Diode Rectifiers

EE 442-642

Half-Bridge Rectifier Circuit: R and R-L Load

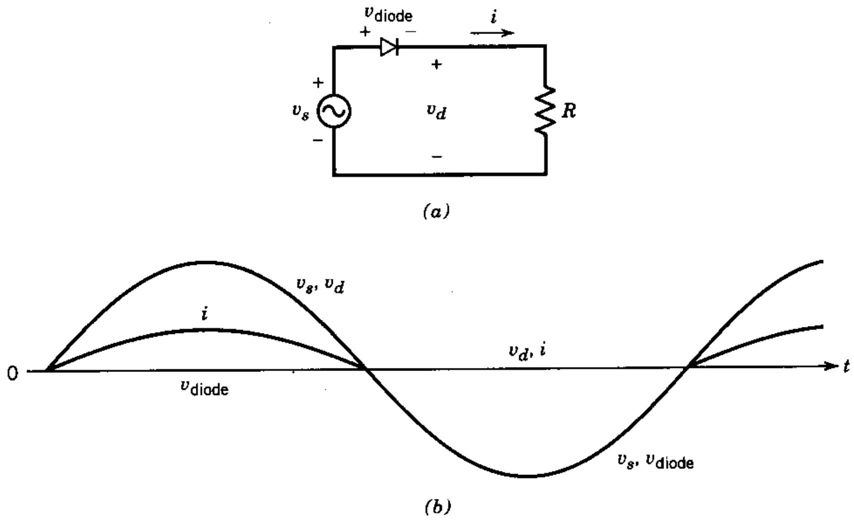


Figure 5-2 Basic rectifier with a load resistance.

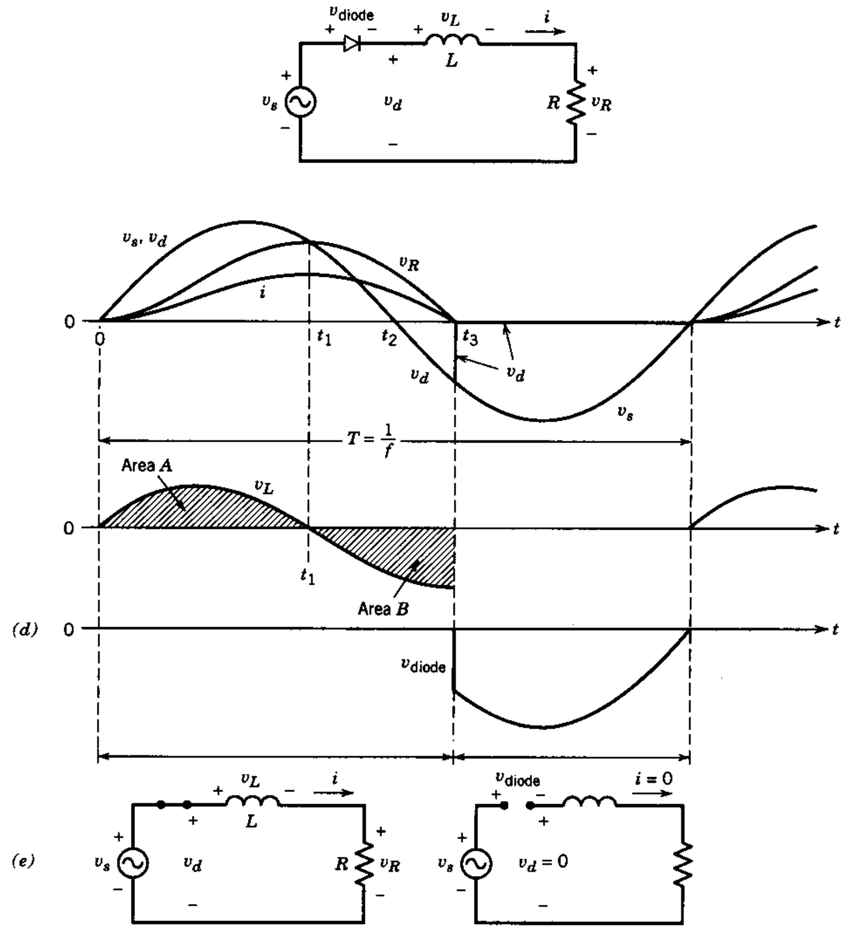
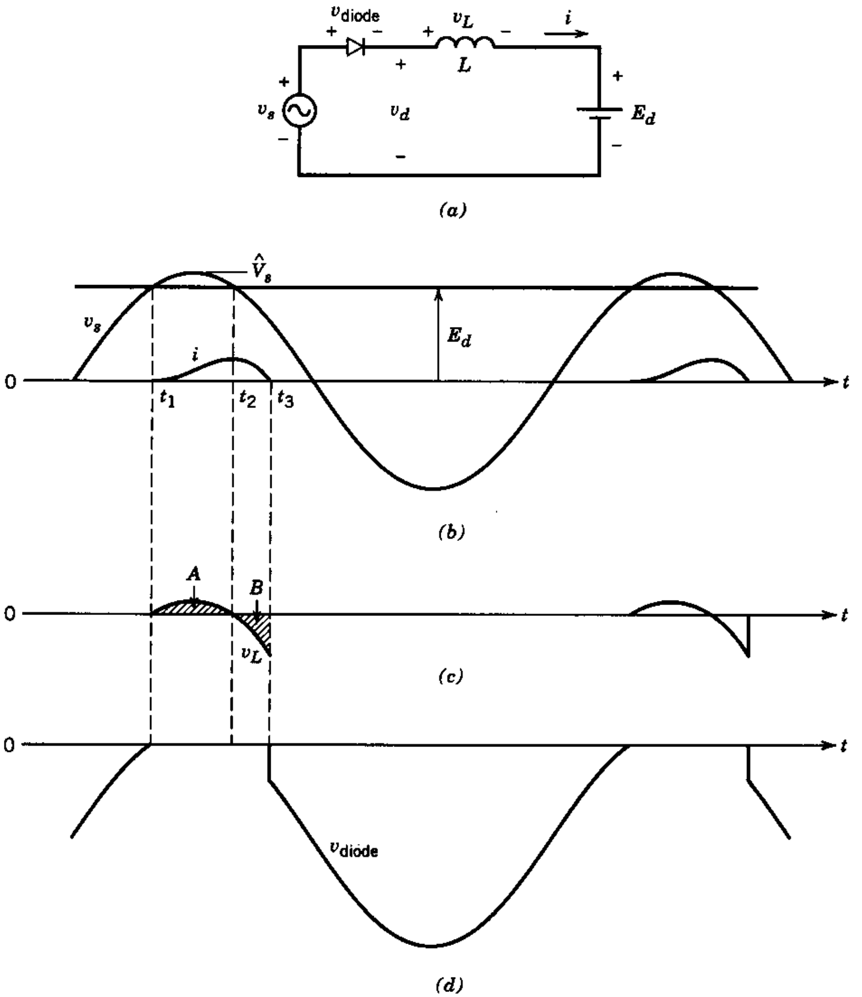


Figure 5-3 Basic rectifier with an inductive load.

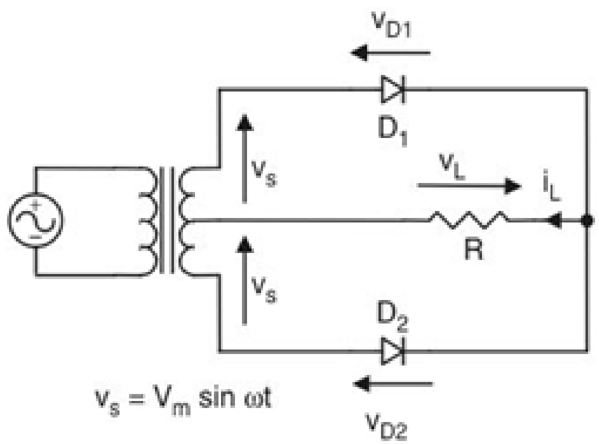
Current continues to flow for a while even after the input voltage has gone negative.

