ELK 331E/331

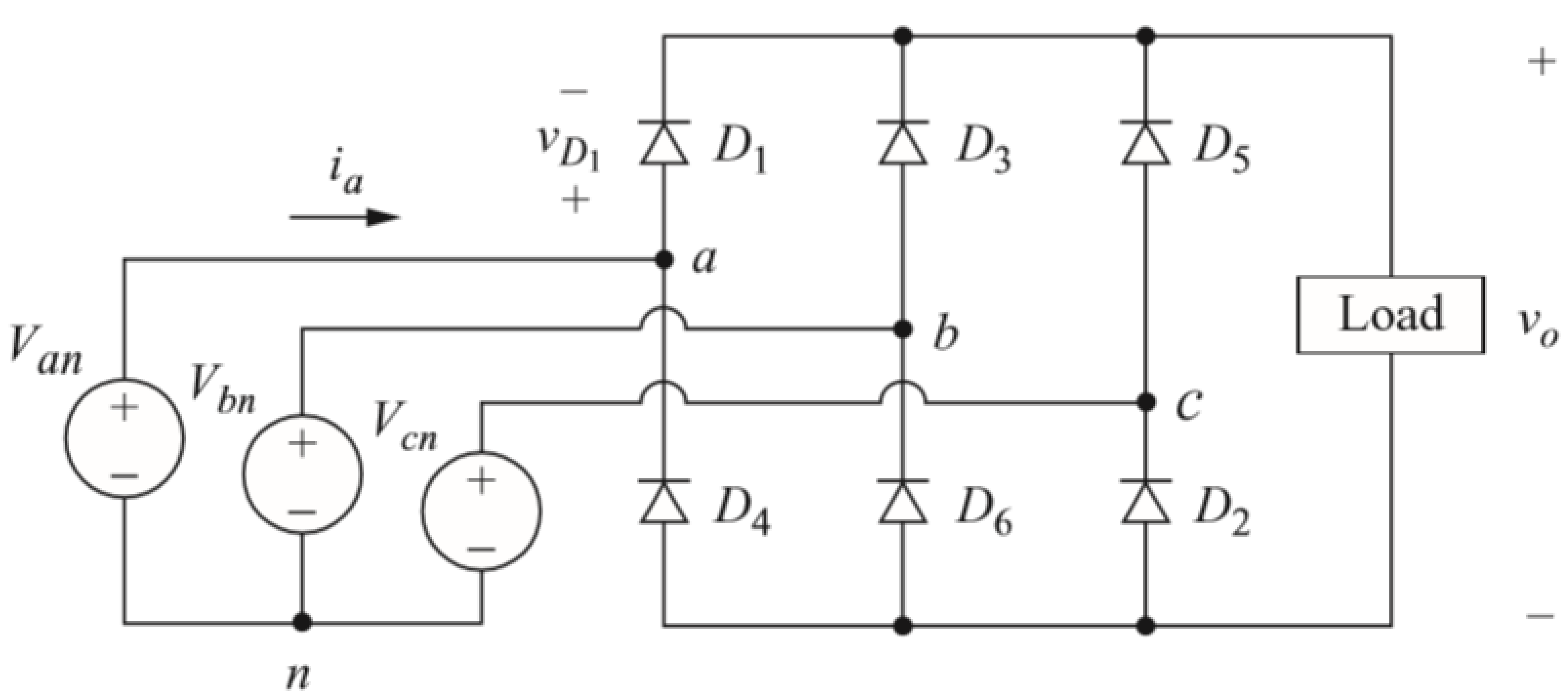
Power Electronic Circuits/Güç Elektroniği Devreleri

The Three Phase Full-Wave Uncontrolled Rectifier

Üç Fazlı Tam Dalga Kontrolsüz Doğrultucular

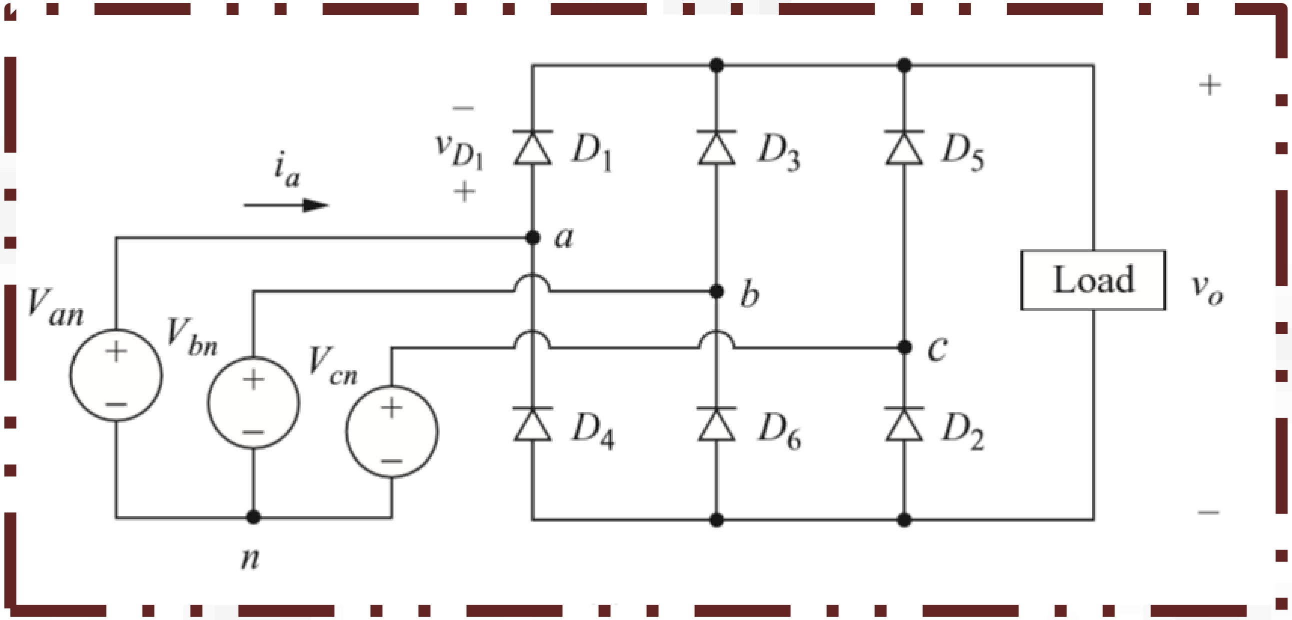
Assoc. Prof. Dr. Mehmet Onur GÜLBAHÇE

Uncontrolled Three-phase Full-wave Rectifier



Three-phase rectifiers are commonly used in industry to produce a dc voltage and current for large loads.

