University of Technology
Laser and Optoelectronic Engineering Department
Power Electronics/2018-2019)
For the third years (Laser Engineering)

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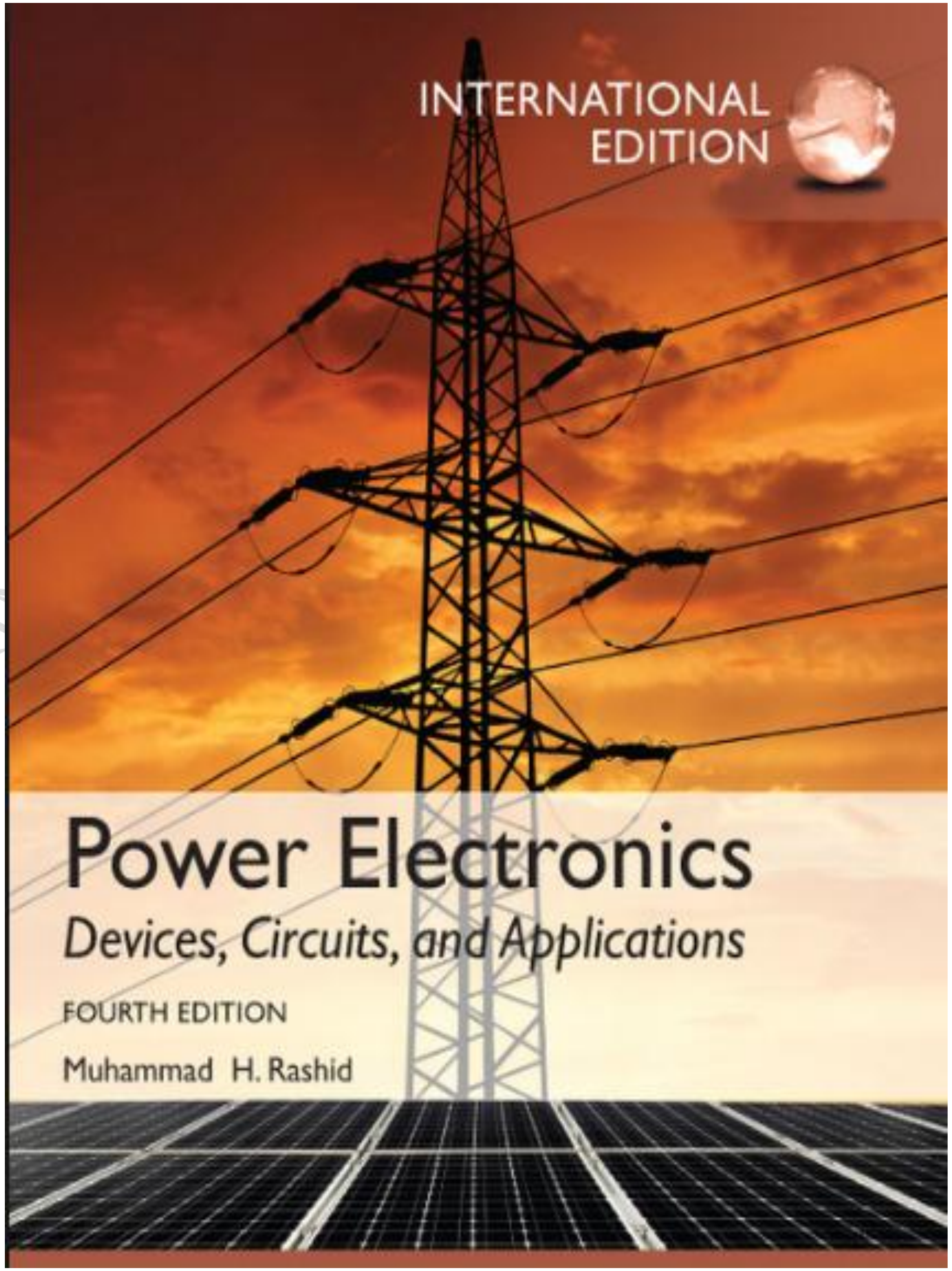
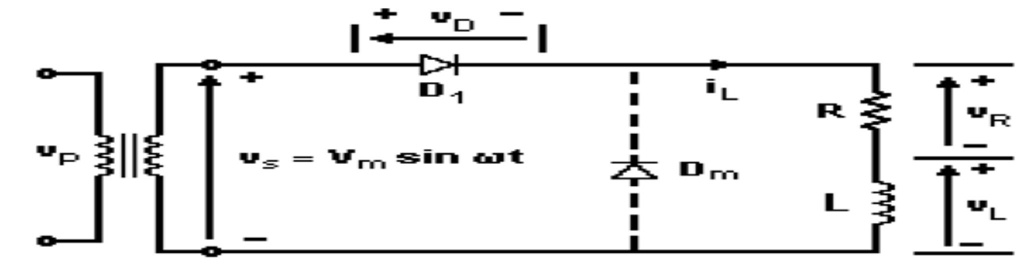