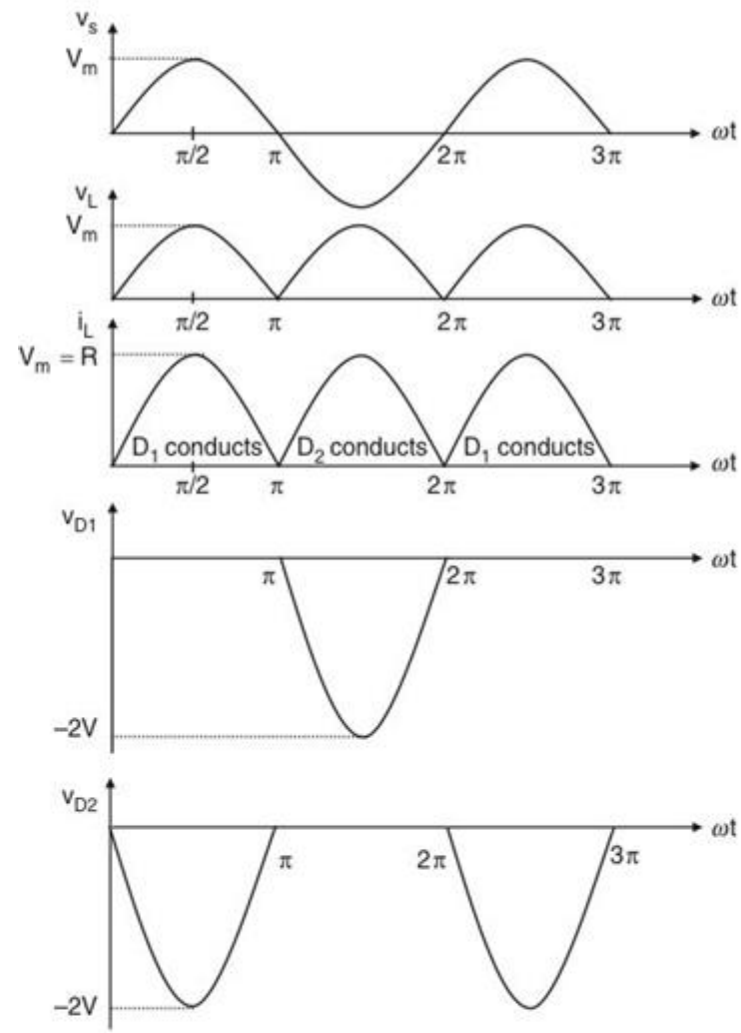
Half Bridge Rectifier Circuit: Load with dc back-emf



- Current begins to flow when the input voltage exceeds the dc back-emf.
- Current continues to flows for a while even after the input voltage has gone below the dc back-emf.

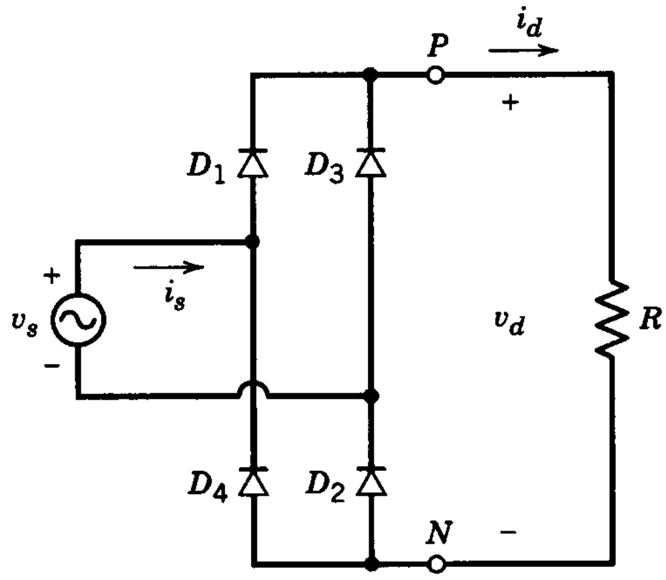
Full-wave Rectifier with Center tap Transformer

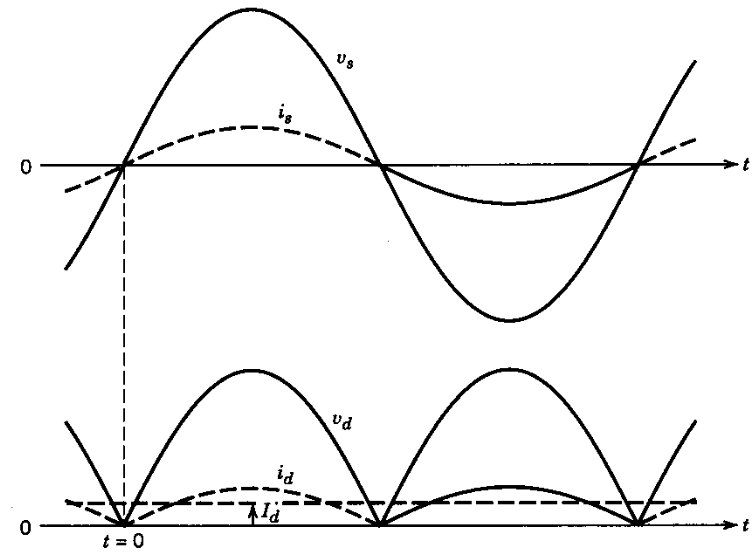




- The DC currents of the two half- wave rectifiers are equal and opposite, Hence, there is no DC current for creating a transformer core saturation problem.
- Each diode carries half of the load average current, but the same peak load current.
- Note that the V_{RRM} rating of the diodes must be chosen to be higher than $2V_m$ to avoid reverse breakdown.
- The center-tap transformer is considered bulky with additional losses.

Full Bridge Rectifier – Simple R Load





Average value of output voltage: $V_{do} = (2\sqrt{2}/\pi)V_s \approx 0.9V_s = (2/\pi)V_m = 0.637V_m$

where V_s and V_m are the RMS and peak values of input voltage.

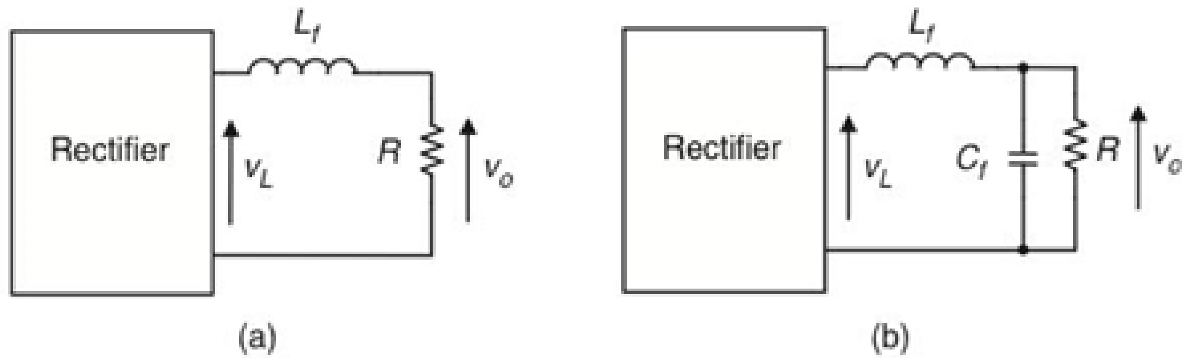
Rectification Ratio = Pdc/Pac = 0.81 or 81%

Form Factor (FF) of DC side voltage (or current) = Vrms/Vdc = 1.11

Ripple Factor = rms value of AC component/DC component = $(FF^2-1)^{1/2}$ = 0.48

Filters

- Filters are employed in rectifier circuits for smoothing out the dc output voltage of the load.

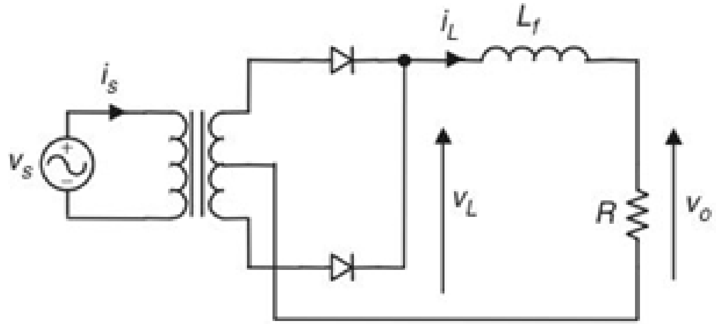


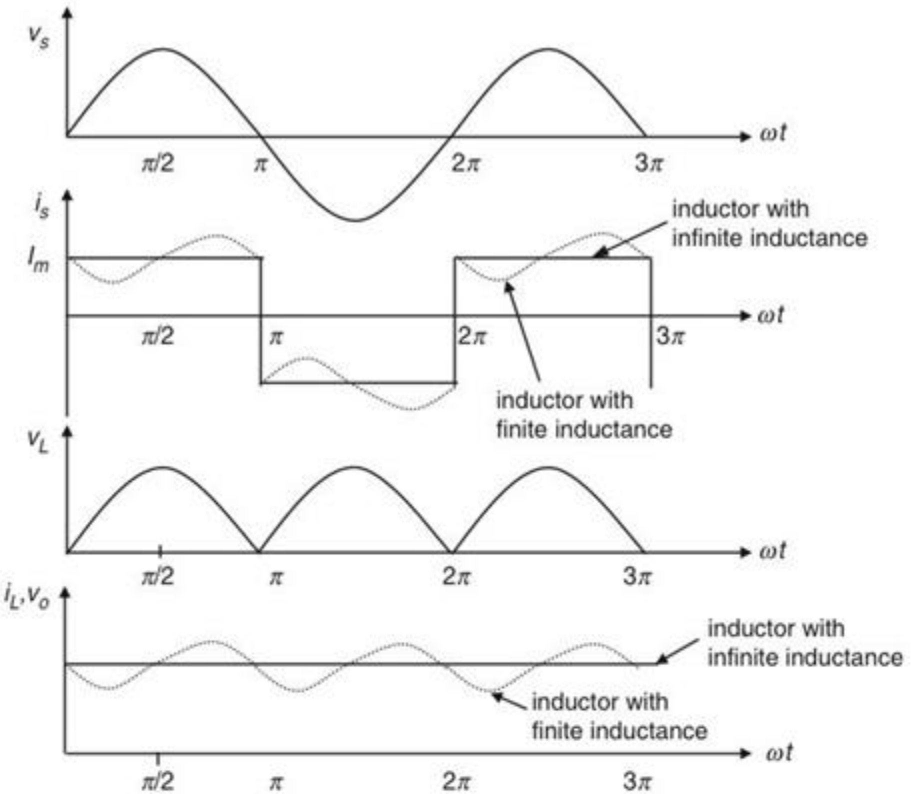
- Ripple Reduction Factor at f_r: $\frac{v_o}{v_L} = \frac{R}{\sqrt{R^2 + (2\pi f_r L_f)^2}}$ $\qquad$ $\frac{v_o}{v_L} = \left| \frac{1}{1 - (2\pi f_r)^2 L_f C_f} \right|$

