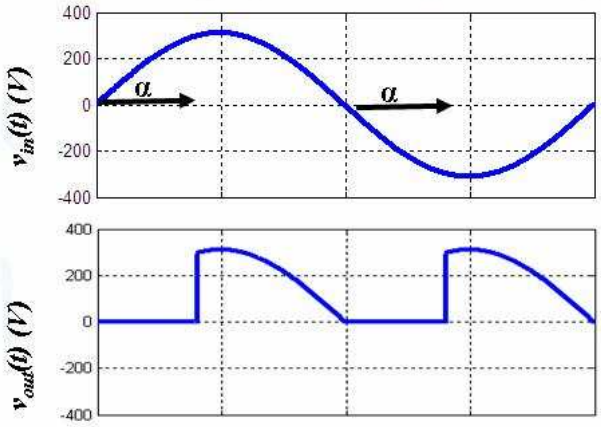
$$V_{out} = \frac{1}{T}\int_0^T v_{out}(t)dt$$

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

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

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

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



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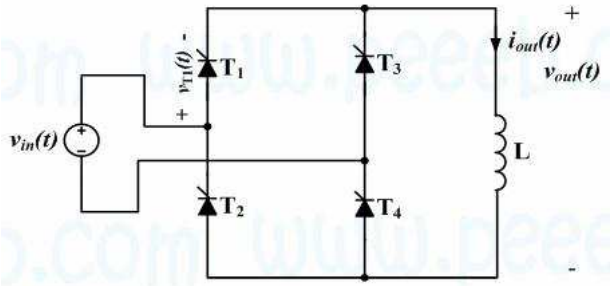
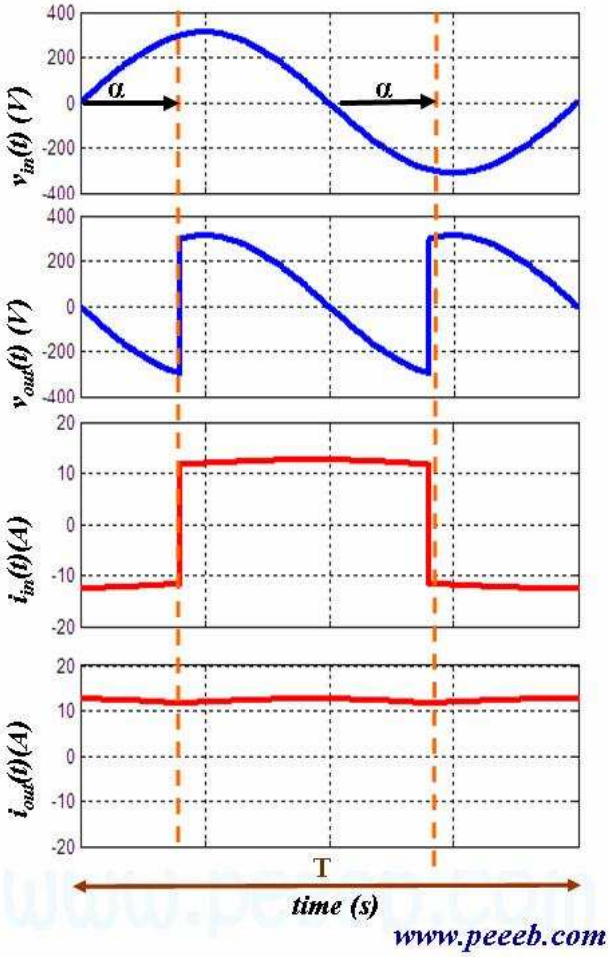
Single phase full wave bridge rectifier (Inductive load)





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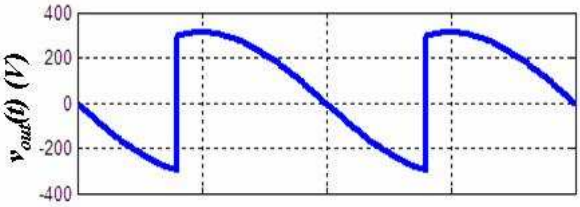
Single phase full wave bridge rectifier (Inductive load)

$$v_{out}(t) = V_m \sin\left(\frac{2\pi t}{T}\right) \qquad t_1 < t \le \frac{T}{2} + t_1$$

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



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

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

$$2\pi \rightarrow T \qquad \alpha \rightarrow t_1 \qquad \frac{\alpha T}{2\pi} = t_1$$

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

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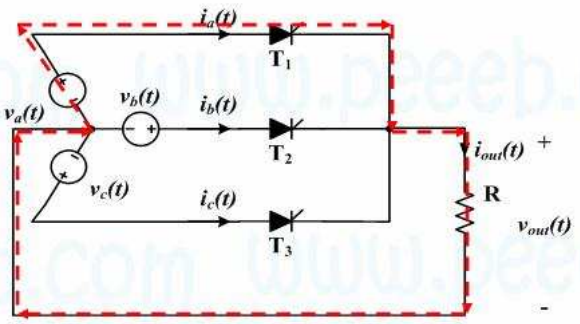
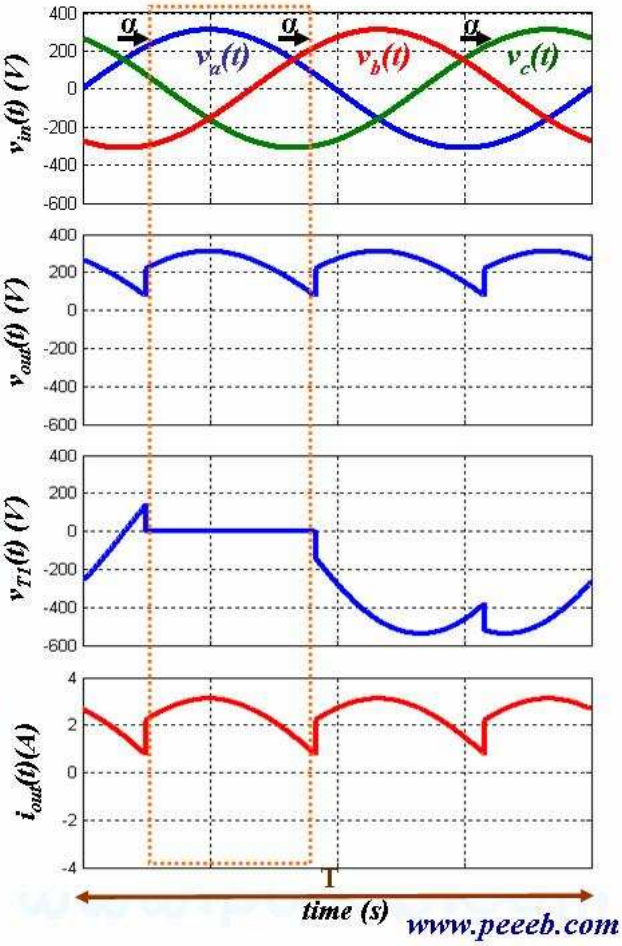
Three phase half wave rectifier (Resistive load and firing angle of 15°)





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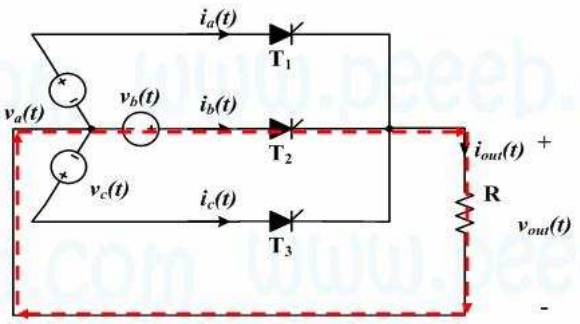
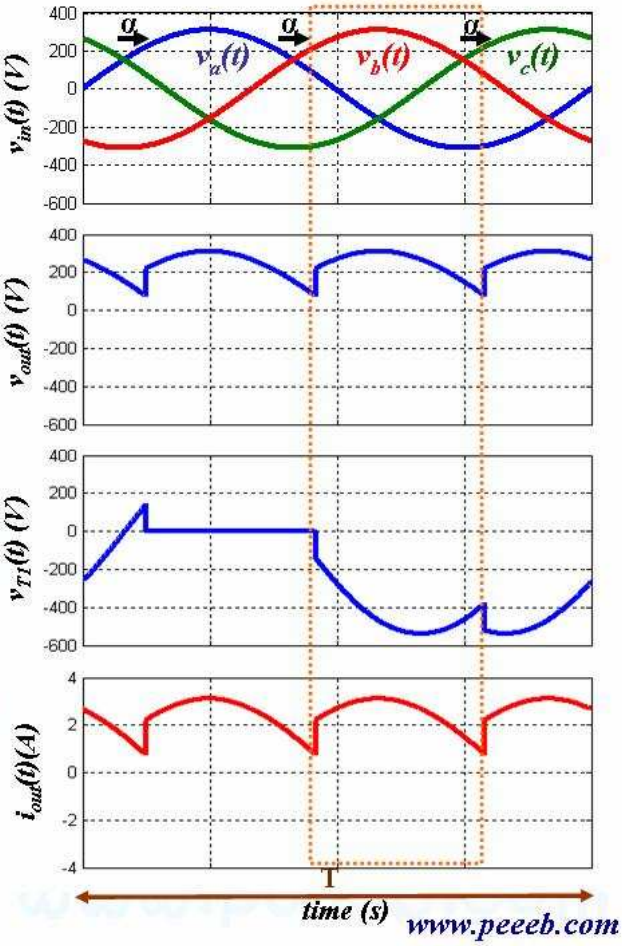
Three phase half wave rectifier (Resistive load and firing angle of 15°)





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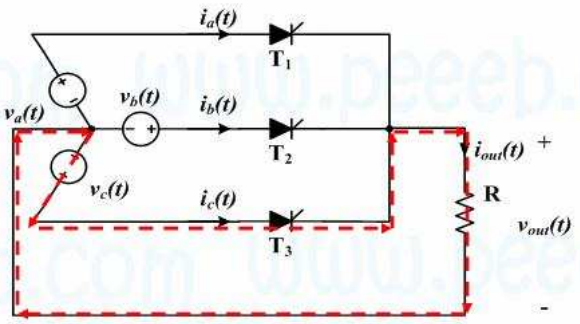
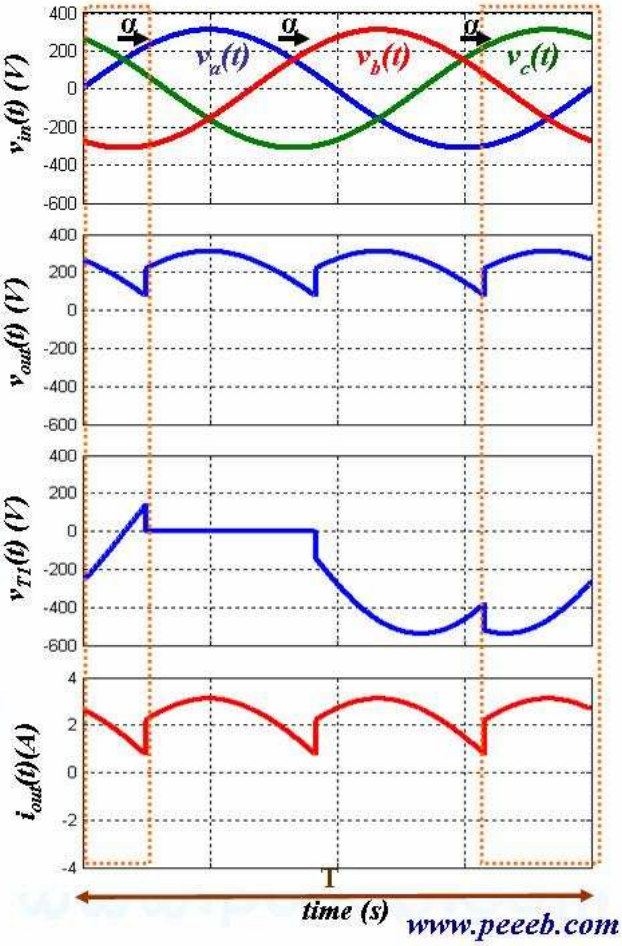
Three phase half wave rectifier (Resistive load and firing angle of 15°)