Ref: Power Electronics 4th edition/ Muhammed H. Rashid

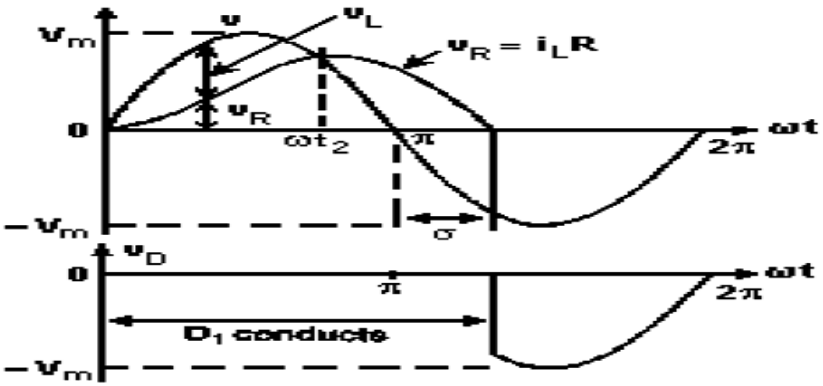
Lecture No.4

Single Phase Half-Wave Rectifier (RL- Load)

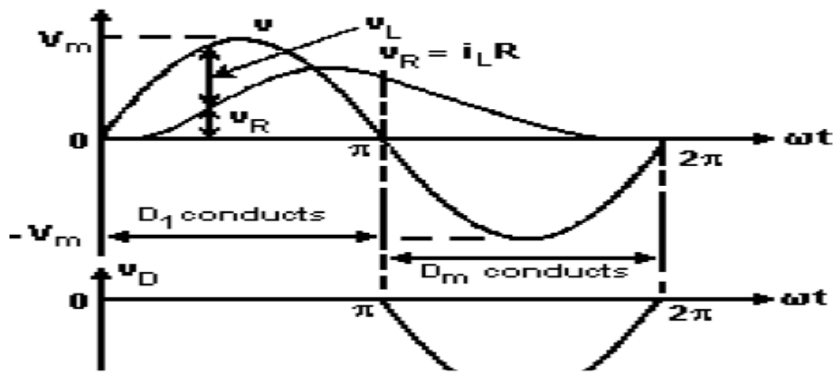
The half wave rectifier with an inductive load (RL) is shown in figure below.



(a) Circuit diagram



Without freewheeling diode



With freewheeling diode

During the interval 0 to π/2

The source voltage **V**s increases from zero to its positive maximum, while the voltage across the inductor $\mathbf{V}_L$ opposes the change of current through the load. It must be noted that the current through an inductor cannot change instantaneously; hence, the current gradually increases until it reaches its maximum value. The current does not reach its peak when the voltage is at its maximum, which is consistent with the fact that the current through an inductor lags the voltage across it. During this time, energy is transferred from the ac source and is stored in the magnetic field of the inductor.

For the interval π/2 and π

The source voltage decreases from its positive maximum to zero. The induced voltage in the inductor reverses polarity and opposes the associated decrease in current, thereby aiding the diode forward current. Therefore, the current starts decreasing gradually at a delayed time, becoming zero when all the energy stored by then inductor is released to the circuit. Again, this is consistent with the fact that current lags voltage in an inductive circuit. Hence, even after the source voltage has dropped past zero volts, there is still load current, which exists a little more than half a cycle.

For the interval greater than π

At π, the source voltage reverses and starts to increase to its negative maximum. However, the voltage induced across the inductor is still positive and will sustain forward conduction of the diode until this induced voltage decreases to zero. When this induced voltage falls to zero, the diode will now be reversed biased, but would have conducted forward current for an angle β, where $\beta = \pi + \sigma$. σ is the extended angle of current conduction due to the energy stored in the magnetic field being returned to the source.

The instantaneous supply voltage $\mathbf{V_s}$ is given by:

$$\mathbf{V_s} = \mathbf{V_R} + \mathbf{V_L}$$

For angles, less than ωt_2 the inductor is storing energy in its magnetic field from the source and the inductor voltage would be such as to oppose the growth of current and the supply voltage. For angles greater than ωt_2 the inductor voltage would have reversed and would aid the supply voltage to prevent the fall of current. Hence, the average inductor voltage is zero.