$$\int \sin b_1 x \sin b_2 x \, \mathrm{d}x = \frac{\sin((b_2 - b_1)x)}{2(b_2 - b_1)} - \frac{\sin((b_1 + b_2)x)}{2(b_1 + b_2)} + C \qquad (\text{for } |b_1| \neq |b_2|)$$

$$\int \sin a_1 x \cos a_2 x \, \mathrm{d}x = -\frac{\cos((a_1 - a_2)x)}{2(a_1 - a_2)} - \frac{\cos((a_1 + a_2)x)}{2(a_1 + a_2)} + C \qquad (\text{for } |a_1| \neq |a_2|)$$

Inductor DC Filter





- Minimum value of inductance required to maintain a continuous current is known as the critical inductance L_C:

$$\text{Full-wave} \quad L_C = \frac{R}{6\pi f_i}$$

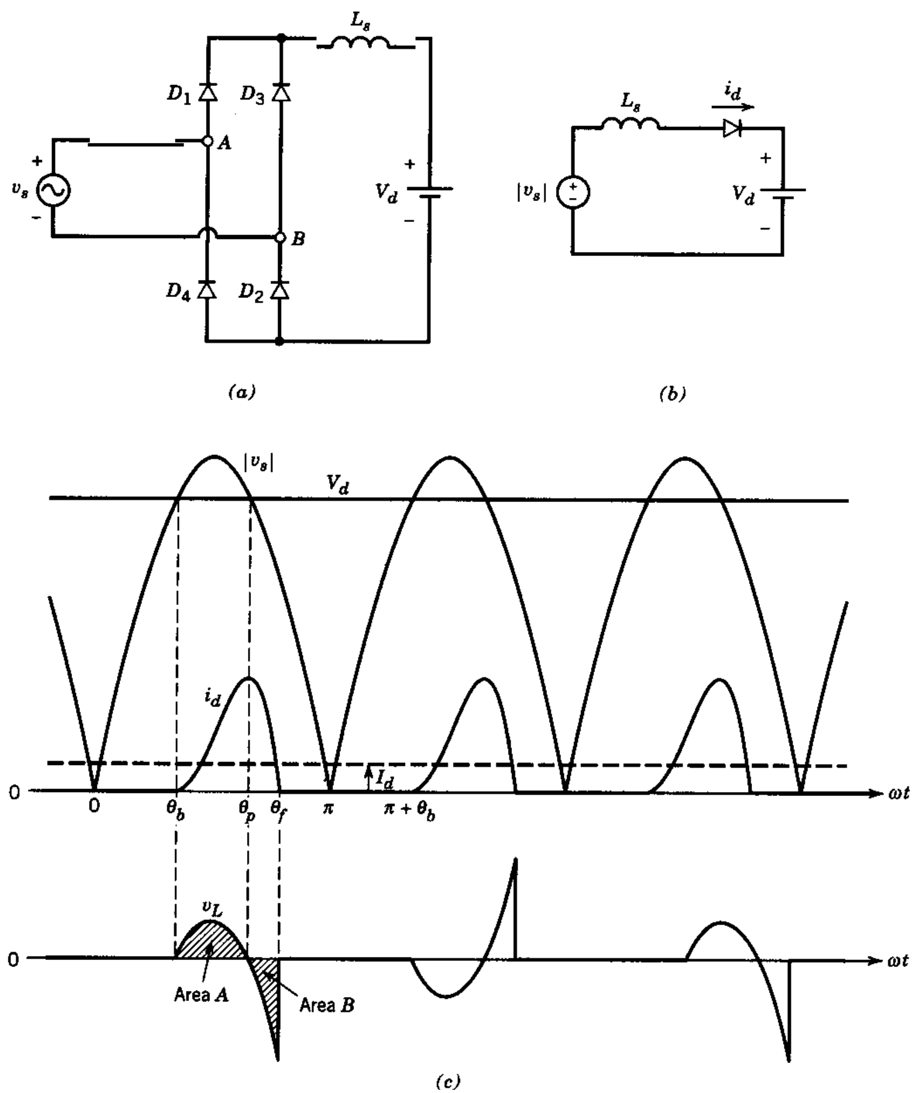
- The choice of the input inductance depends on the required ripple factor . Ripple voltage of a rectifier without filtering:

$$v_{L_n} = \frac{-4V_m}{\pi(n^2-1)} \qquad \text{RF} = \sqrt{2\sum_{n=2,4,8,}\left(\frac{1}{n^2-1}\right)^2}$$

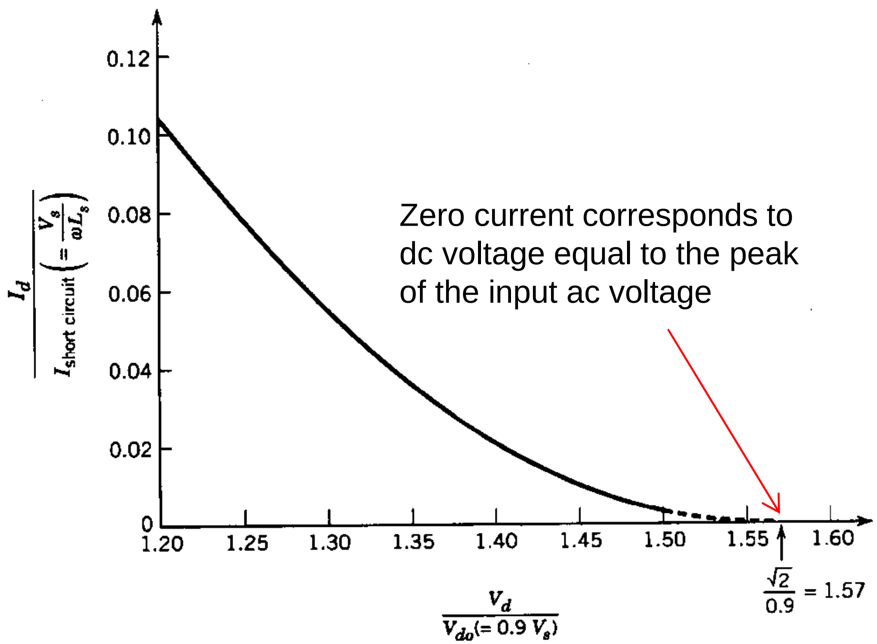
- Considering only the lowest-order harmonic (n = 2), the output ripple factor of a simple inductor-input dc filter is

$$\text{Filtered} \quad \text{RF} = \frac{0.4714}{\sqrt{1+(4\pi f_i L_f/R)^2}}$$

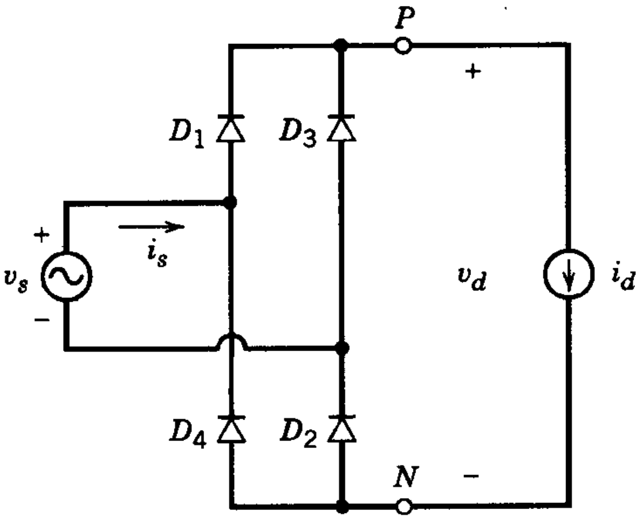
Full Bridge Rectifier with dc-side Voltage