Uncontrolled Three-phase Full-wave Rectifier



- Diode 1, 3 and 5, whichever has a more positive voltage at its anode, conducts.

- Similarly, diode 2, 4 and 6, whichever has a more negative voltage at its cathode, returns the load current.

- With the numbering of diodes as indicated above, the conduction patterns is 12-23-34-45-56-61-12 for a positive voltage sequence a-b-c.

- For the negative voltage sequence a-c-b, the pattern is 16-65-54-43-32-21-16.

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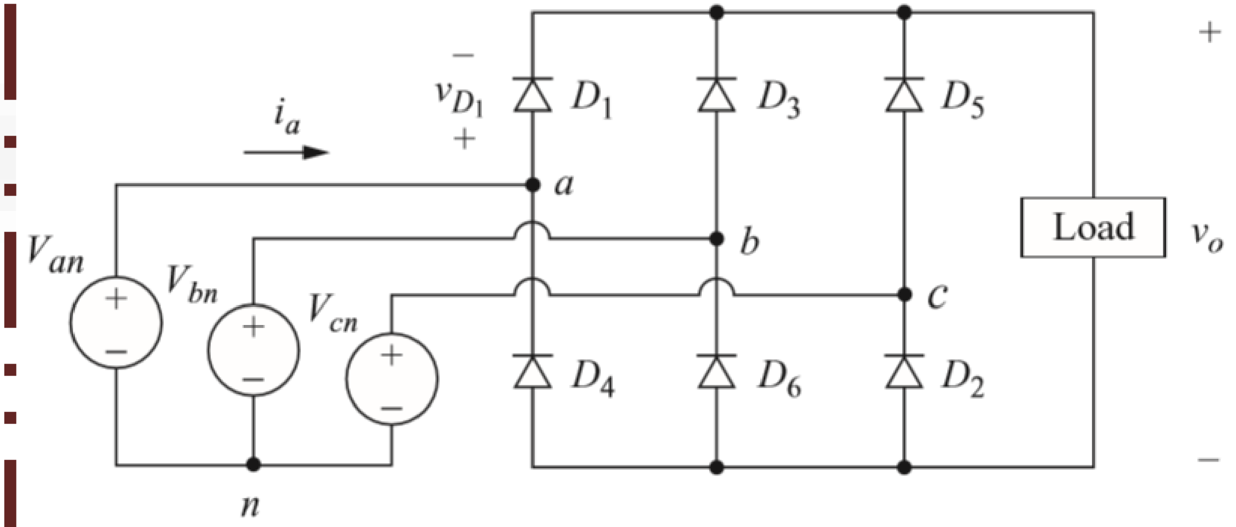
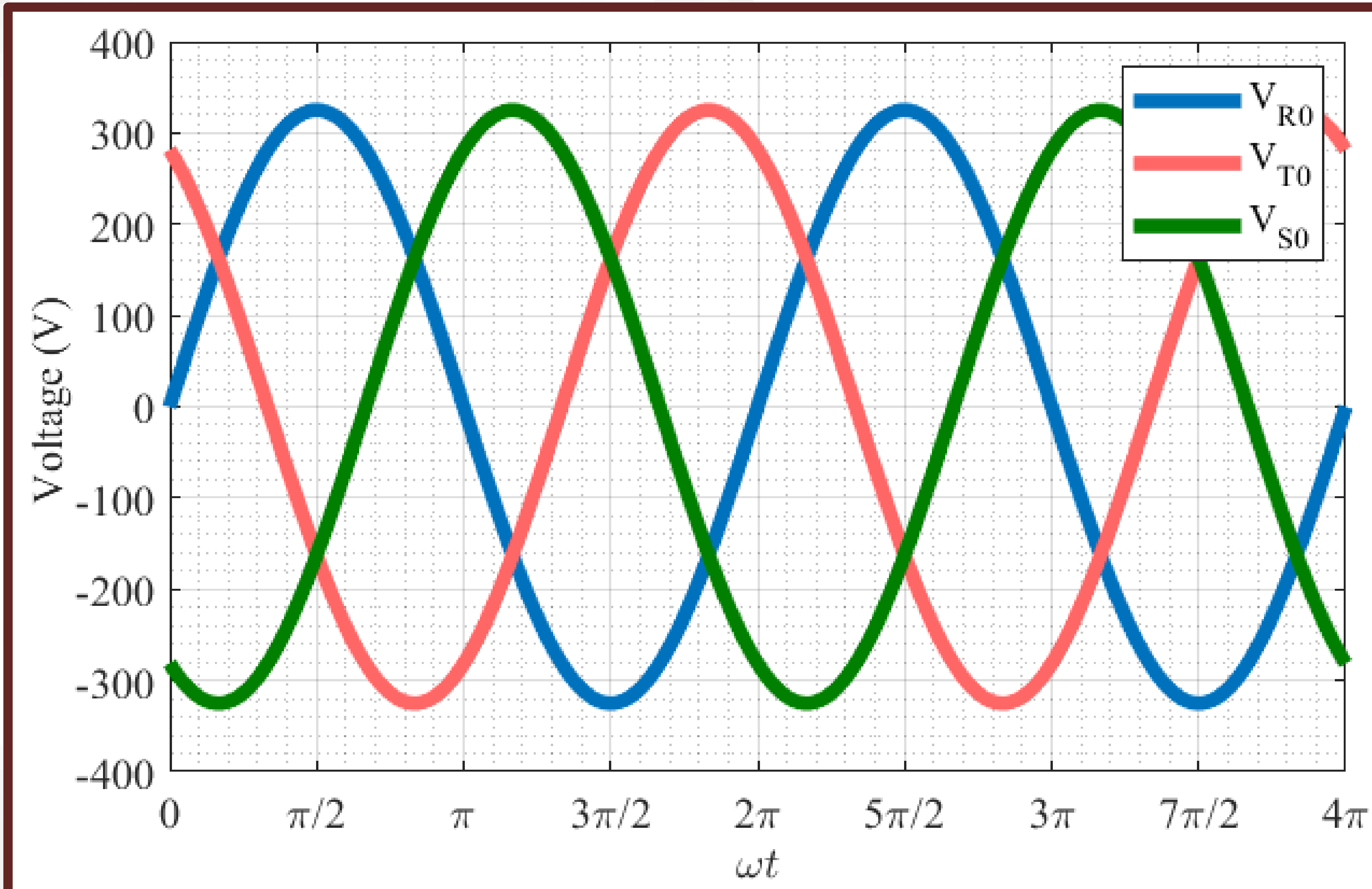