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Three phase half wave rectifier

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

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

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

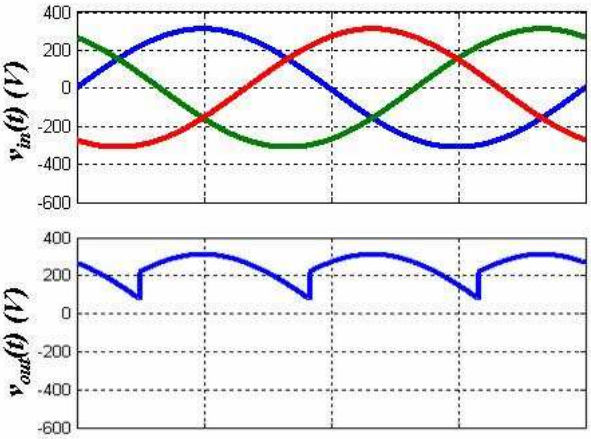
$$= \frac{3V_m}{2\pi}\left[\sin\left(\frac{2\pi}{T}\left(\frac{T}{6}+\Delta t\right)\right) - \sin\left(\frac{2\pi}{T}\left(-\frac{T}{6}+\Delta t\right)\right)\right]$$

$$= \frac{3V_m}{2\pi}\left[2\sin\left(\frac{2\pi}{T}\left(\frac{T}{6}\right)\right)\right]\cos\left(\frac{2\pi}{T}(\Delta t)\right)$$

$$= \frac{3V_m}{\pi}\sin\left(\frac{\pi}{3}\right)\cos\left(\frac{2\pi\Delta t}{T}\right)$$

$$\begin{array}{cc} \Delta t & \alpha \\ T & 2\pi \end{array} \Rightarrow \Delta t = \frac{T\alpha}{2\pi}$$

$$= \frac{3\sqrt{3}V_m}{2\pi}\cos(\alpha)$$



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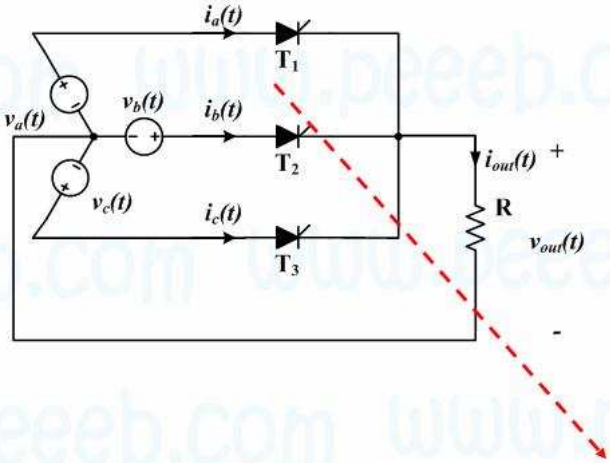
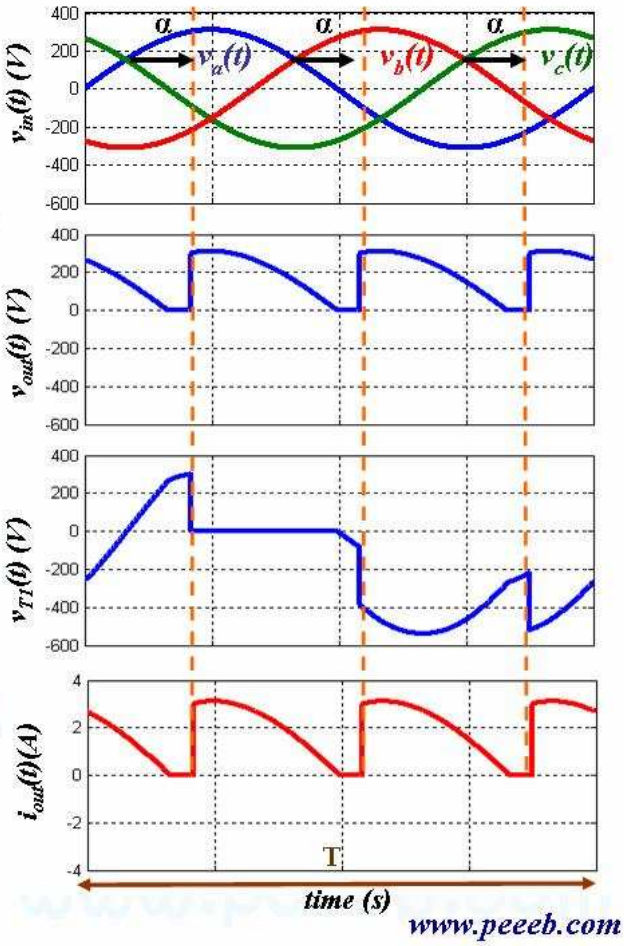
Three phase half wave rectifier (Resistive load and firing angle of 45°)





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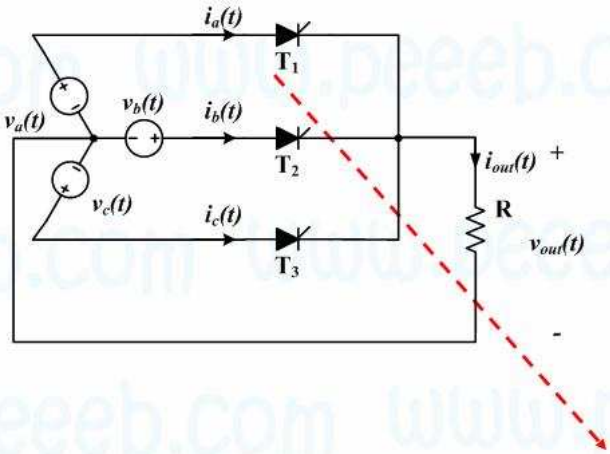
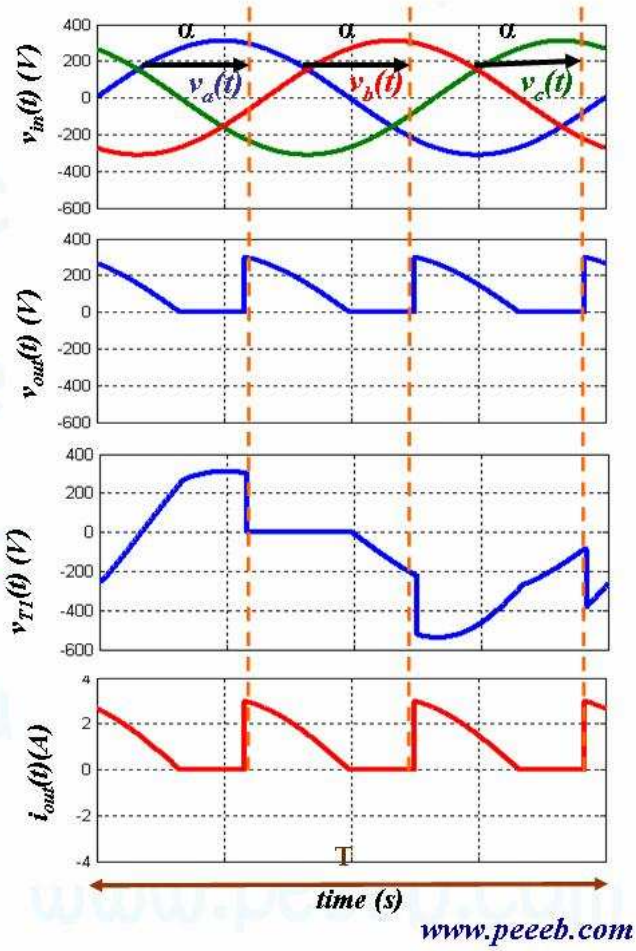
Three phase half wave rectifier (Resistive load and firing angle of 75°)





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Three phase half wave rectifier

$$V_{out} = \frac{1}{\frac{T}{3}} \int_{-\frac{T}{6}+\Delta t}^{\frac{T}{6}+\Delta t} v_{out}(t)dt$$

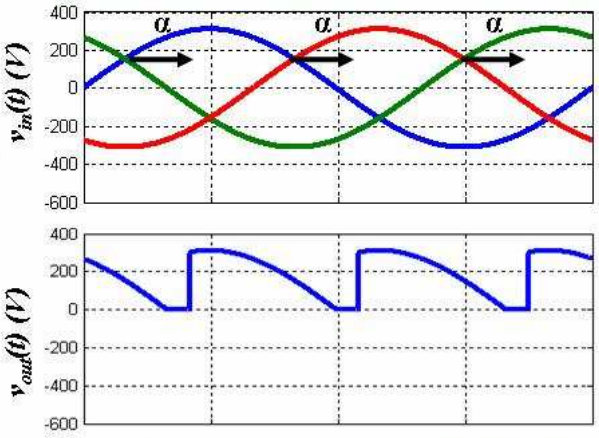
$$= \frac{3}{T} \int_{-\frac{T}{6}+\Delta t}^{\frac{T}{4}} V_m \cos\left(\frac{2\pi t}{T}\right)dt$$

$$= \frac{3V_m}{T}\left(\frac{T}{2\pi}\right)\left[\sin\left(\frac{2\pi t}{T}\right)\Big|_{-\frac{T}{6}+\Delta t}^{\frac{T}{4}}\right]$$

$$= \frac{3V_m}{2\pi}\left[\sin\left(\frac{\pi}{2}\right) - \sin\left(\frac{2\pi}{T}\left(-\frac{T}{6}+\Delta t\right)\right)\right]$$

$$= \frac{3V_m}{2\pi}\left[1 - \sin\left(-\frac{\pi}{3}+\frac{2\pi\Delta t}{T}\right)\right]$$

$$= \frac{3V_m}{2\pi}\left[1 + \sin\left(\frac{\pi}{3}-\frac{2\pi\Delta t}{T}\right)\right] = \frac{3V_m}{2\pi}\left[1 + \sin\left(\frac{\pi}{3}-\alpha\right)\right]$$