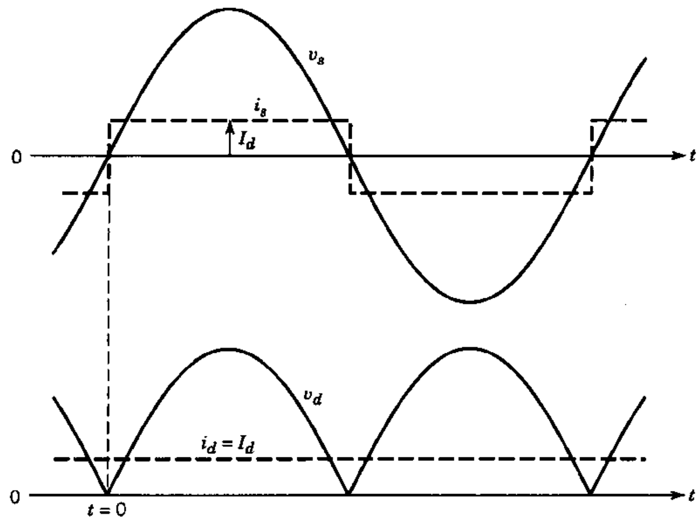


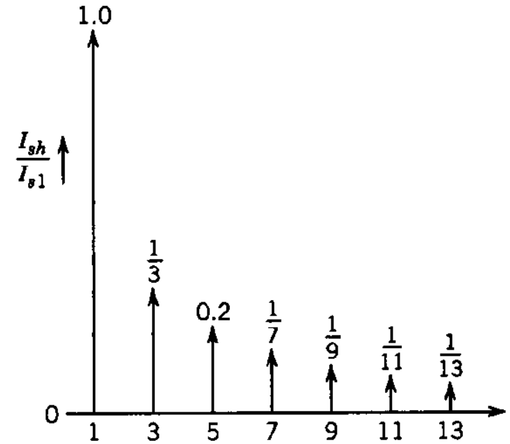
Average value of DC-side current (obtained numerically):



Full Bridge Rectifier – Simple Constant Load Current







RSM value of source current $I_s = I_d$

RMS value of fundamental current $I_{s1} = (2\sqrt{2}/\pi)I_d \approx 0.9 I_d$

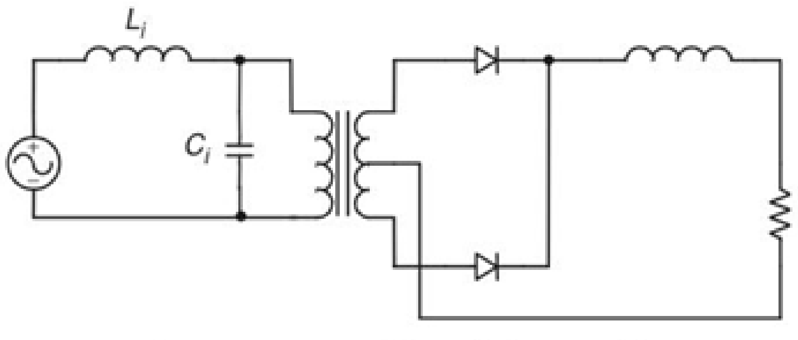
RMS value of harmonic current $I_{sh} = I_{s1}/h, \quad h = 3,5,7,\ldots$

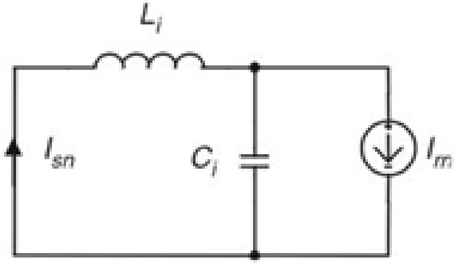
Current THD $THD = 100[\sqrt{(\pi^2/8) - 1}] = 48.43\%$

Displacement Power Factor $DPF = 1$

Power Factor $PF = 0.9$

Full Bridge Rectifier – Simple Constant Load Current (AC-side filtering)





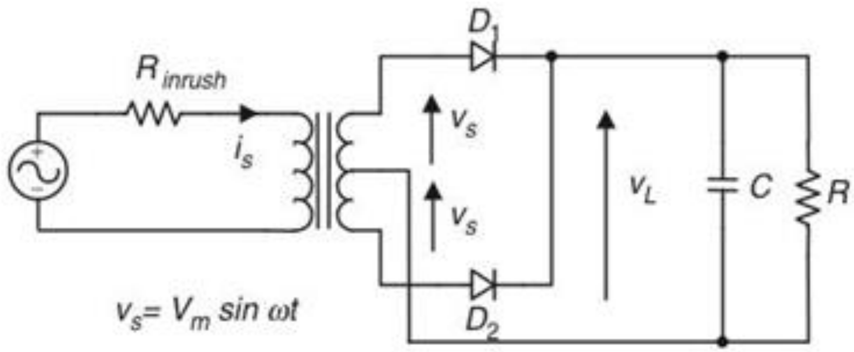
RMS value of harmonic source current

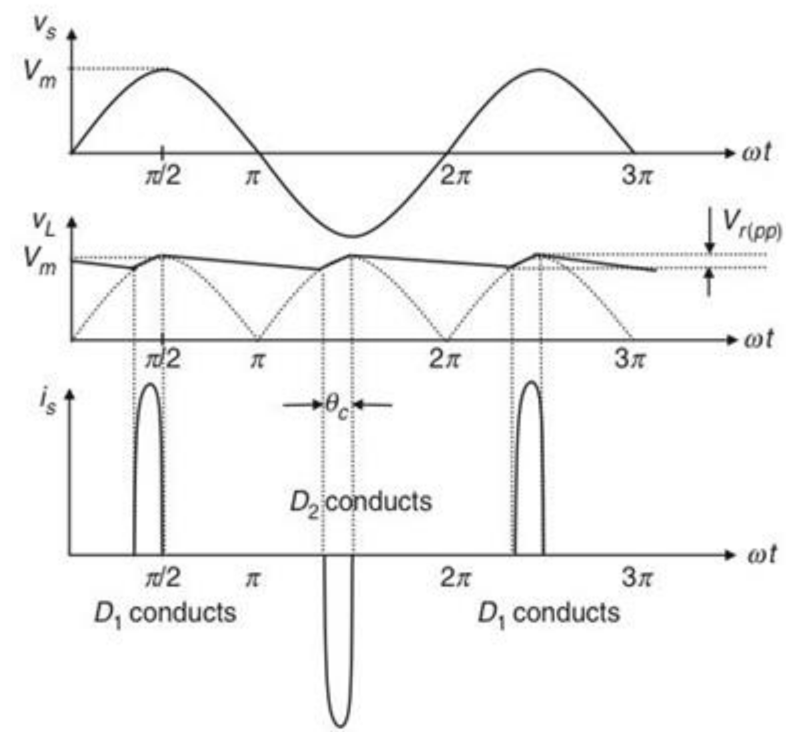
$$I_{sn} = \left| \frac{1}{1 - (2n\pi f_i)^2 L_i C_i} \right| I_{rn}$$

THD of Source Current:

$$\text{THD} = \sqrt{\sum_{n=3,5} \frac{1}{n^2} \left| \frac{1}{1 - (2n\pi f_i)^2 L_i C_i} \right|^2}$$

Diode-Rectifier with a Capacitor Filter





- Approximate value of peak-to-peak ripple:

$$V_{r(pp)} = \frac{V_m}{f_r RC}$$

- Average output voltage:

$$V_{dc} = V_m \left(1 - \frac{1}{2f_r RC}\right)$$

- RMS value of output ripple voltage:

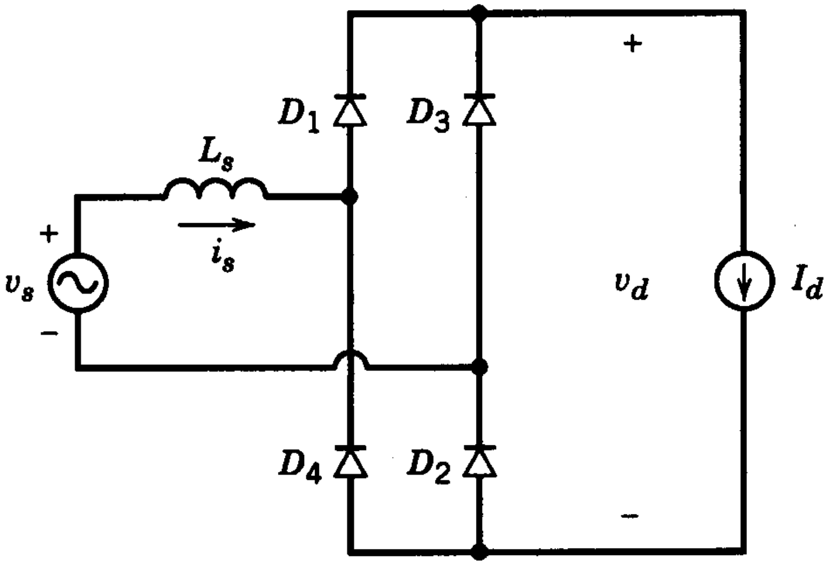
$$V_{ac} = \frac{V_m}{2\sqrt{2} f_r RC}$$