- Assuming that the load current is continuous (i.e., non zero) at all times,
- Each diode conducts for 120° in each cycle of the ac waveform, followed by 240° of non conduction.
- The supply current is bipolar, conducting for 120° in each half cycle, followed by 60° of non conduction.
- Clearly, there is no dc component in the supply current to the rectifier.

Uncontrolled Three-phase Full-wave Rectifier



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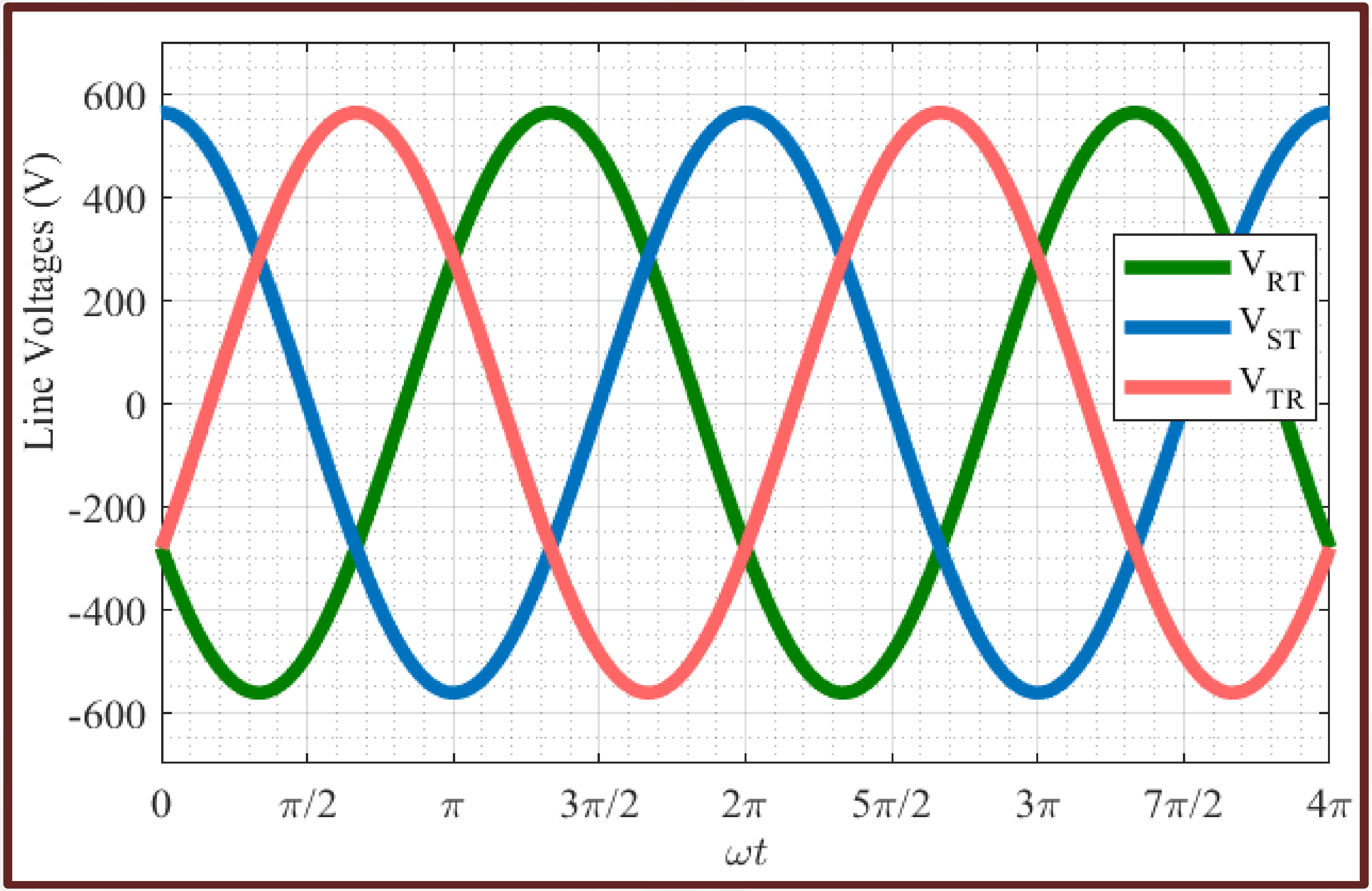