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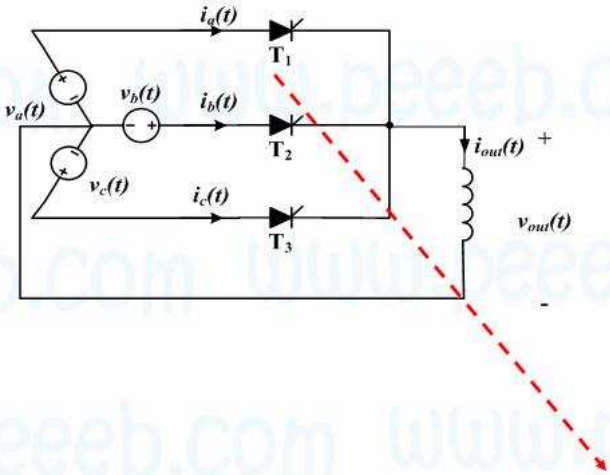
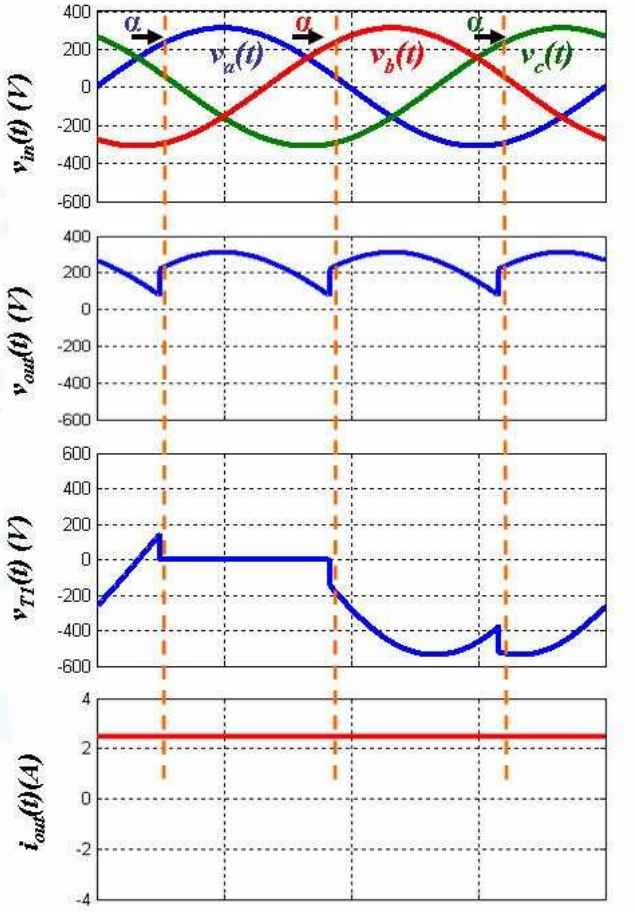
Three phase half wave rectifier (Inductive load and firing angle of 15°)





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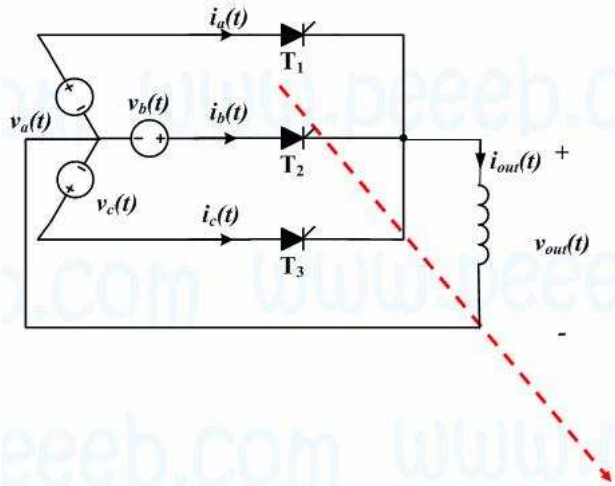
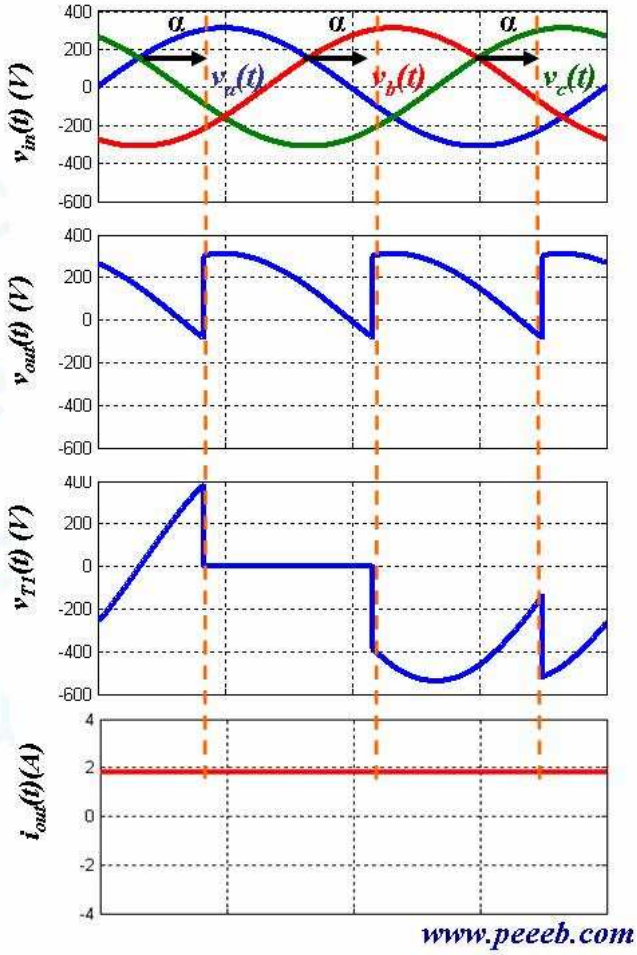
Three phase half wave rectifier
(Inductive load and firing angle of 45°)





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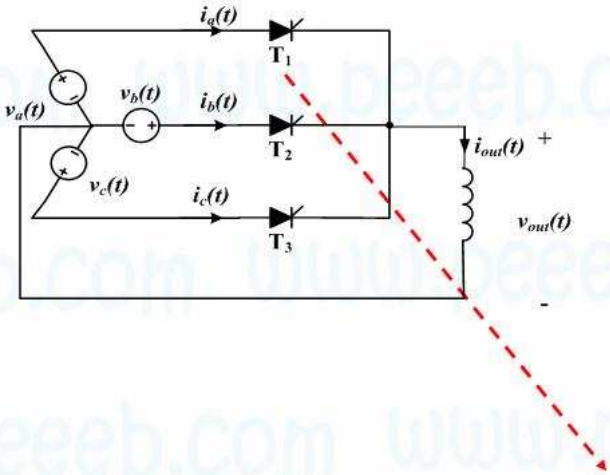
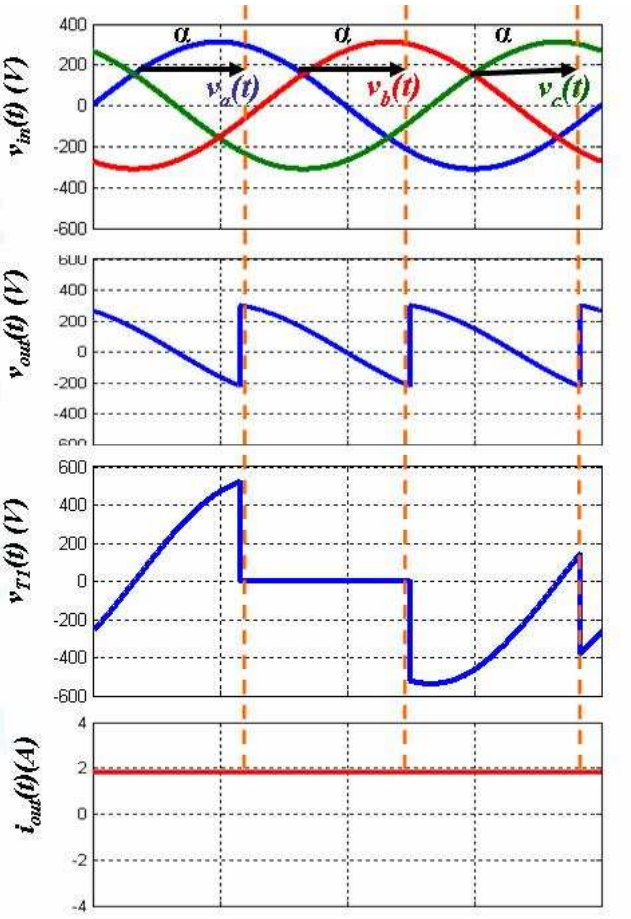
Three phase half wave rectifier (Inductive load and firing angle of 75°)





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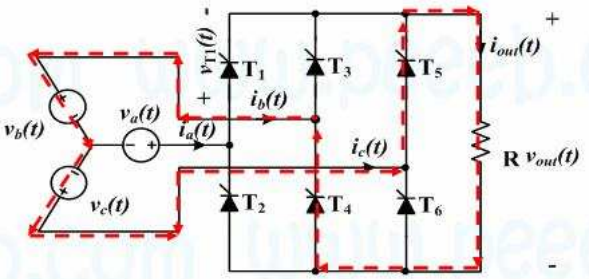
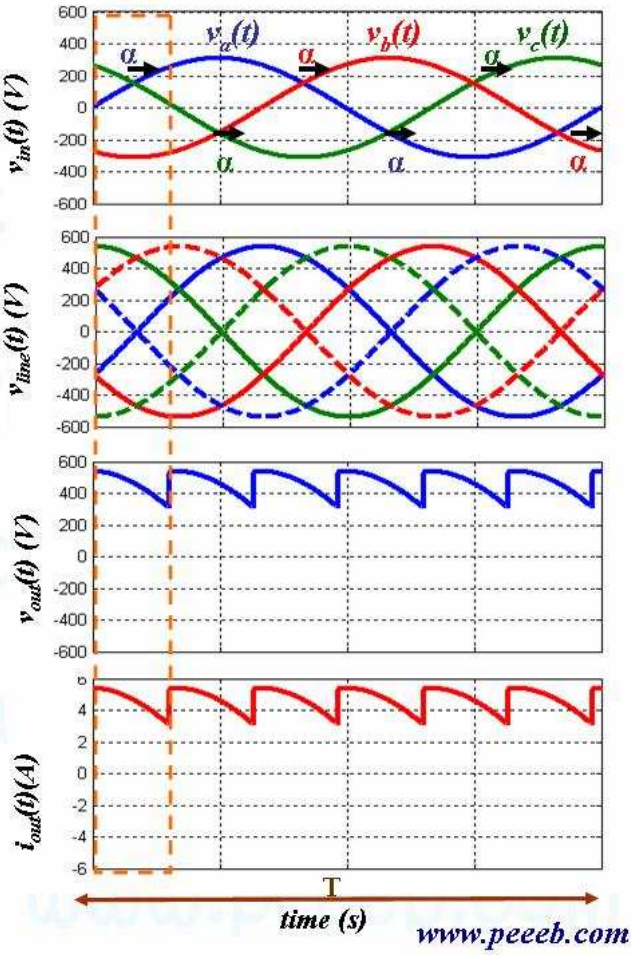
Three phase full wave rectifier (Resistive load and firing angle of 15°)