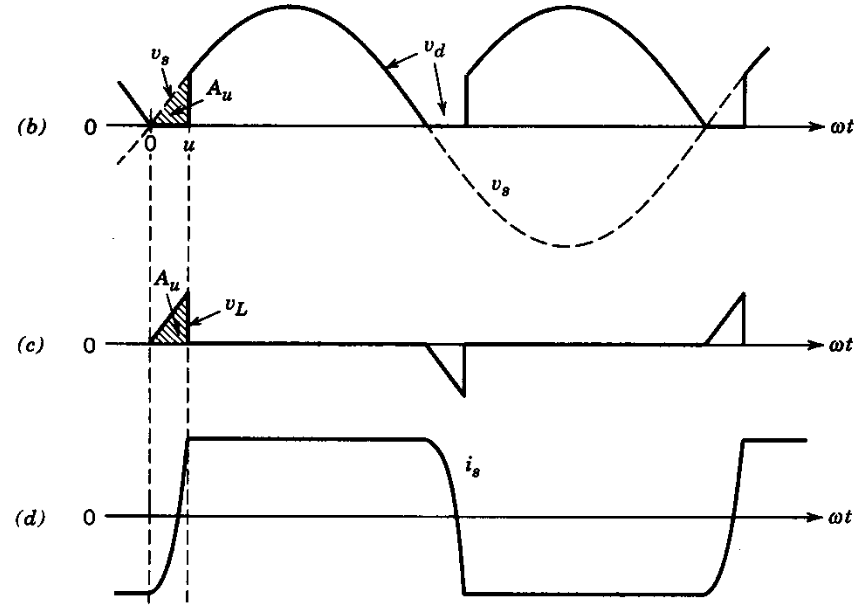
- Ripple Factor:

$$\mathrm{RF} = \frac{1}{\sqrt{2}\,(2f_r RC - 1)}$$

- Inrush resistance R_{inrush} is sometimes needed to limit the initial inrush current to a value below that of the diodes. It is usually placed on the DC side, then shorted out afterwards.
- In many cases, R_{inrush} is not needed if the Equivalent Series Resistance of the capacitor and cable/transformer wire resistance are sufficiently large.

Diode-Rectifier Bridge with AC-Side Inductance

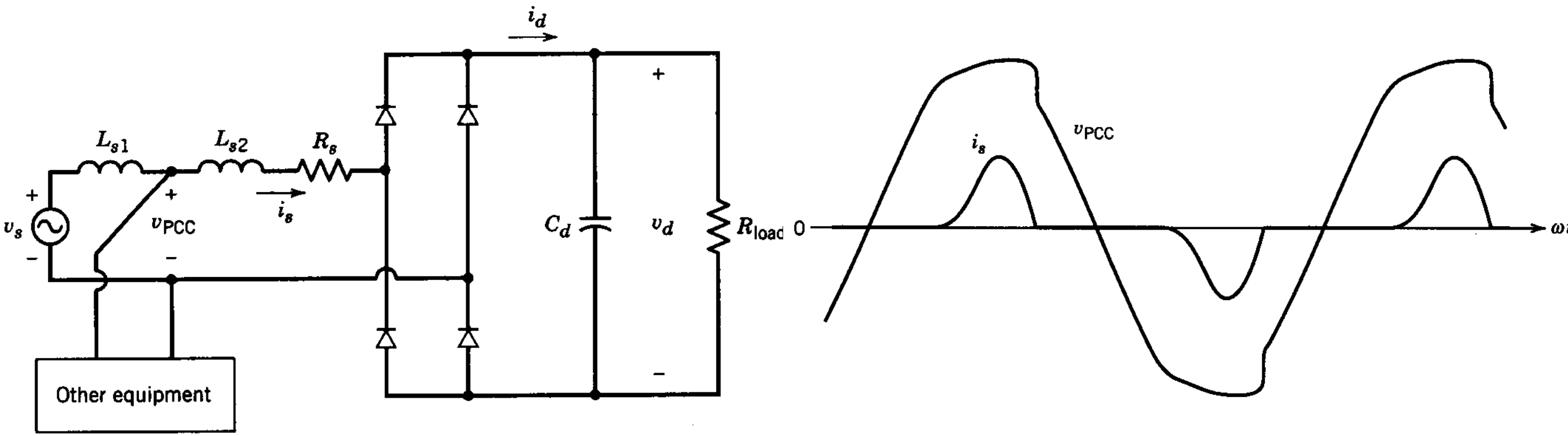




Commutation angle: $$\cos\mu = 1 - \frac{2\omega L_s I_d}{\sqrt{2}V_s}$$

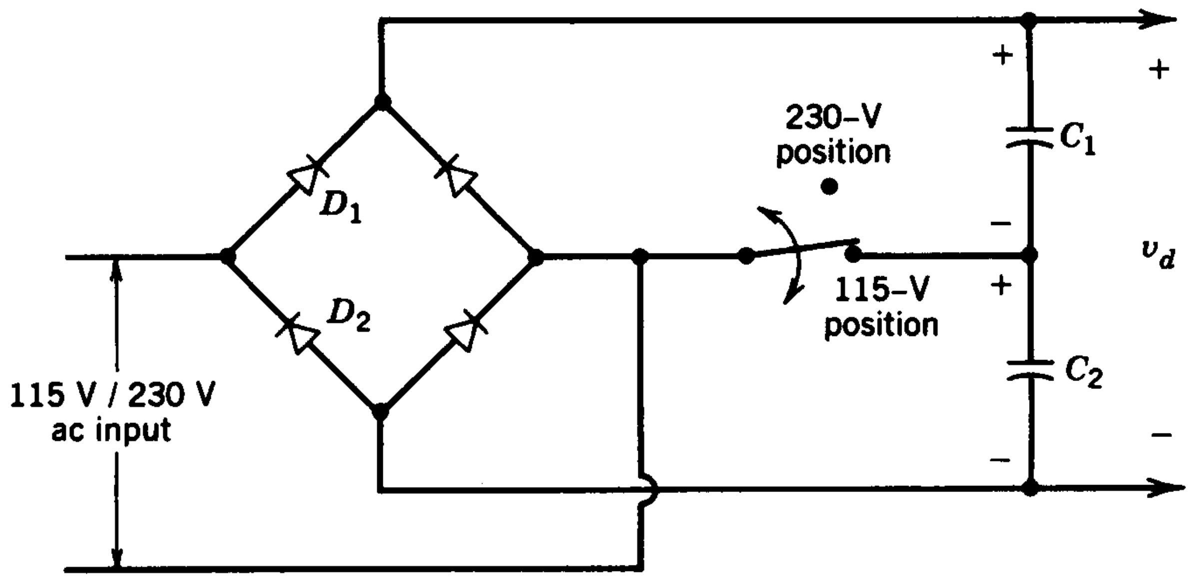
Average of DC-side voltage: $$V_d = 0.9V_s - \frac{2\omega L_s I_d}{\pi}$$

Voltage Distortion at PCC



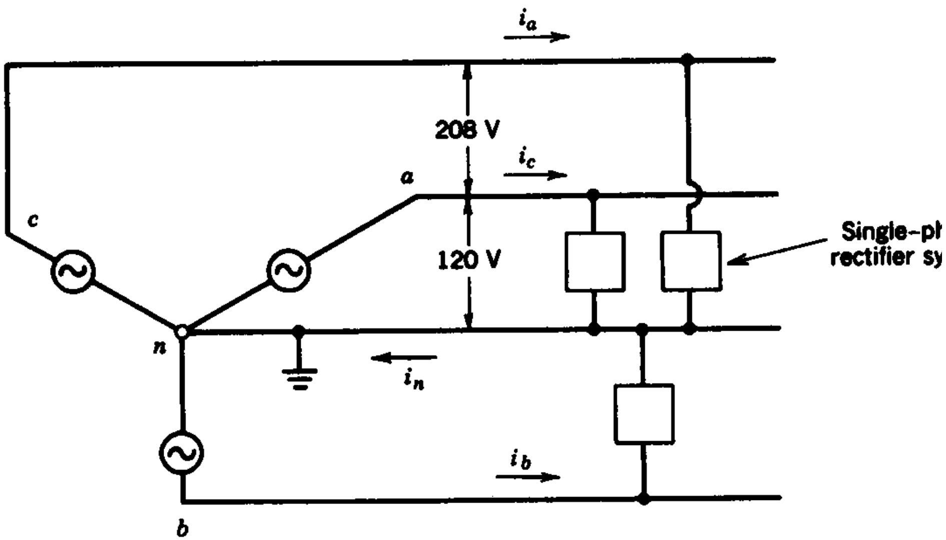
- PCC is the point of common coupling
- Distorted current flow results in distorted voltage

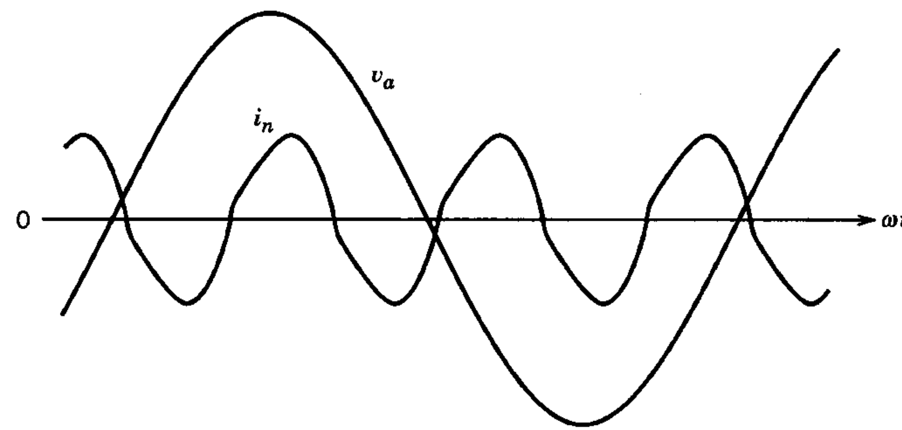
Dual Voltage Rectifier



- In 115-V position, one capacitor at-a-time is charged from the input.