From the preceding discussion

$v_D = 0$

-For $0 \le \omega t \le \beta$

$v_o = v_i$ $i_o = i_i$

For $\beta \le \omega t \le 2\pi$

$v_o = 0$

$i_o = i_i = 0$

$v_D = v_i - v_o = v_i$

The average output voltage is given by:

$$V_{dc} = \frac{1}{2\pi}\int_0^{2\pi} v_o d\omega t = \frac{1}{2\pi}\int_0^{\beta}\sqrt{2}V_i \sin\omega t d\omega t$$

$$= \frac{\sqrt{2}V_i}{\pi}\left(\frac{1-\cos\beta}{2}\right)$$

Where, $V_m = \sqrt{2}V_i$

The rms output voltage is given by:

$$V_L = \sqrt{\frac{1}{2\pi}\int_0^{\beta} 2V_i^2 \sin^2\omega t d\omega t}$$

$$= \sqrt{\frac{V_i^2}{2\pi}\left(\beta - \frac{1}{2}\sin 2\beta\right)} = \frac{V_i}{\sqrt{2}}\sqrt{\frac{2\beta - \sin 2\beta}{2\pi}}$$

$$FF = \frac{V_L}{V_{dc}} = \pi\sqrt{\frac{2\beta - \sin 2\beta}{2\pi(1-\cos\beta)^2}}$$

$$RF = \sqrt{FF^2 - 1}$$

$$= \sqrt{\frac{\pi(2\beta - \sin 2\beta)}{2(1-\cos\beta)^2} - 1}$$

All these quantities are functions of β which can be found as follows.

-For $0 \le \omega t \le \beta$

$$v_i = \sqrt{2}V_i \sin\omega t = L\frac{di_o}{dt} + Ri_o$$

$$i_O(\omega t = 0) = i_O(\omega t = \beta) = 0$$

The solution is given by:

$$i_0 = I_0 e^{-\frac{\omega t}{\tan\varphi}} + \frac{\sqrt{2}V_i}{Z}\sin(\omega t - \varphi)$$

Where;

$$\tan\varphi = \frac{\omega L}{R} \qquad Z = \sqrt{R^2 + \omega^2 L^2}$$

The addition of a freewheeling diode

The average dc voltage varies proportionately to $[1 - \cos(\beta)]$. This can be made to be a maximum, thereby increasing the average dc voltage, by making $\cos(\beta)$ a maximum. The maximum value that this can take is given by $\cos(\pi + \sigma) = 1$, which can be obtained if $\sigma = 0$. We can make $\sigma = 0$ with the addition of a freewheeling diode given by $\mathbf{D}_m$ as shown with the dotted line.

When the supply voltage goes to zero, the current from $\mathbf{D}_1$ is transferred across to diode $\mathbf{D}_m$. This is called commutation of diodes. The result is the charge in the inductor will be used to keep diode $\mathbf{D}_m$ on, instead of previously forcing $\mathbf{D}_1$ to remain in its forward state. This would reduce the value of the extended angle of conduction of the diode $\mathbf{D}_1$, σ to zero.

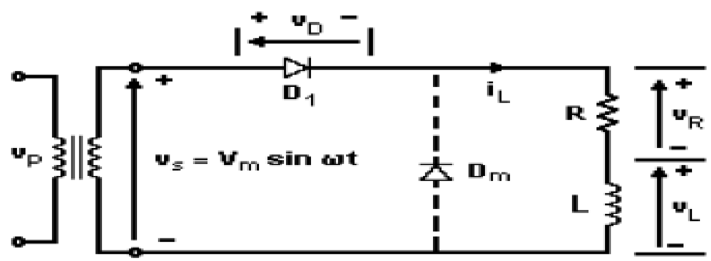
We can see that if the value of the inductance is high, it will store more charge and therefore be able to keep diode $\mathbf{D}_m$ on for a longer time.

Then the inductor would be able to keep diode $\mathbf{D}_m$ on for the entire duration of the negative half cycle, and by so doing, maintain a continuous load current.

Home work: Consider the circuit shown with:

i) Purely resistive load.
ii) Resistive-inductive load.
Then determine the following factors:

a. The efficiency
b. The ripple factor
c. The peak inverse voltage (PIV) of diode D_1
d. Form factor



(a) Circuit diagram

$R=110\Omega$, $L=100mH$, $V_s=30V$