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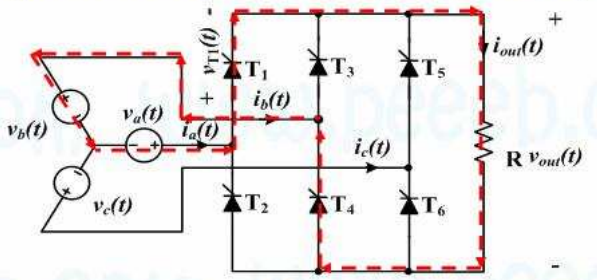
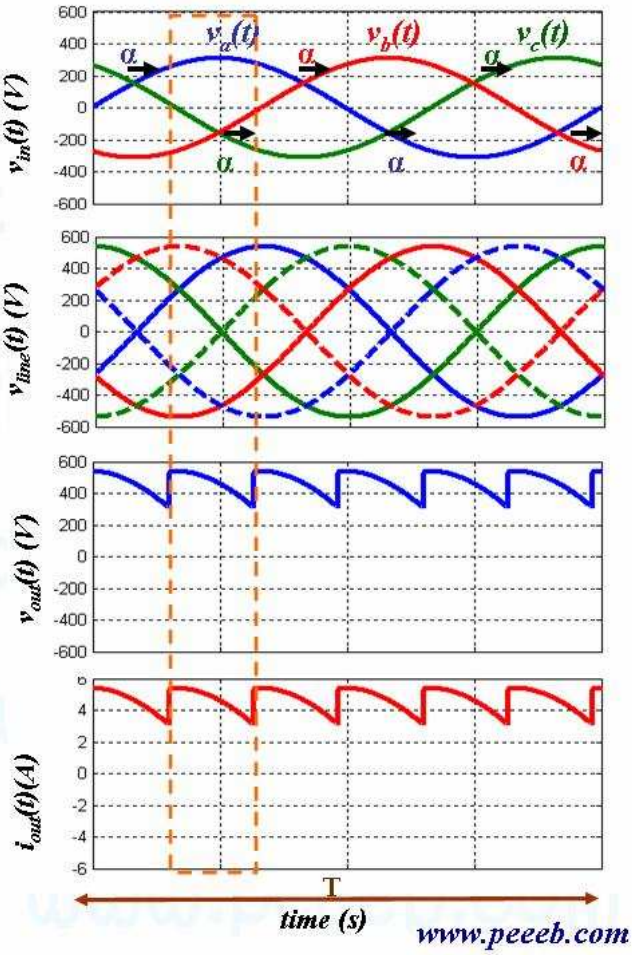
Three phase full wave rectifier (Resistive load and firing angle of 15°)





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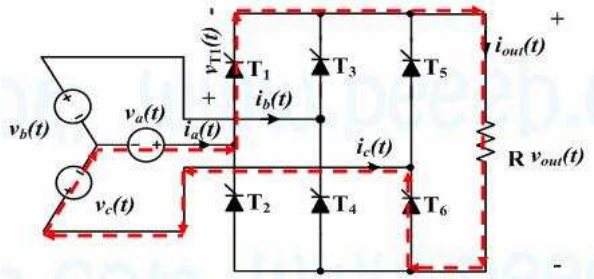
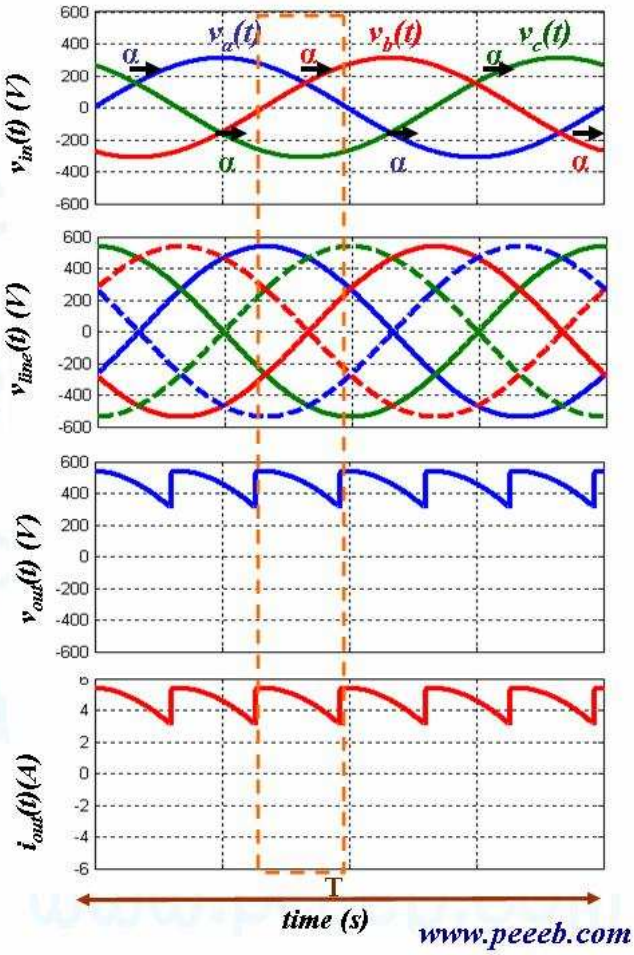
Three phase full wave rectifier (Resistive load and firing angle of 15°)





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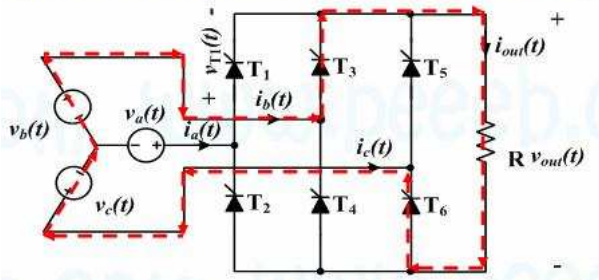
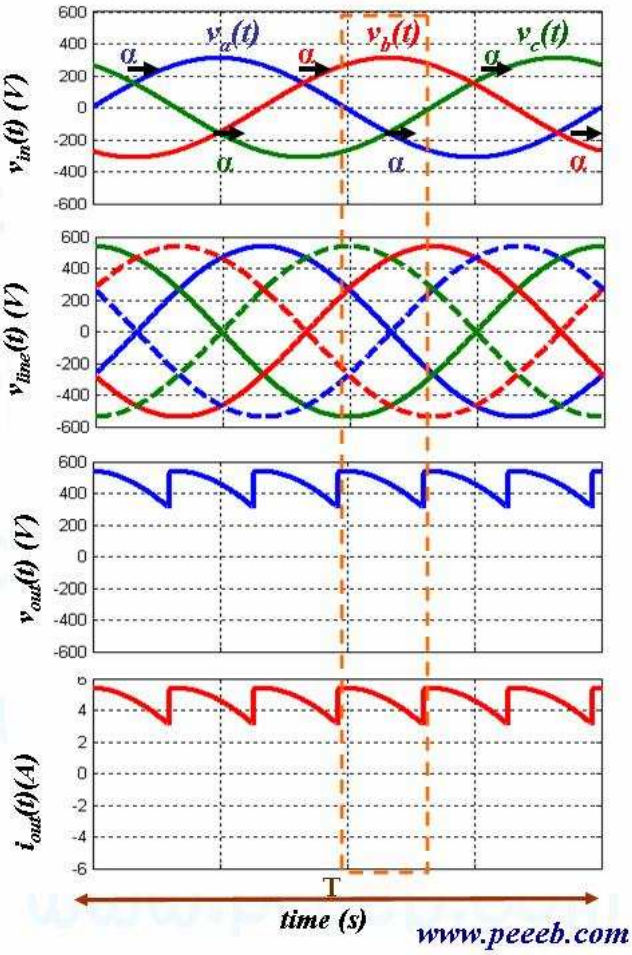
Three phase full wave rectifier (Resistive load and firing angle of 15°)





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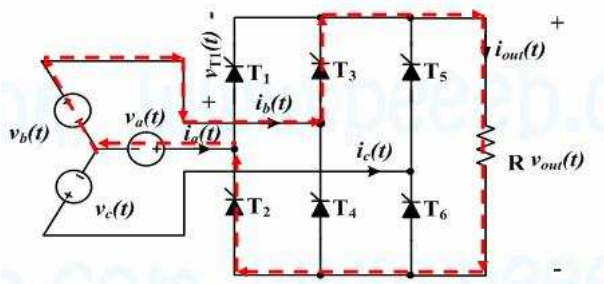
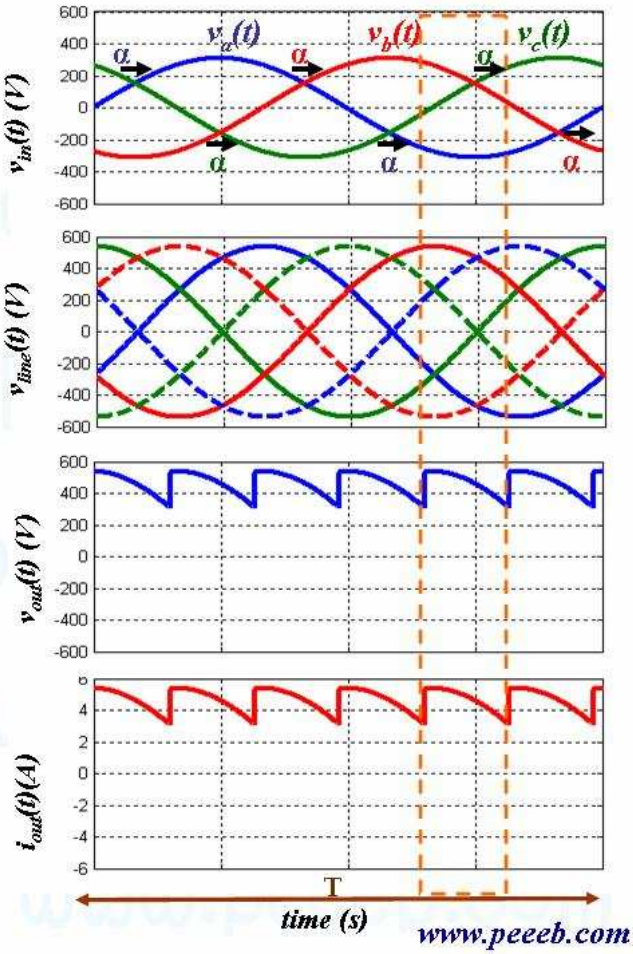
Three phase full wave rectifier (Resistive load and firing angle of 15°)





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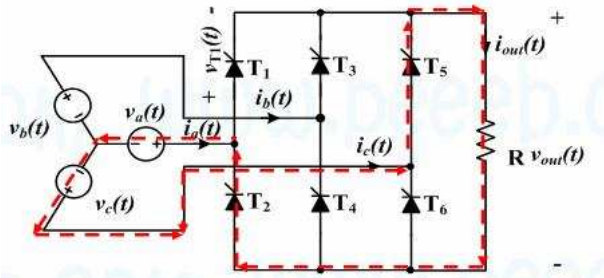
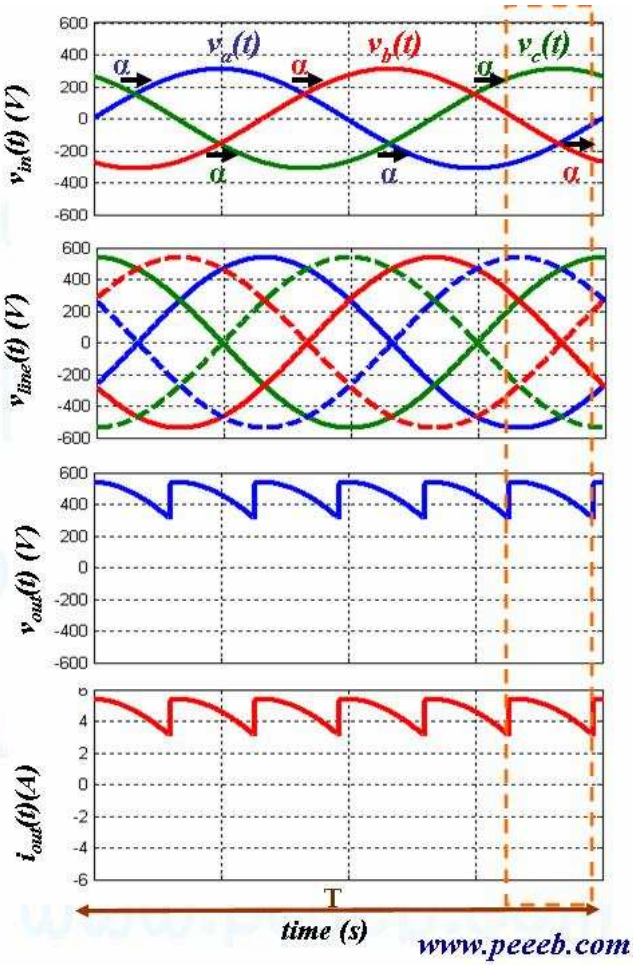
Three phase full wave rectifier (Resistive load and firing angle of 15°)