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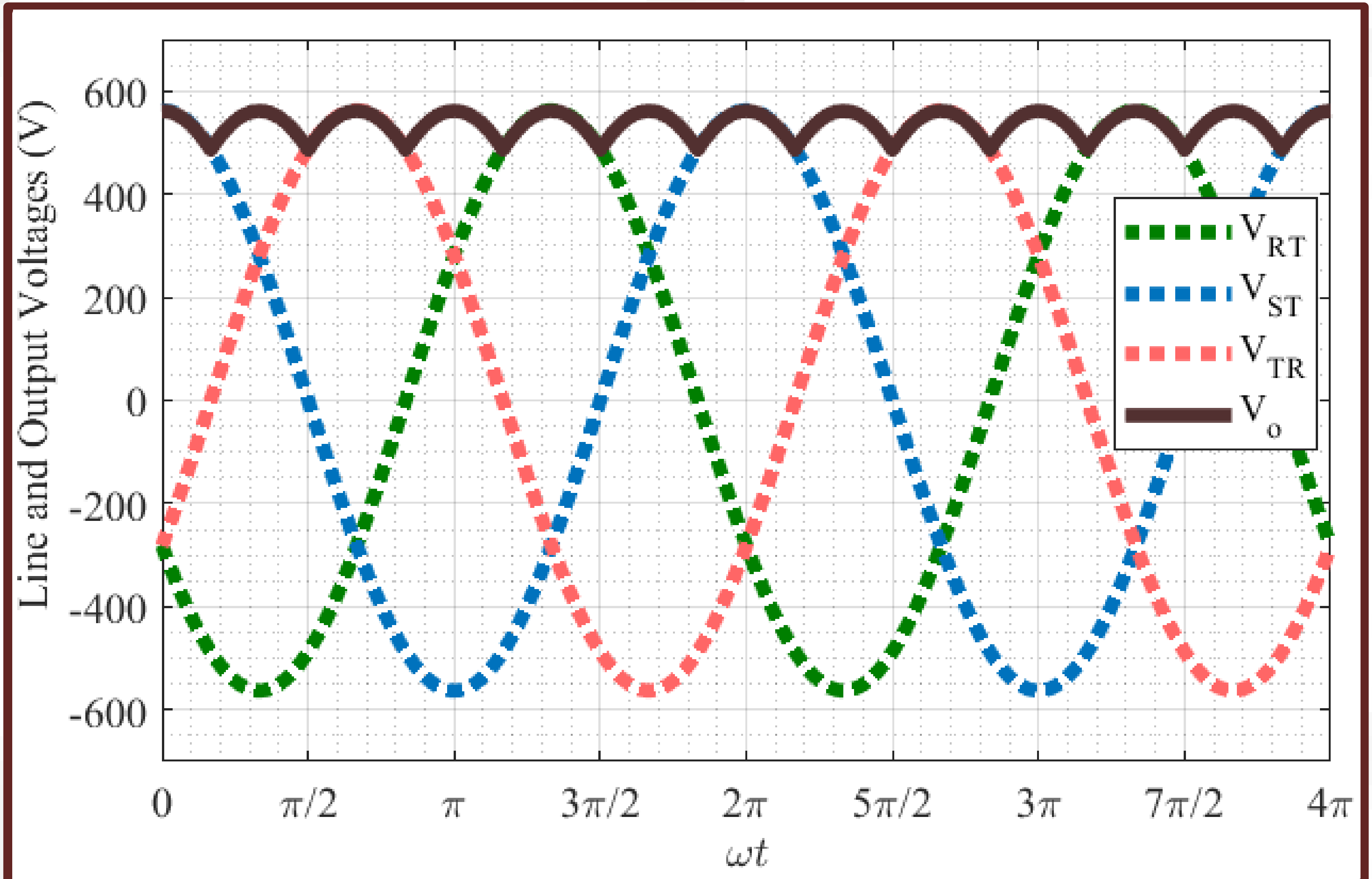