Three-Phase, Four-Wire System

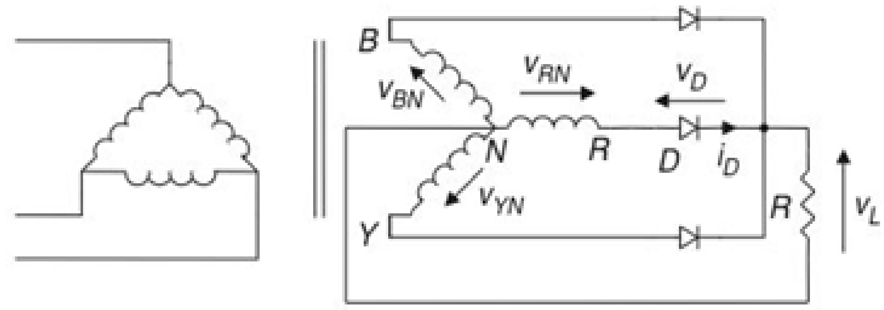




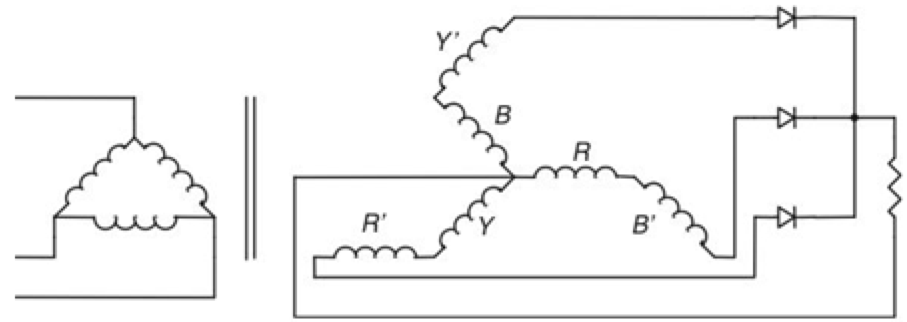
- A common neutral wire is assumed
- The current in the neutral wire is composed mainly of the third harmonic and can be higher than the phase currents

3-Phase Rectifier Circuit

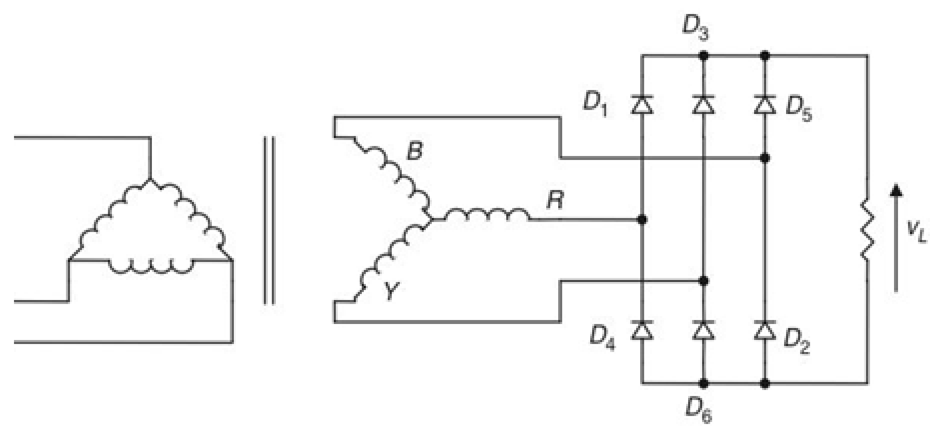
- Star Connection: direct currents in the secondary windings cause transformer core saturation problem.



- The transformer core saturation problem in the three-phase star rectifier can be avoided by zig-zag (or inter-star) connection.



- Three-phase Bridge (or 6-pulse) Rectifier – most commonly used in industry applications.



Three-Phase Bridge Rectifier with R Load

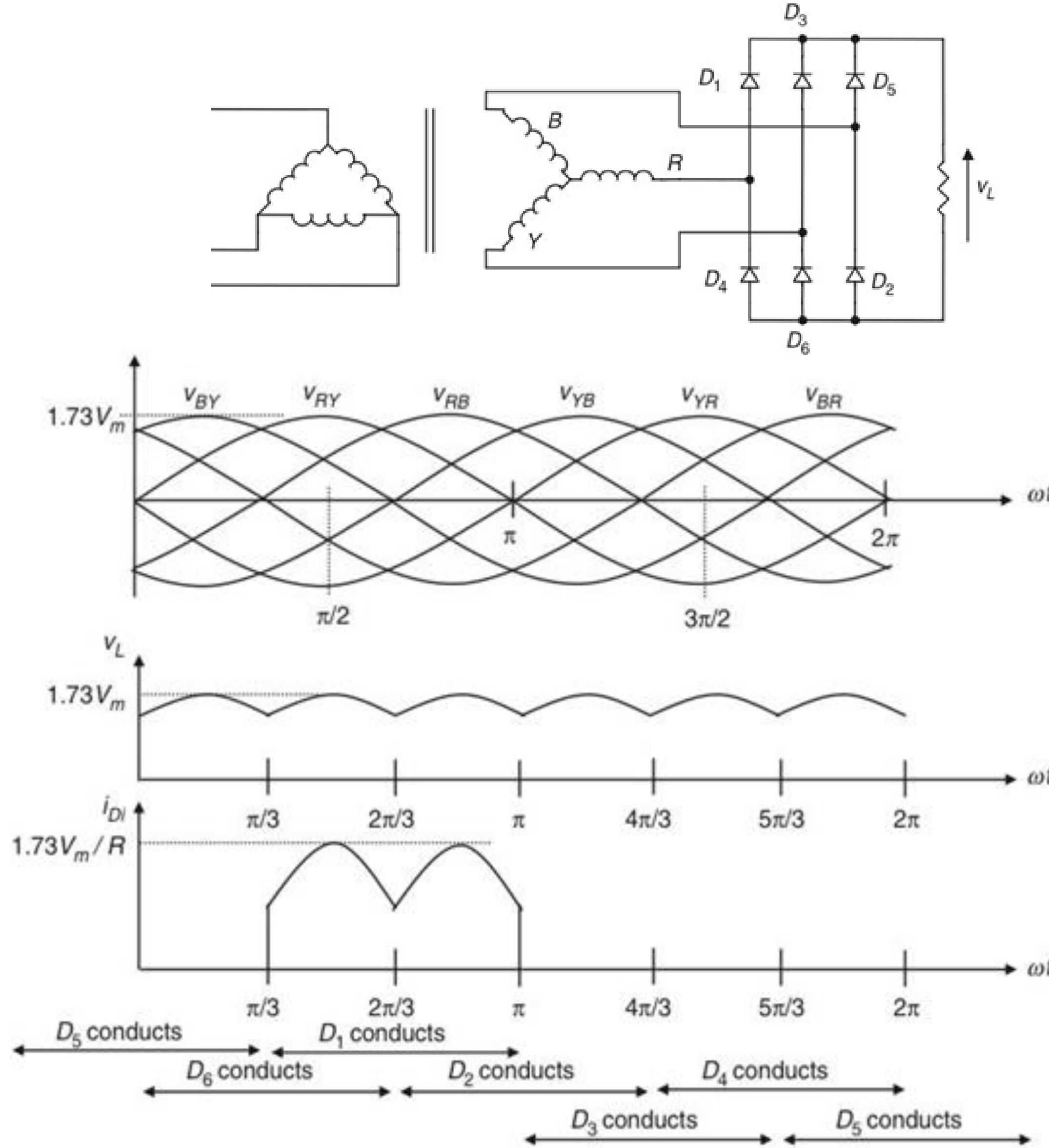
- Average value of DC-side voltage:

$$V_{do} = \frac{3}{\pi}\sqrt{3}V_m = 1.654V_m$$

where V_m is the peak value of the phase voltage.