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Three phase full wave rectifier

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

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

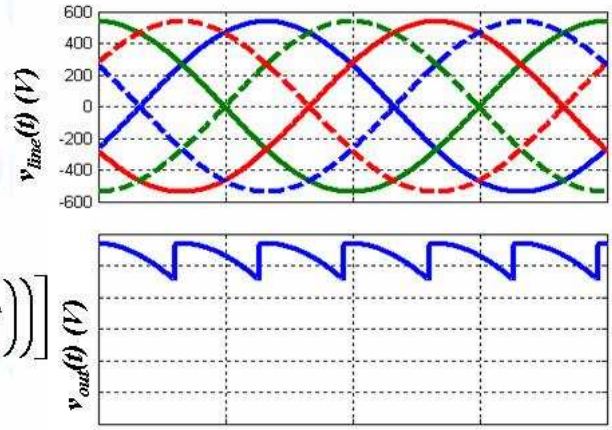
$$= \frac{3\sqrt{3}V_m}{\pi}\left[\sin\left(\frac{2\pi}{T}\left(\frac{T}{12}+\Delta t\right)\right) - \sin\left(\frac{2\pi}{T}\left(-\frac{T}{12}+\Delta t\right)\right)\right]$$

$$= \frac{3\sqrt{3}V_m}{\pi}\left[\sin\left(\frac{\pi}{6}+\frac{2\pi\Delta t}{T}\right) - \sin\left(-\frac{\pi}{6}+\frac{2\pi\Delta t}{T}\right)\right]$$

$$= \frac{3\sqrt{3}V_m}{\pi}\left[2\sin\left(\frac{\pi}{6}\right)\cos\left(\frac{2\pi\Delta t}{T}\right)\right]$$

$$= \frac{3\sqrt{3}V_m}{\pi}\left[2\times\frac{1}{2}\times\cos\left(\frac{2\pi\Delta t}{T}\right)\right] = \frac{3\sqrt{3}V_m}{\pi}\cos\left(\frac{2\pi\Delta t}{T}\right)$$

$$= \frac{3\sqrt{3}V_m}{\pi}\cos(\alpha)$$



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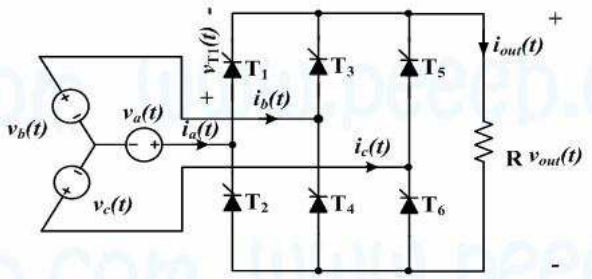
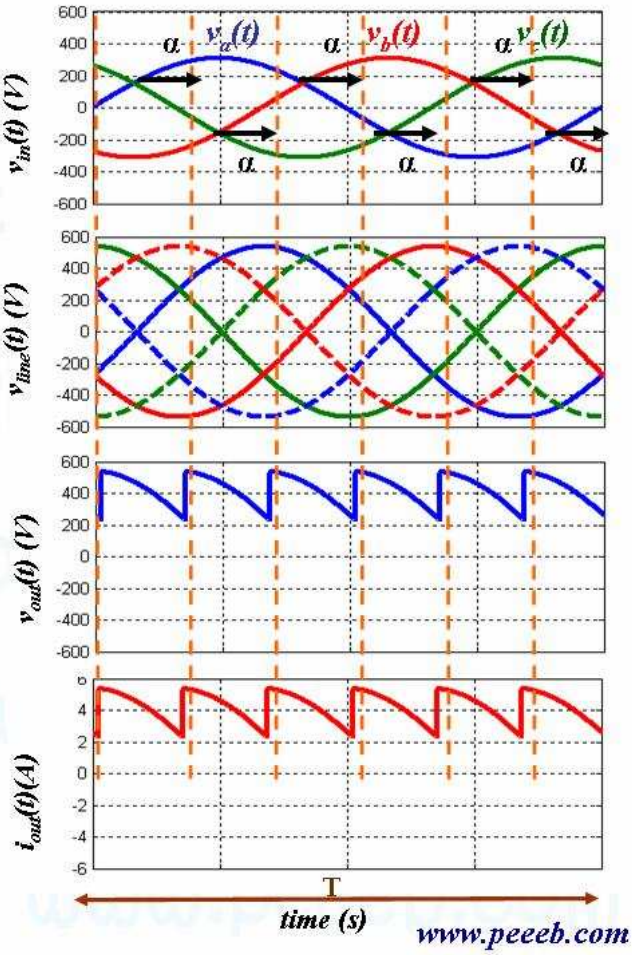
Three phase full wave rectifier (Resistive load and firing angle of 45°)





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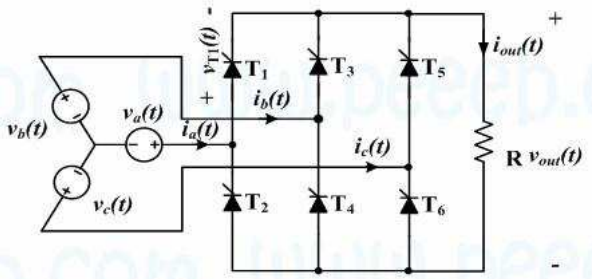
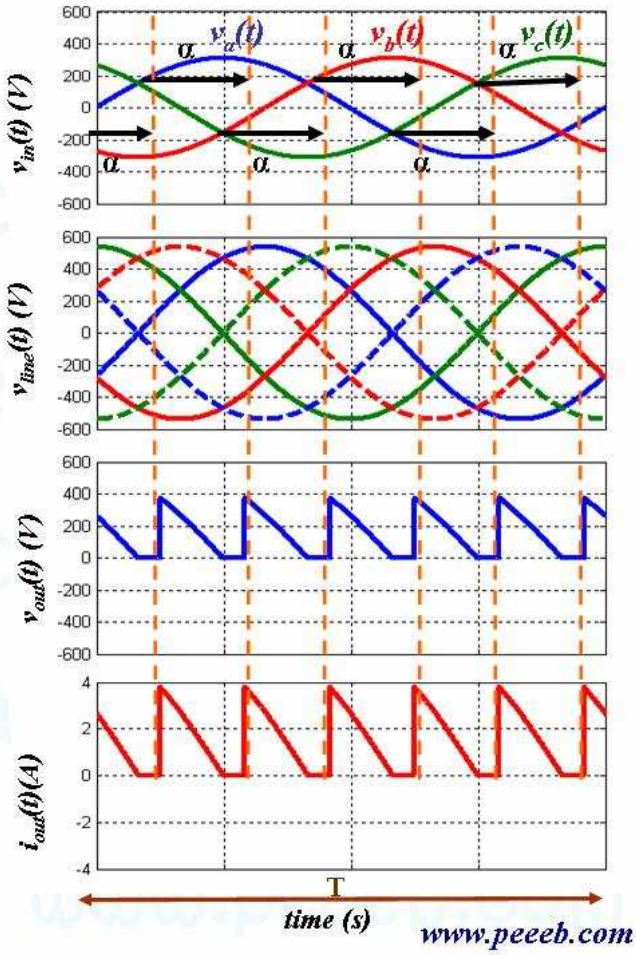
Three phase full wave rectifier (Resistive load and firing angle of 75°)





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Three phase full wave rectifier

$$V_{out} = \frac{1}{\frac{T}{6}} \int_{-\frac{T}{12}+\Delta t}^{\frac{T}{12}+\Delta t} v_{out}(t)\,dt$$

$$V_{out} = \frac{1}{\frac{T}{6}} \int_{-\frac{T}{12}+\Delta t}^{\frac{T}{4}} \sqrt{3}V_m \cos\left(\frac{2\pi t}{T}\right) dt$$

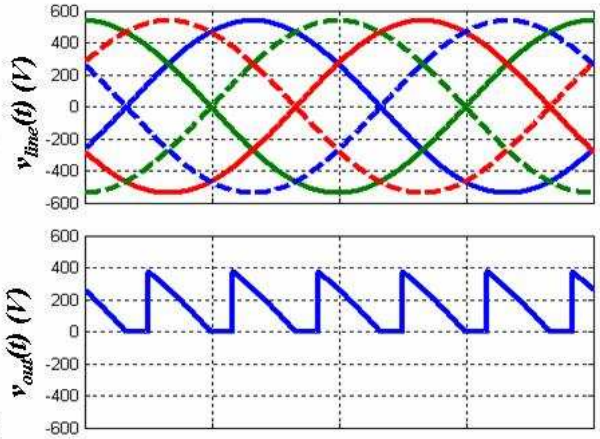
$$= \frac{6\sqrt{3}V_m}{T}\left(\frac{T}{2\pi}\right)\left[\sin\left(\frac{2\pi t}{T}\right)\Big|_{-\frac{T}{12}+\Delta t}^{\frac{T}{4}}\right]$$

$$= \frac{3\sqrt{3}V_m}{\pi}\left[\sin\left(\frac{\pi}{2}\right) - \sin\left(\frac{2\pi}{T}\left(-\frac{T}{12}+\Delta t\right)\right)\right]$$

$$= \frac{3\sqrt{3}V_m}{\pi}\left[1 - \sin\left(-\frac{\pi}{6}+\frac{2\pi\Delta t}{T}\right)\right]$$

$$= \frac{3\sqrt{3}V_m}{\pi}\left[1 + \sin\left(\frac{\pi}{6}-\frac{2\pi\Delta t}{T}\right)\right] \qquad \Delta t = \frac{T\alpha}{2\pi}$$

$$= \frac{3\sqrt{3}V_m}{\pi}\left[1 + \sin\left(\frac{\pi}{6}-\alpha\right)\right]$$