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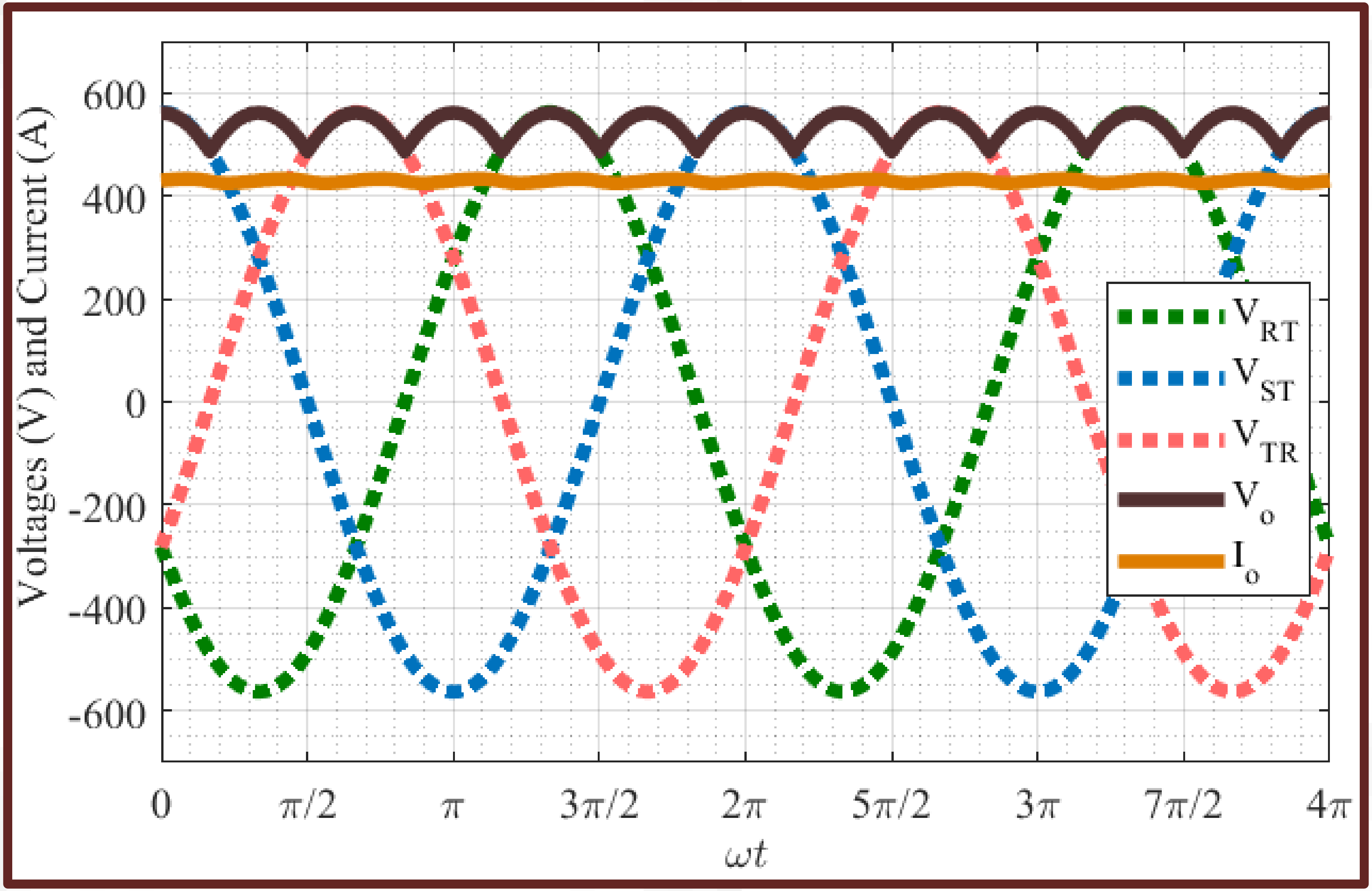
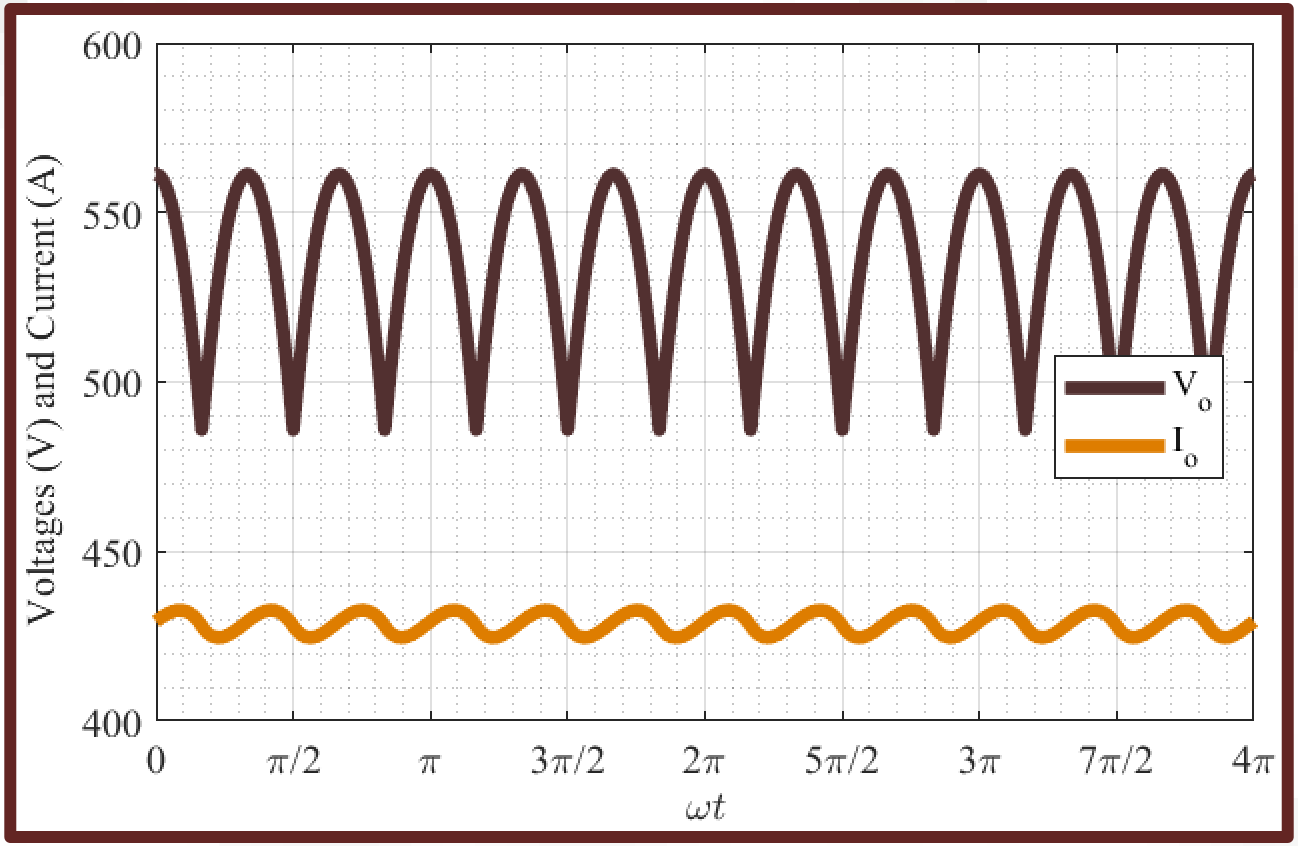


Uncontrolled Three-phase Full-wave Rectifier

- There are six combinations of line-to-line voltages (three phases taken two at a time).
- Considering one period of the source to be 360°, a transition of the highest line-to-line voltage must take place every 360 ° /6 =60 °.
- Because of the six transitions that occur for each period of the source voltage, the circuit is called a six-pulse rectifier.
- The fundamental frequency of the output voltage is 6, where is the frequency of the three-phase source.