- RMS value of DC-side voltage:

$$V_{rms} = V_m\sqrt{\frac{3}{2} + \frac{9\sqrt{3}}{4\pi}} = 1.655V_m$$

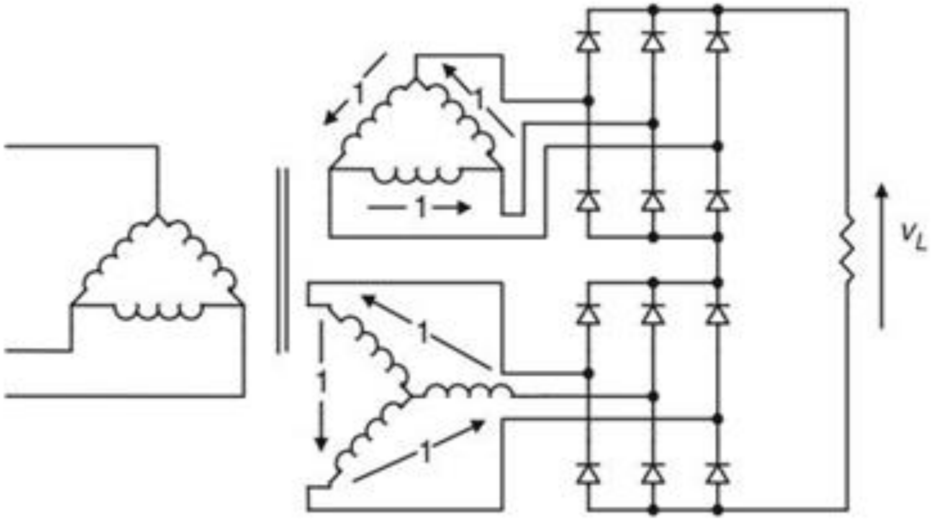


Six-Phase Bridge Rectifier (12-Pulse)

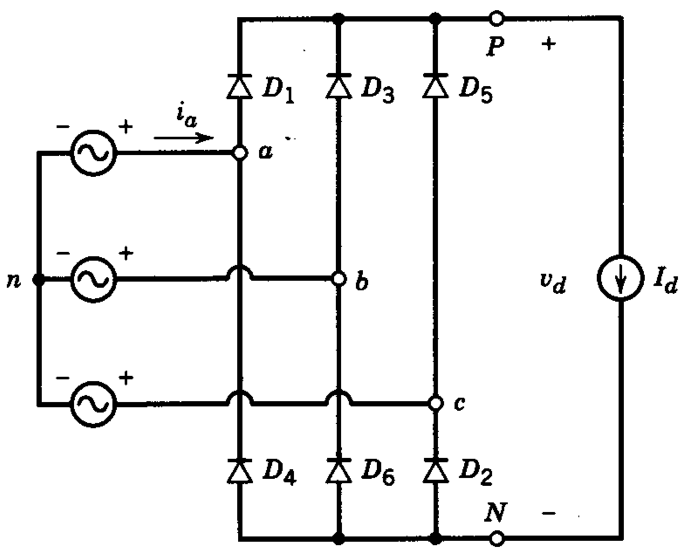
- Average and RMS values of DC-side voltage:

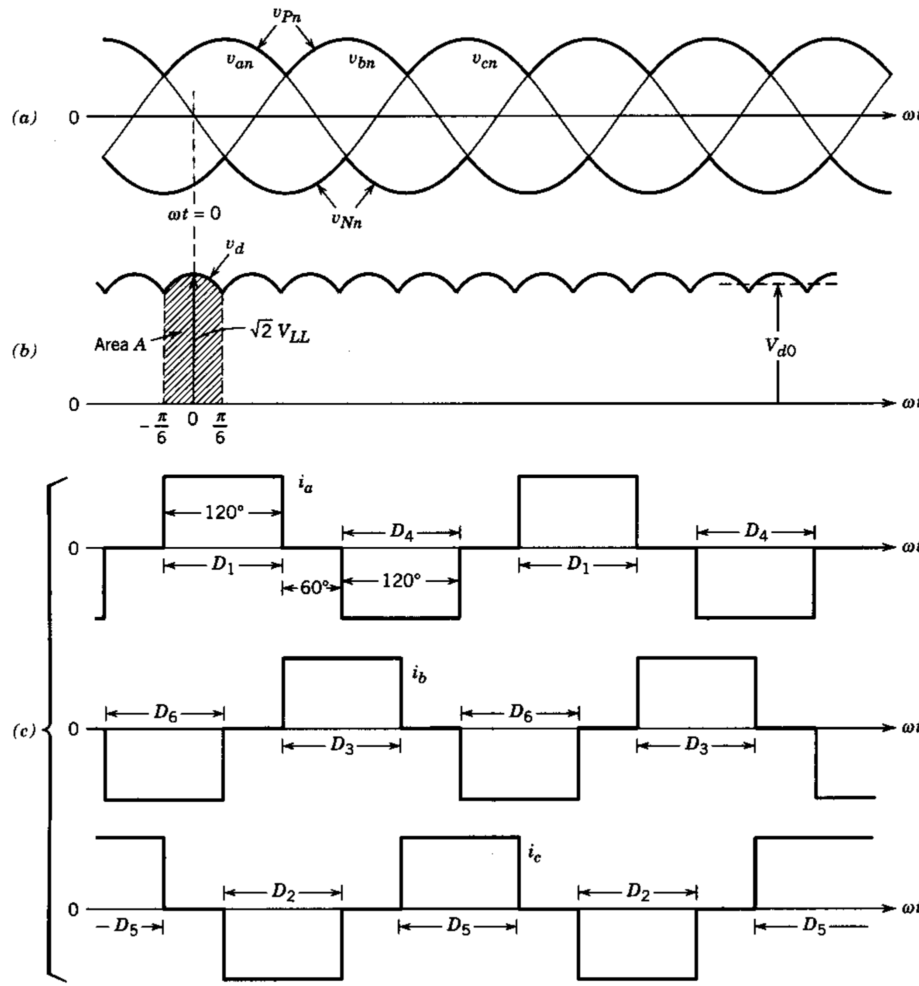
$$V_{do} \approx V_{rms} \approx 1.712 V_m$$

where V_m is the peak value of the phase voltage.

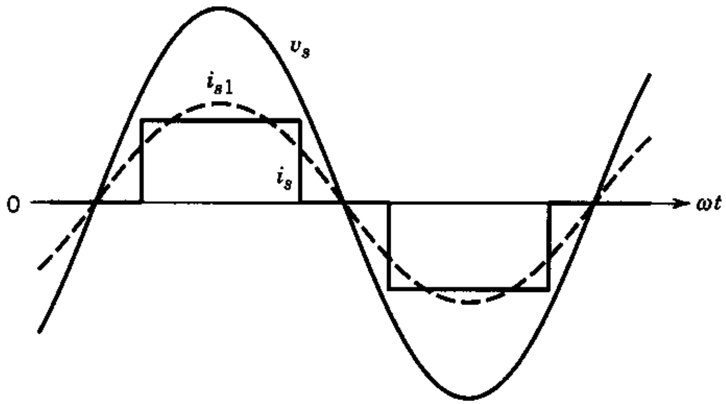


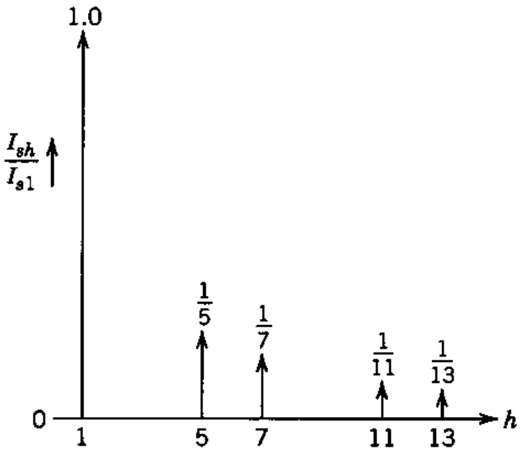
Three-Phase Full-Bridge Rectifier with DC Current