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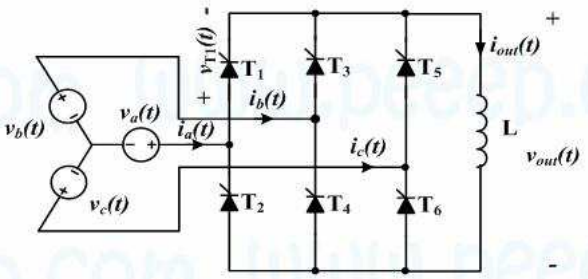
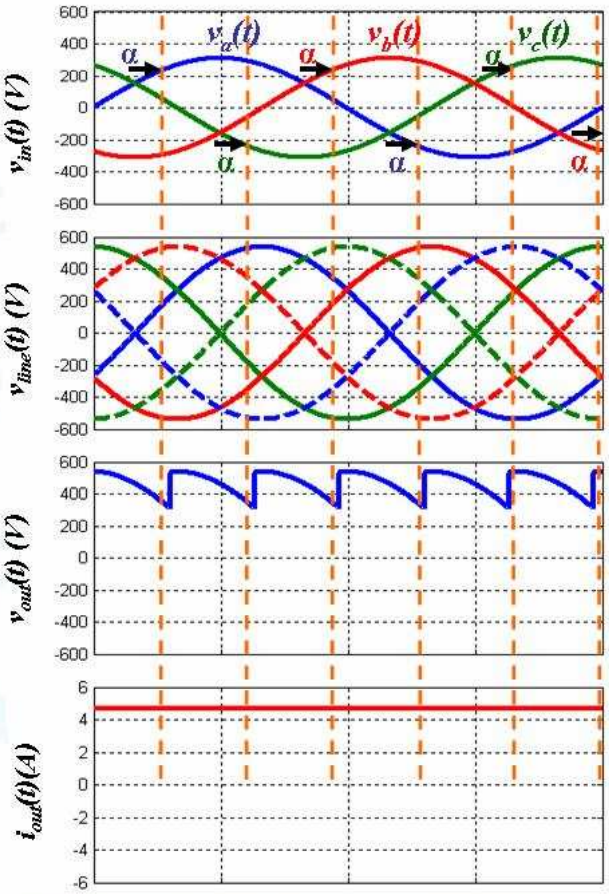
Three phase full wave rectifier (Inductive load and firing angle of 15^0)





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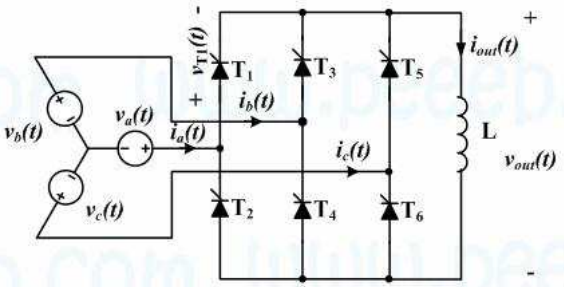
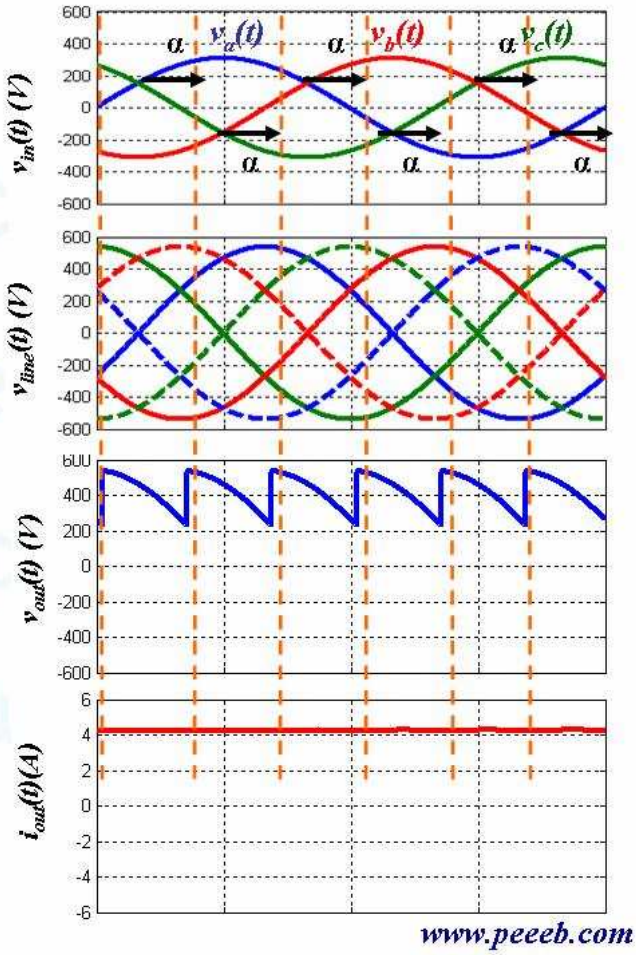
Three phase full wave rectifier (Inductive load and firing angle of 45°)





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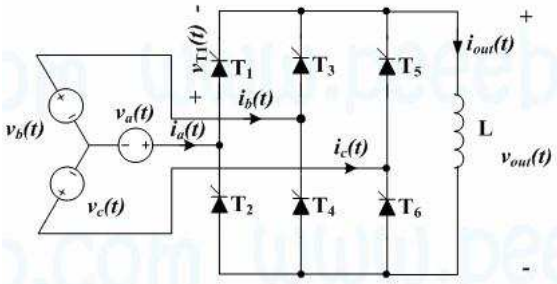
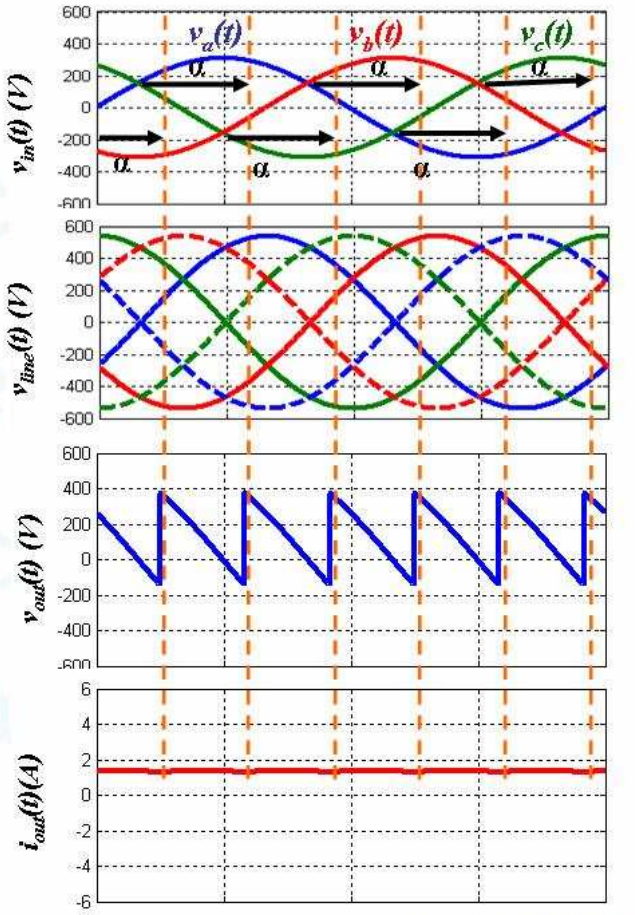
Three phase full wave rectifier (Inductive load and firing angle of 75°)





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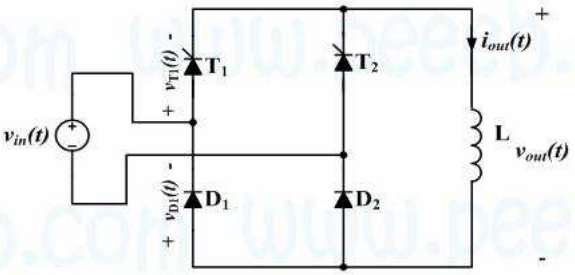
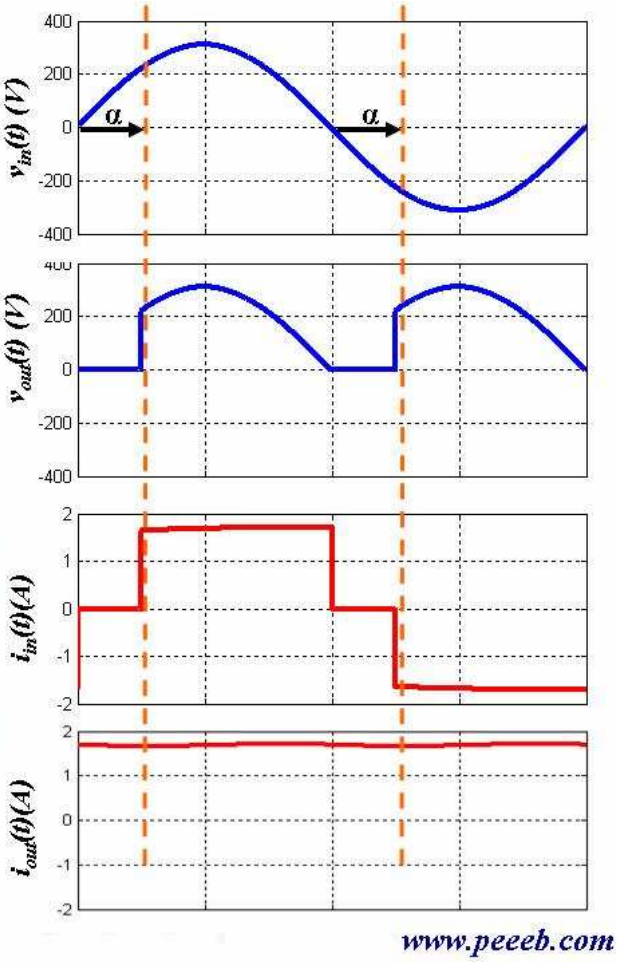
Single phase full wave half controlled rectifier
(Inductive load, firing angle of 45°)





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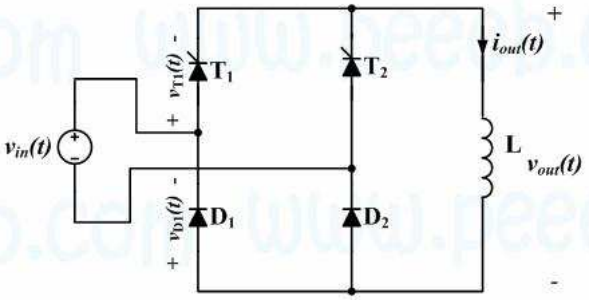
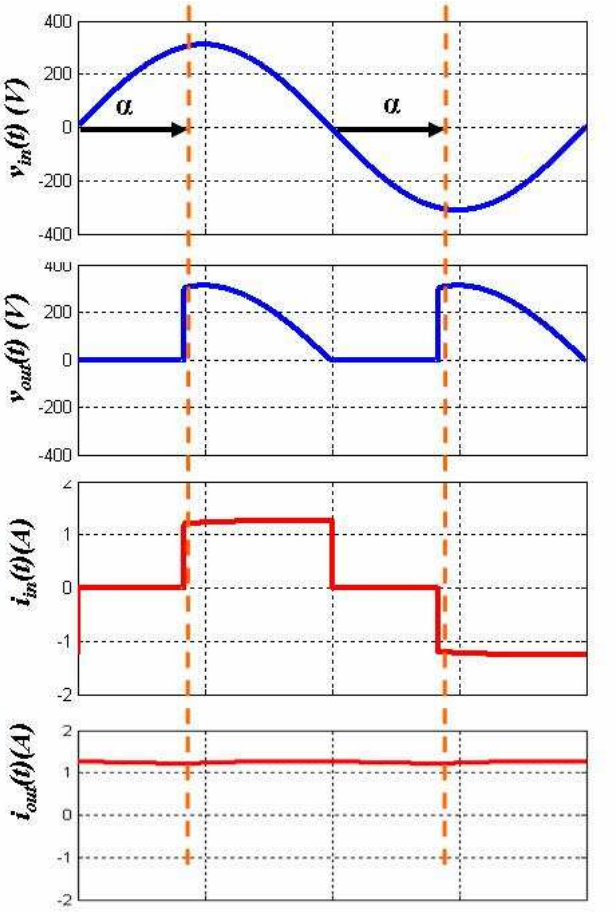
Single phase full wave half controlled rectifier
(Inductive load, firing angle of 75°)