Uncontrolled Three-phase Full-wave Rectifier



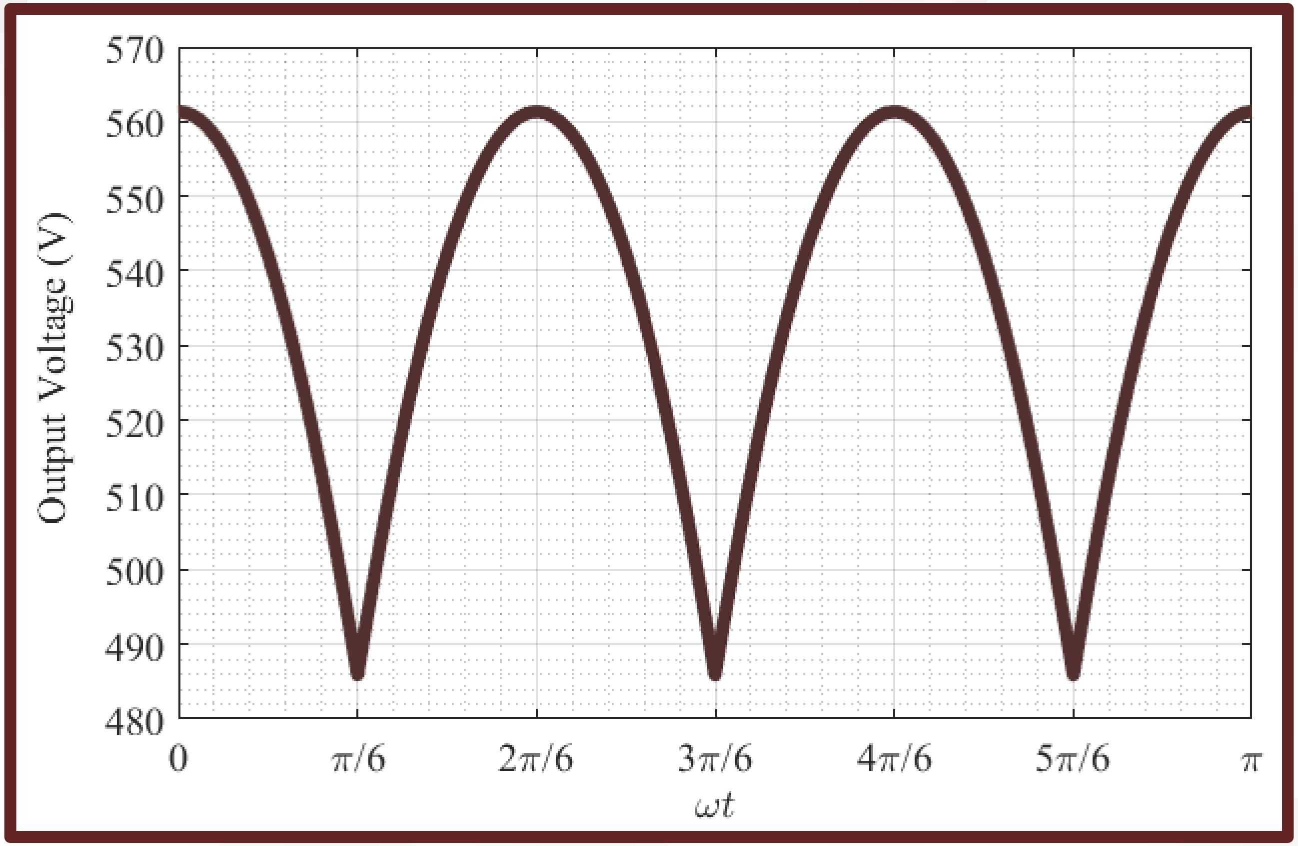
$$V_{R0} = V_m \sin(\omega t)$$

$$V_{S0} = V_m \sin(\omega t - \frac{2\pi}{3})$$

$$V_{T0} = V_m \sin(\omega t - \frac{4\pi}{3})$$

$$V_{o\,(AVG)} = \frac{1}{\pi/3} \int_{-\frac{\pi}{6}}^{\frac{\pi}{6}} V_{m,L-L} \cos(\omega t)\, d(\omega t) = \frac{3V_{m,L-L}}{\pi} = \frac{3\sqrt{3}V_m}{\pi}$$

Uncontrolled Three-phase Full-wave Rectifier



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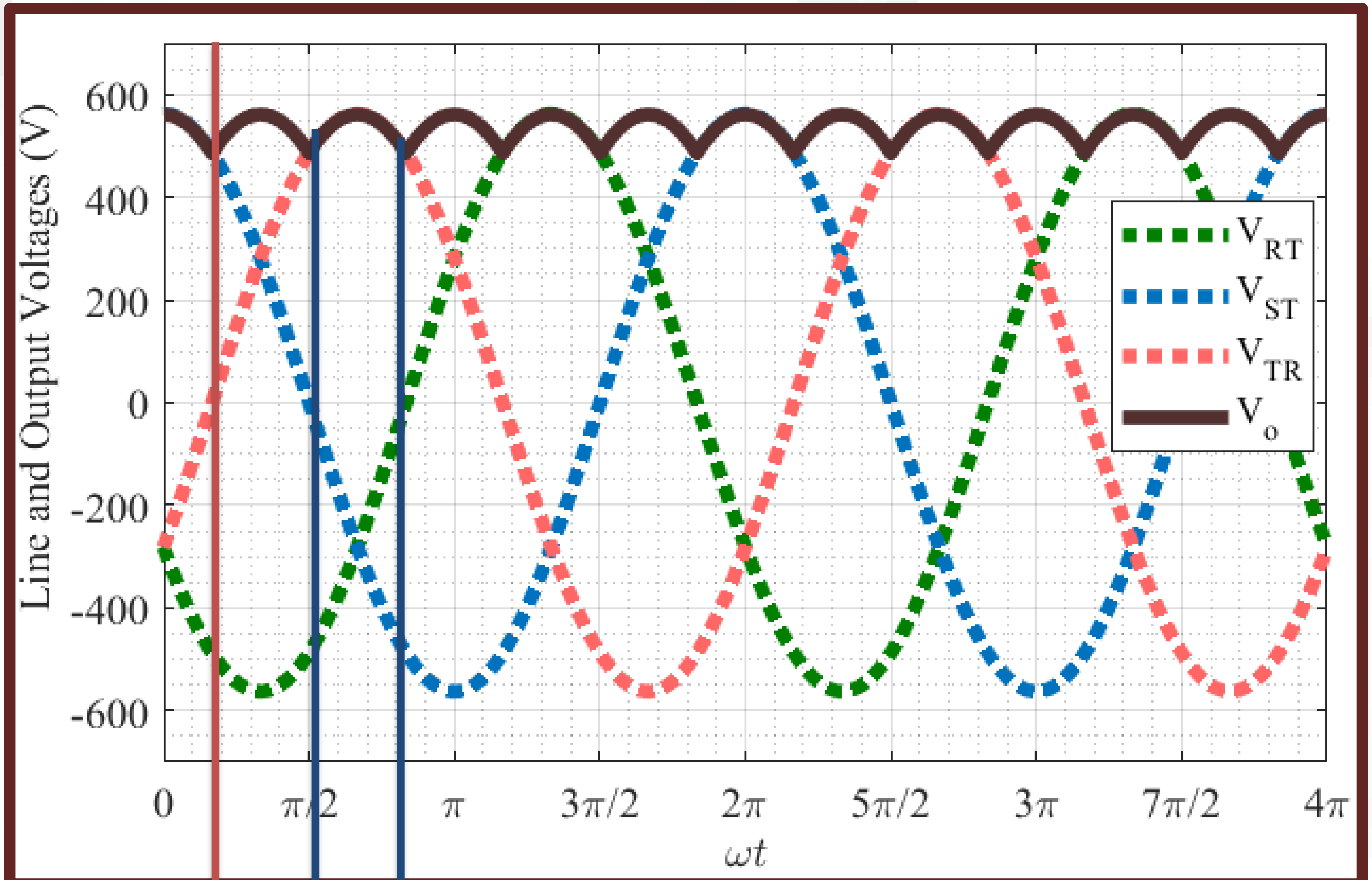
Uncontrolled Three-phase Full-wave Rectifier