Three-Phase, Full-Bridge Rectifier with DC Current





RSM value of source current $I_s = \sqrt{2/3}I_d = 0.816I_d$

RMS value of fundamental current $I_{s1} = (\sqrt{6}/\pi)I_d \approx 0.78I_d$

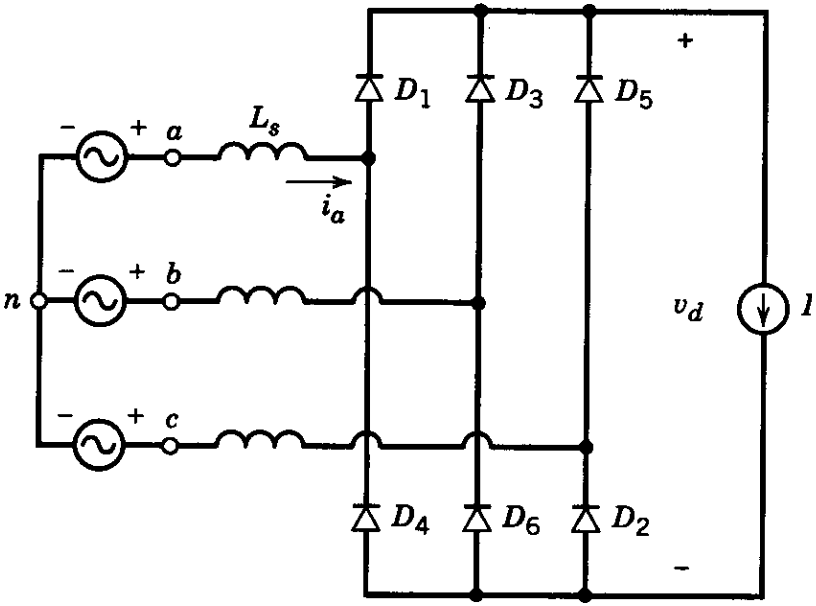
RMS value of harmonic current $I_{sh} = I_{s1}/h, \quad h = 3,5,7,...$

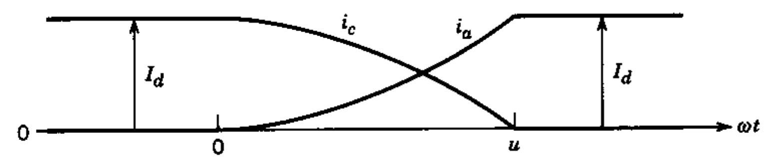
Current THD $THD = 100[\sqrt{(\pi^2/9)-1}] = 31\%$

Displacement Power Factor $DPF = 1$

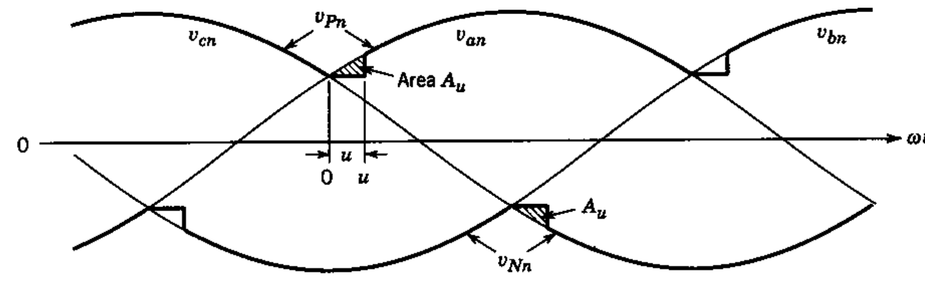
Power Factor $PF = \frac{3}{\pi} = 0.955$

3-Phase, Full-Bridge Rectifier with Inductance





(b)

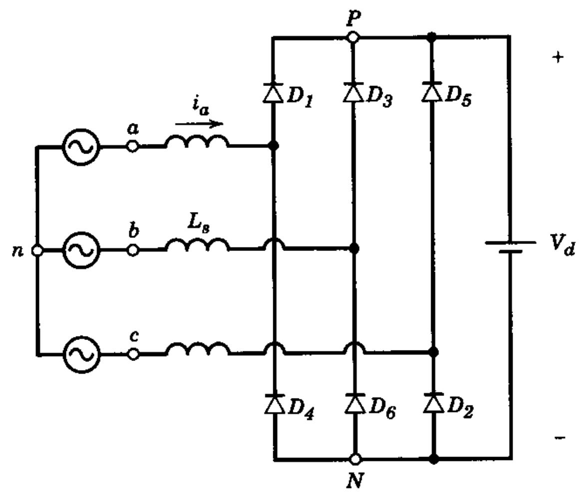


(c)

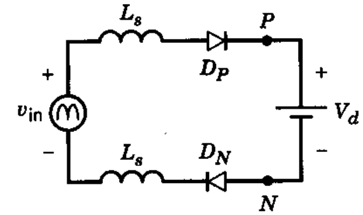
Commutation angle: $\cos\mu = 1 - \dfrac{2\omega L_s I_d}{\sqrt{2}V_{LL}}$

Average of DC-side voltage: $V_d = 1.35V_{LL} - \dfrac{3\omega L_s I_d}{\pi}$

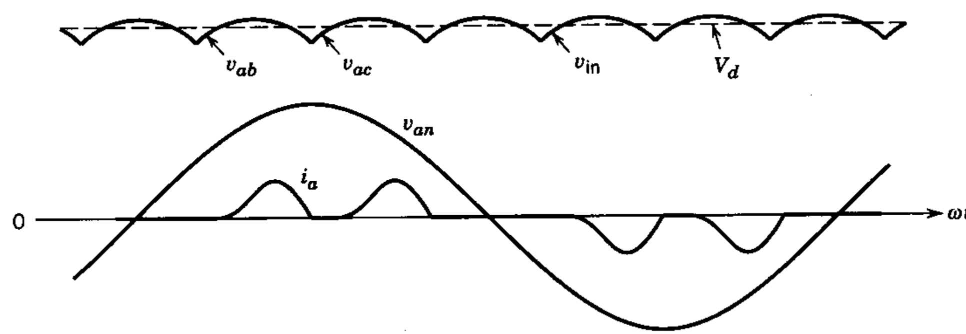
3-Phase Rectifier with DC Source



(a)

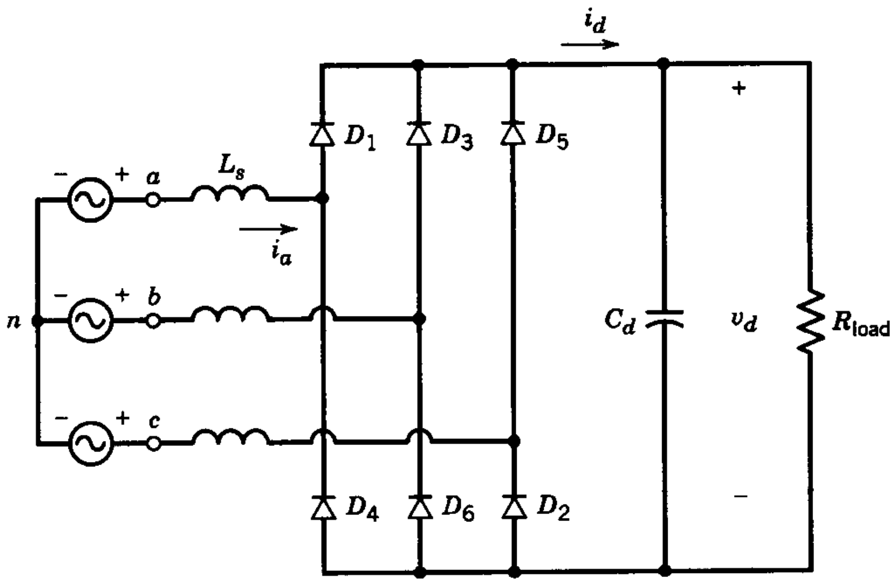


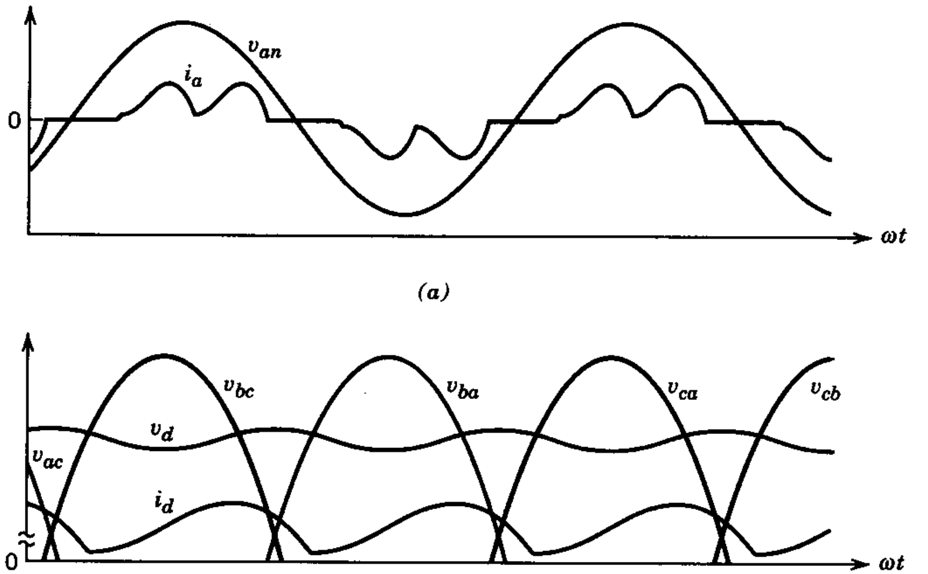
(b)



(c)

Three-Phase Rectifier with Capacitor Filter





- PSpice-based analysis