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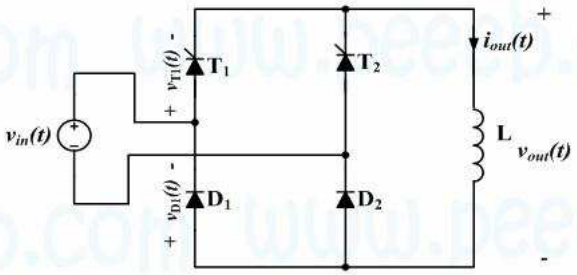
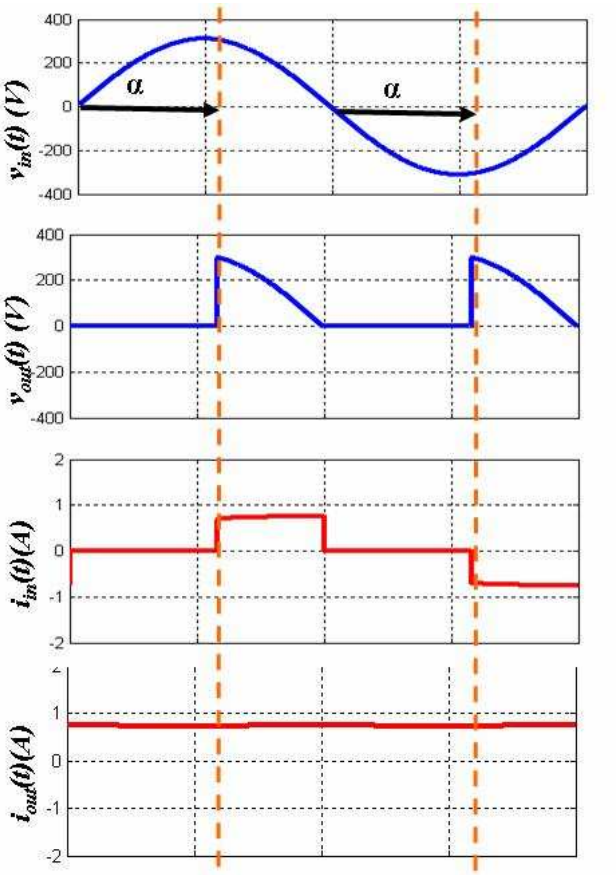
Single phase full wave half controlled rectifier
(Inductive load, firing angle of 105°)





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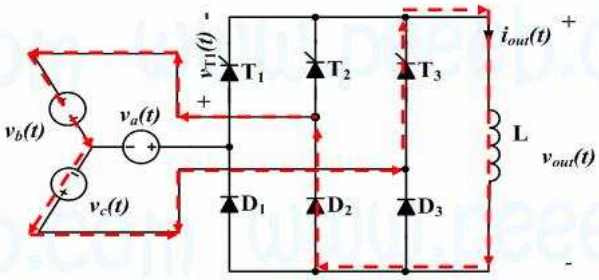
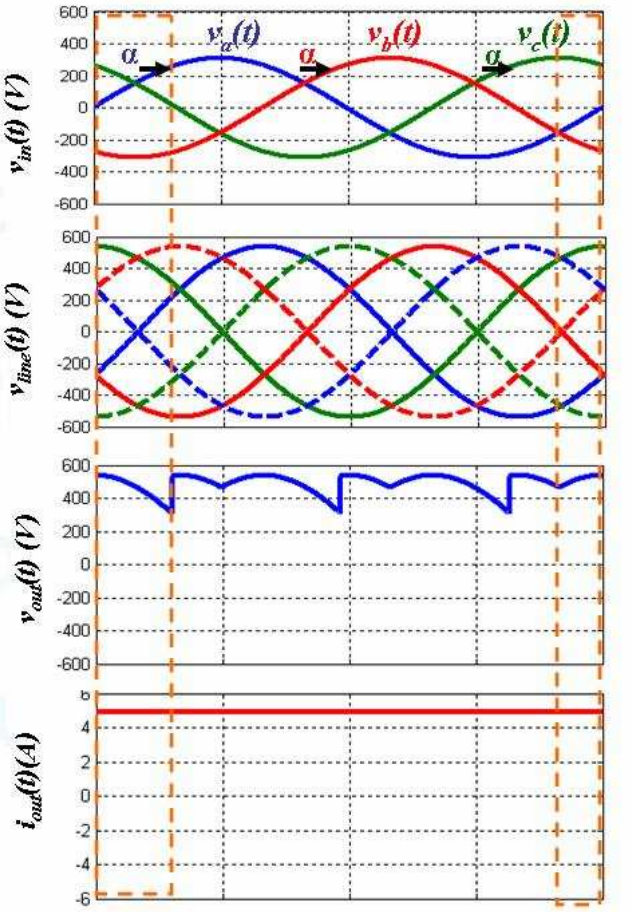
Three phase full wave half controlled rectifier
(Inductive load, firing angle of 15°)





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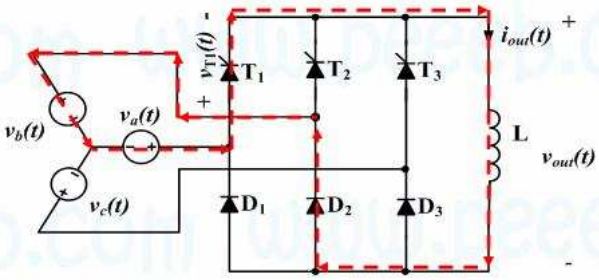
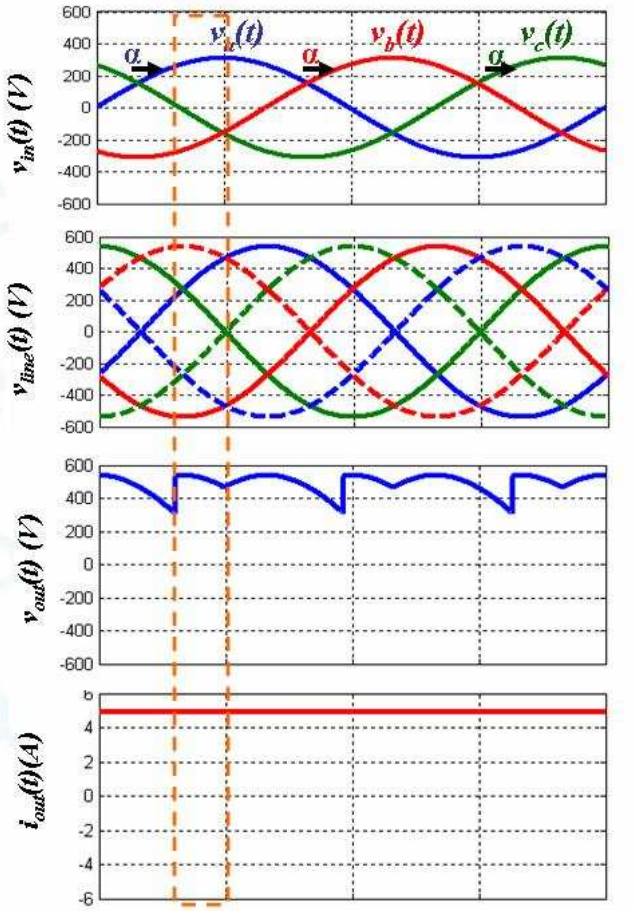
Three phase full wave half controlled rectifier
(Inductive load, firing angle of 15°)





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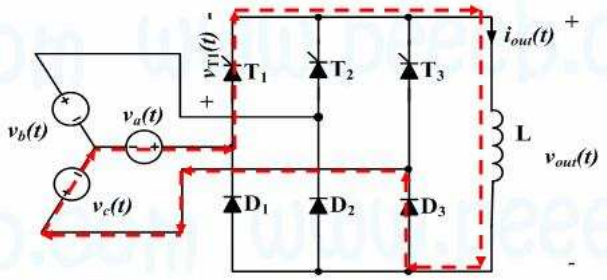
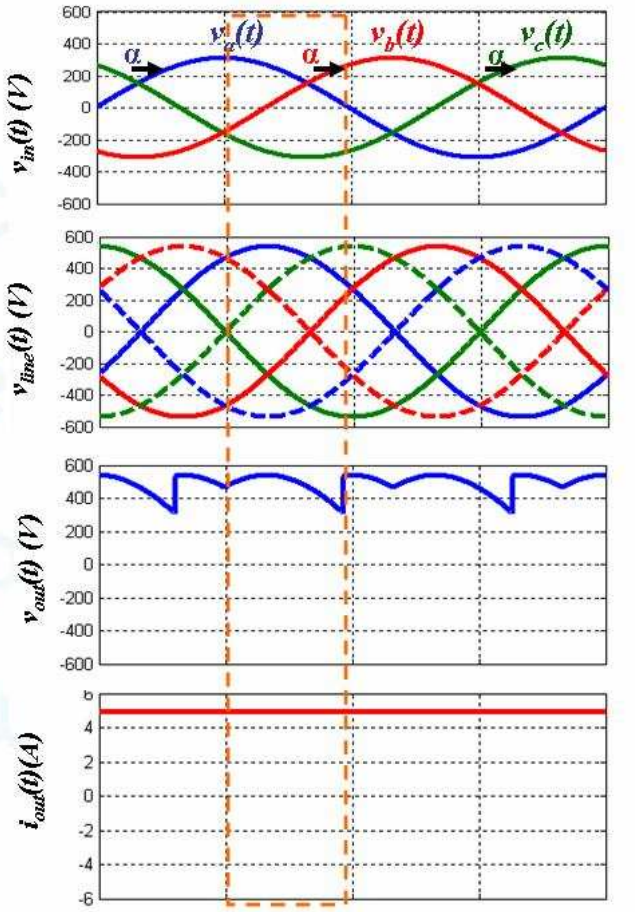
Three phase full wave half controlled rectifier
(Inductive load, firing angle of 15°)