ωt=2π/3

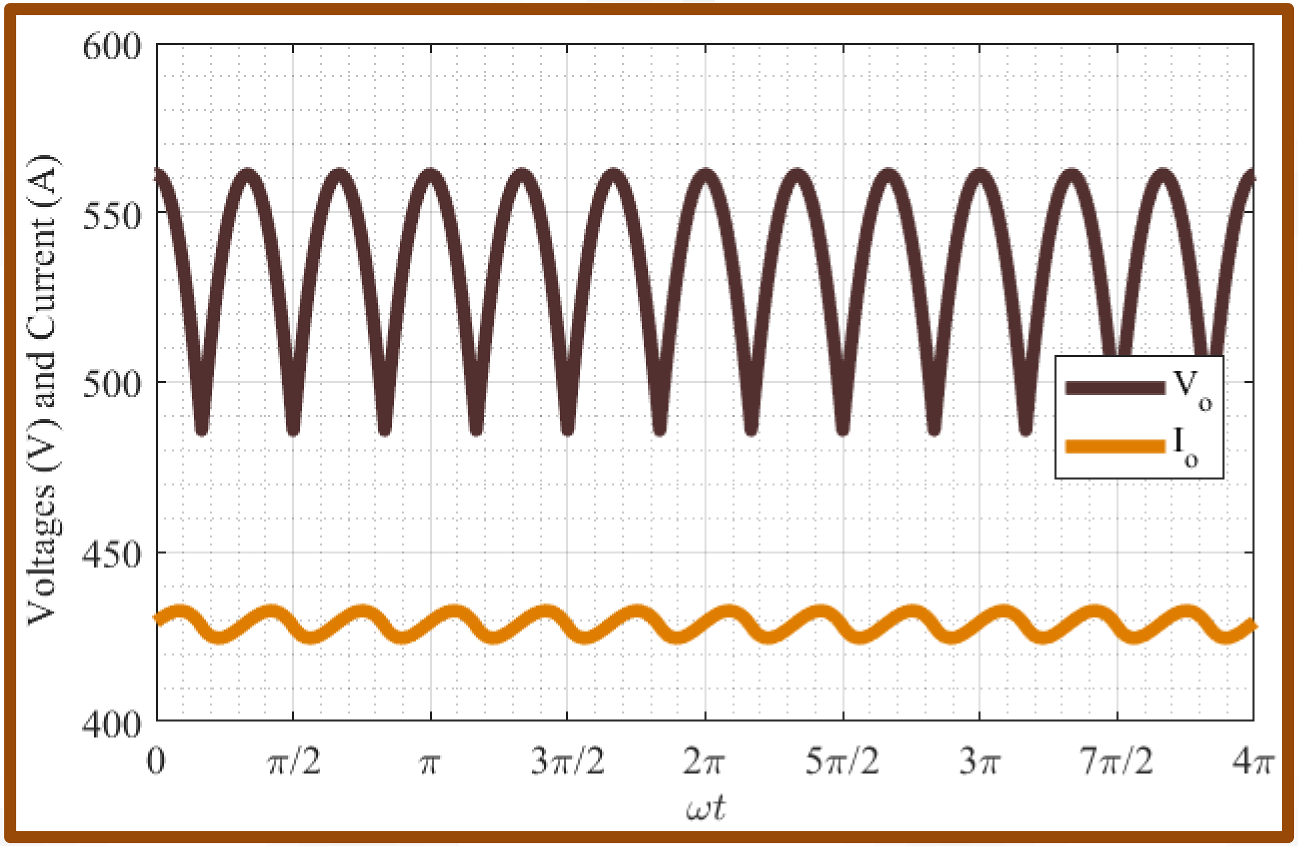
ωt=0

ωt=π/3

$$V_{o\,(AVG)} = \frac{1}{\pi/3}\int_{\frac{\pi}{3}}^{\frac{2\pi}{3}} V_{m,L-L}\sin(\omega t)\,d(\omega t) = \frac{3V_{m,L-L}}{\pi} = \frac{3\sqrt{3}V_m}{\pi}$$

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

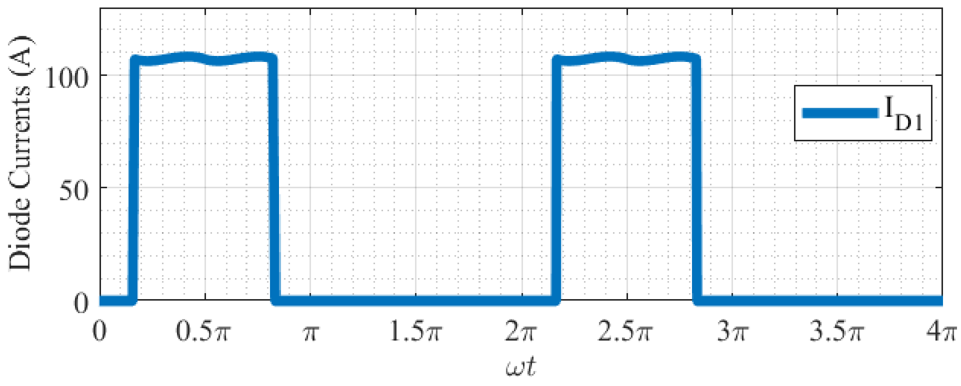
Uncontrolled Three-phase Half-wave Rectifier