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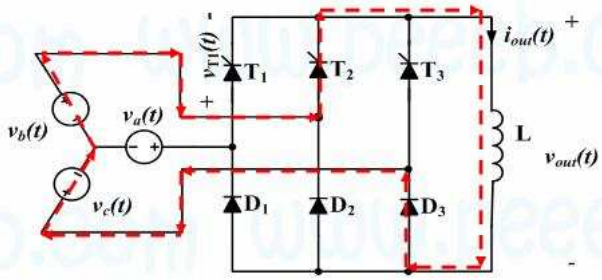
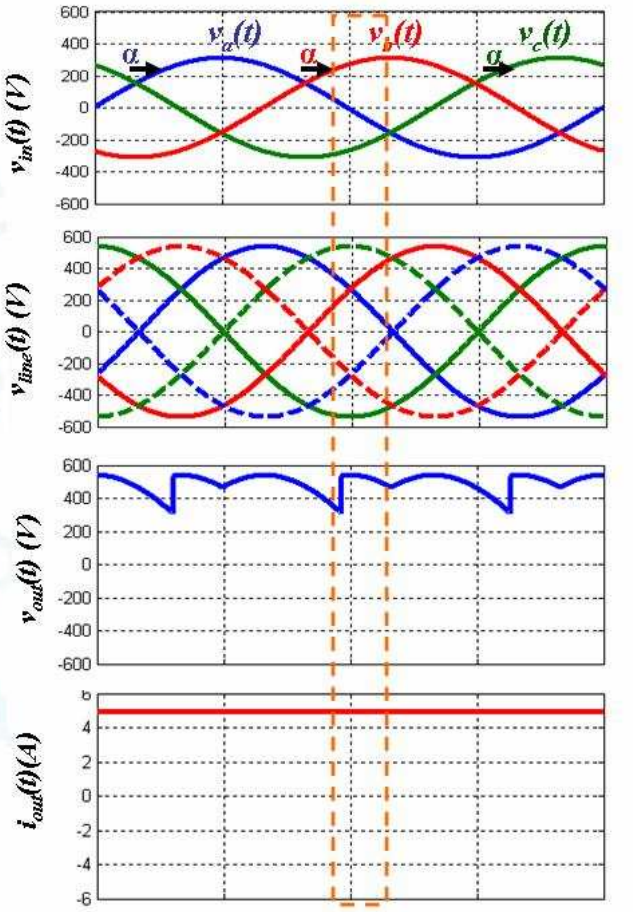
Three phase full wave half controlled rectifier
(Inductive load, firing angle of 15°)





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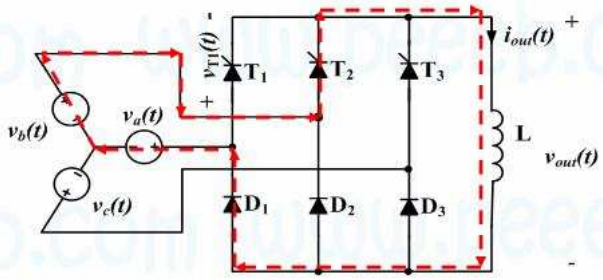
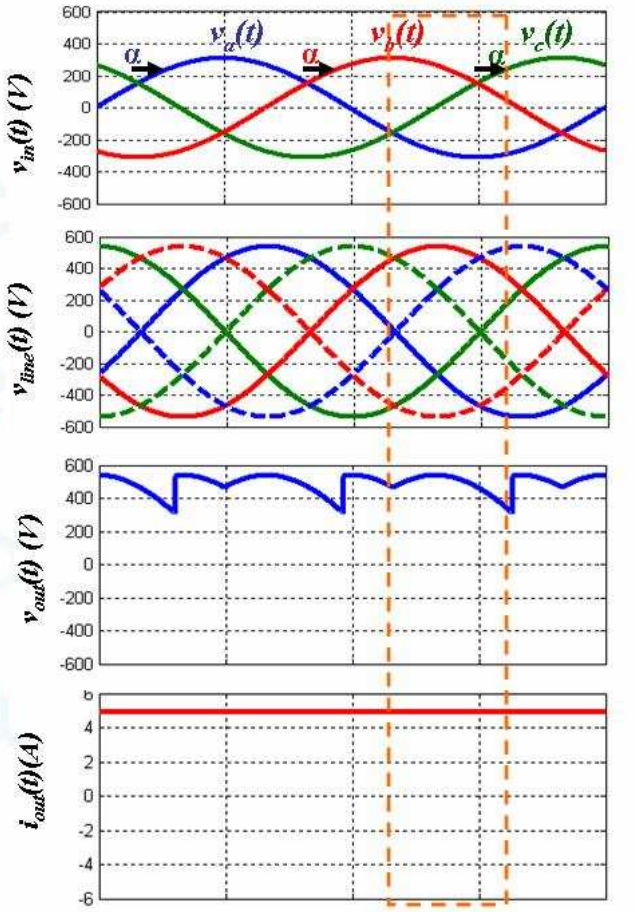
Three phase full wave half controlled rectifier
(Inductive load, firing angle of 15°)





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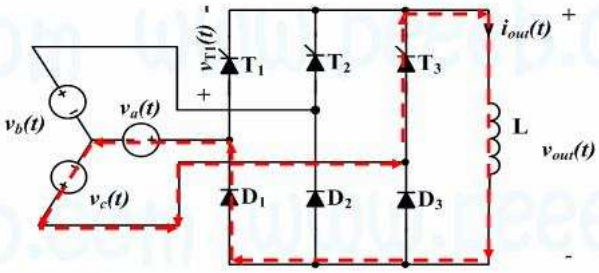
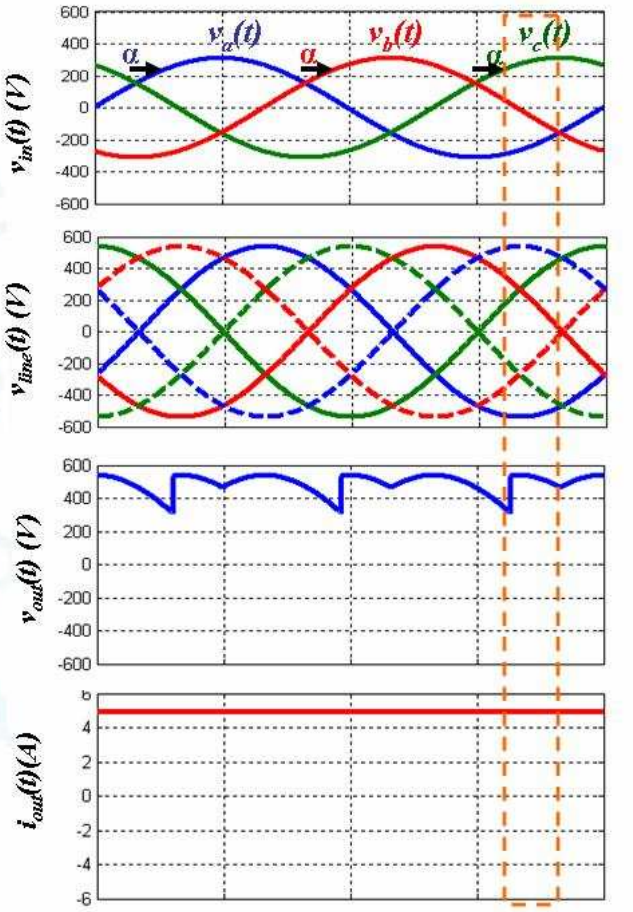
Three phase full wave half controlled rectifier
(Inductive load, firing angle of 15°)





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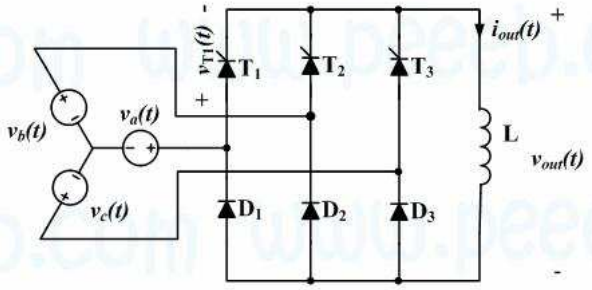
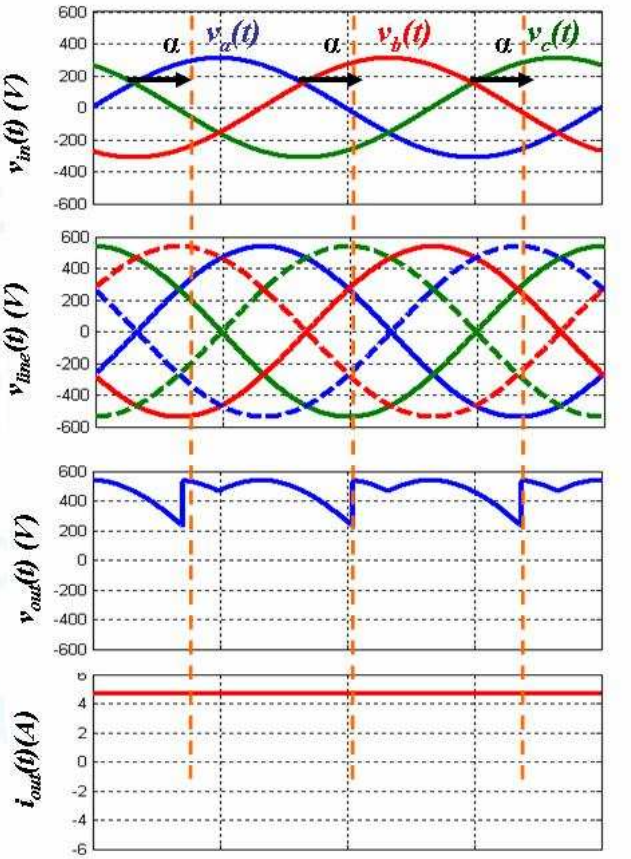
Three phase full wave half controlled rectifier
(Inductive load, firing angle of 45°)





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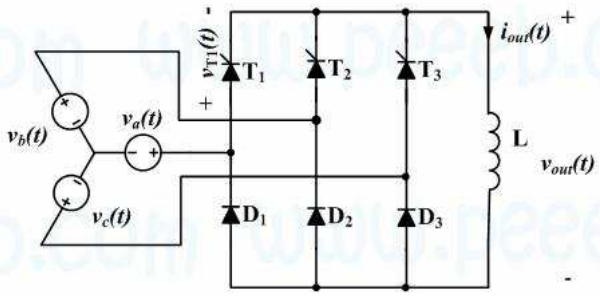
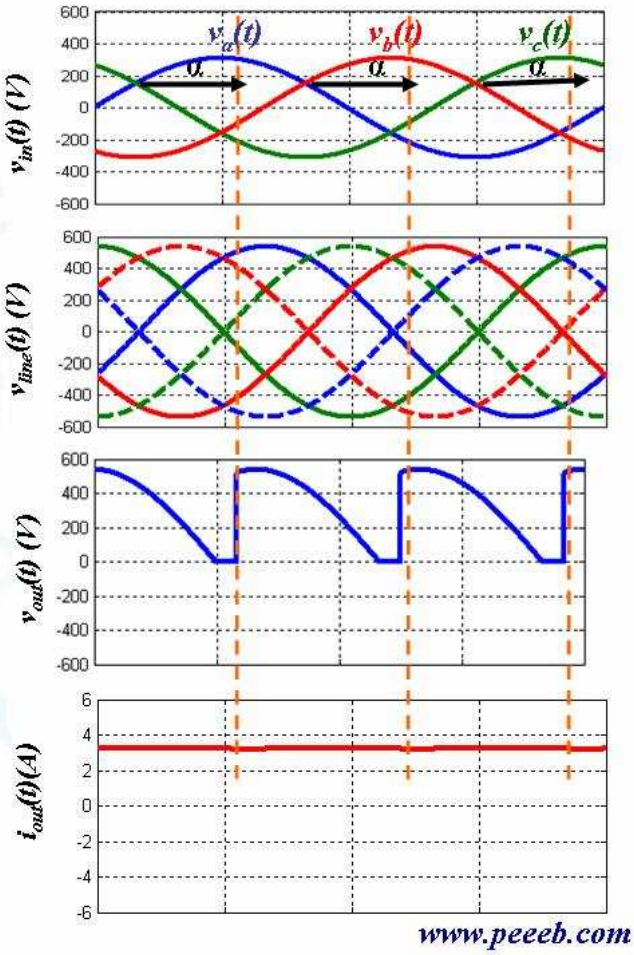
Three phase full wave half controlled rectifier
(Inductive load, firing angle of 75°)





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