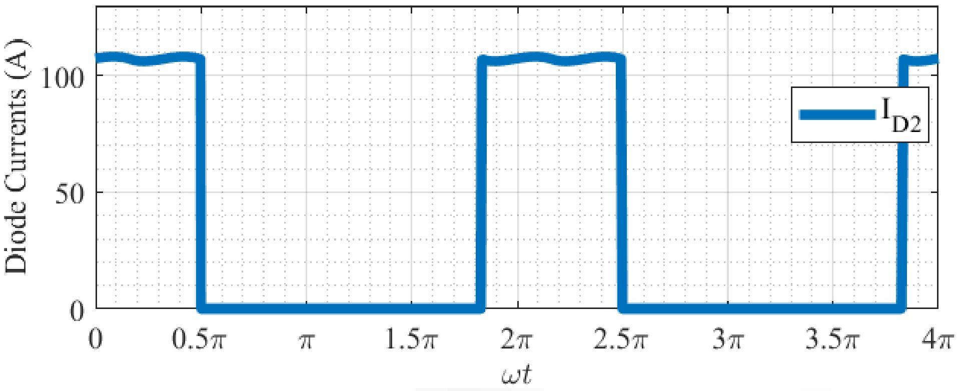


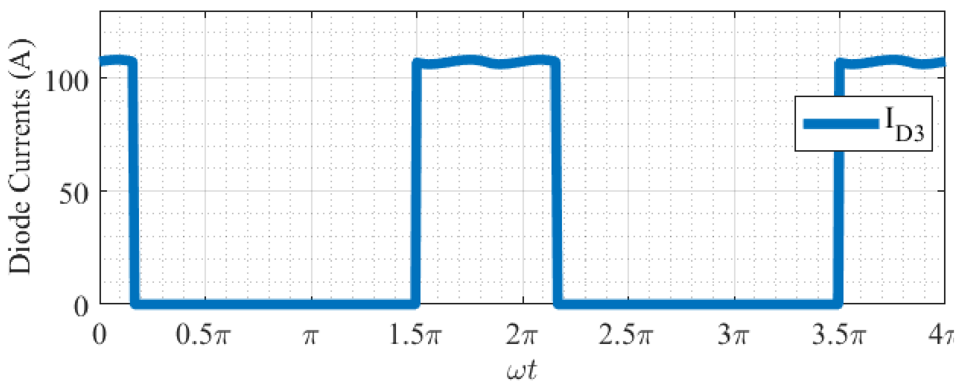
$$V_{o\,(RMS)} = \sqrt{\frac{1}{\pi/3}\int_{\frac{\pi}{3}}^{\frac{2\pi}{3}} (V_{m,L-L}\sin(\omega t))^2\, d(\omega t)} = 1.655V_m$$

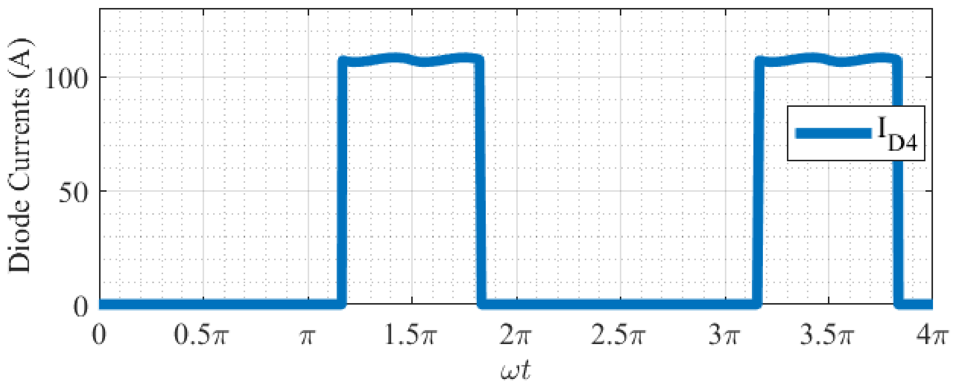
$$I_{o\,(AVG)} = \frac{V_{o(AVG)}}{R}$$

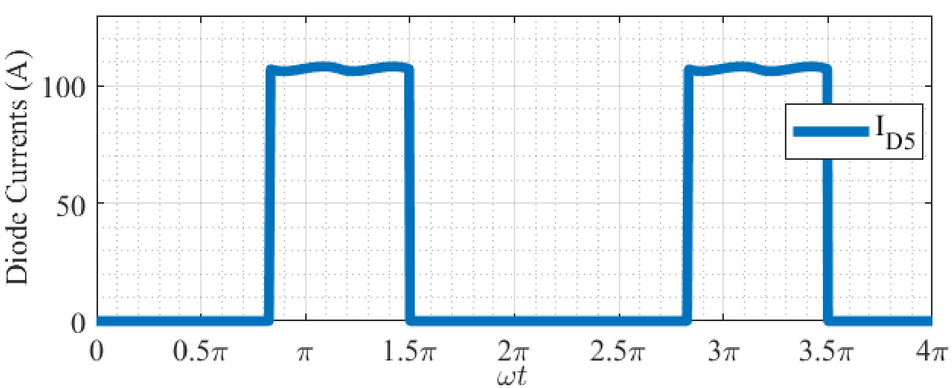
Diode Currents

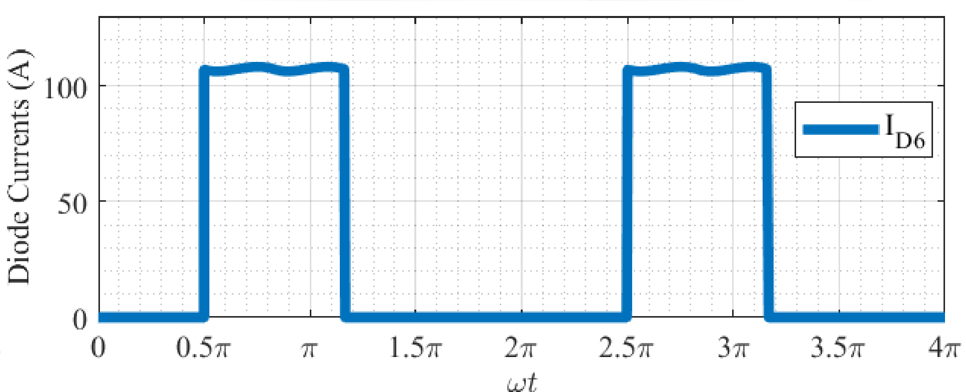




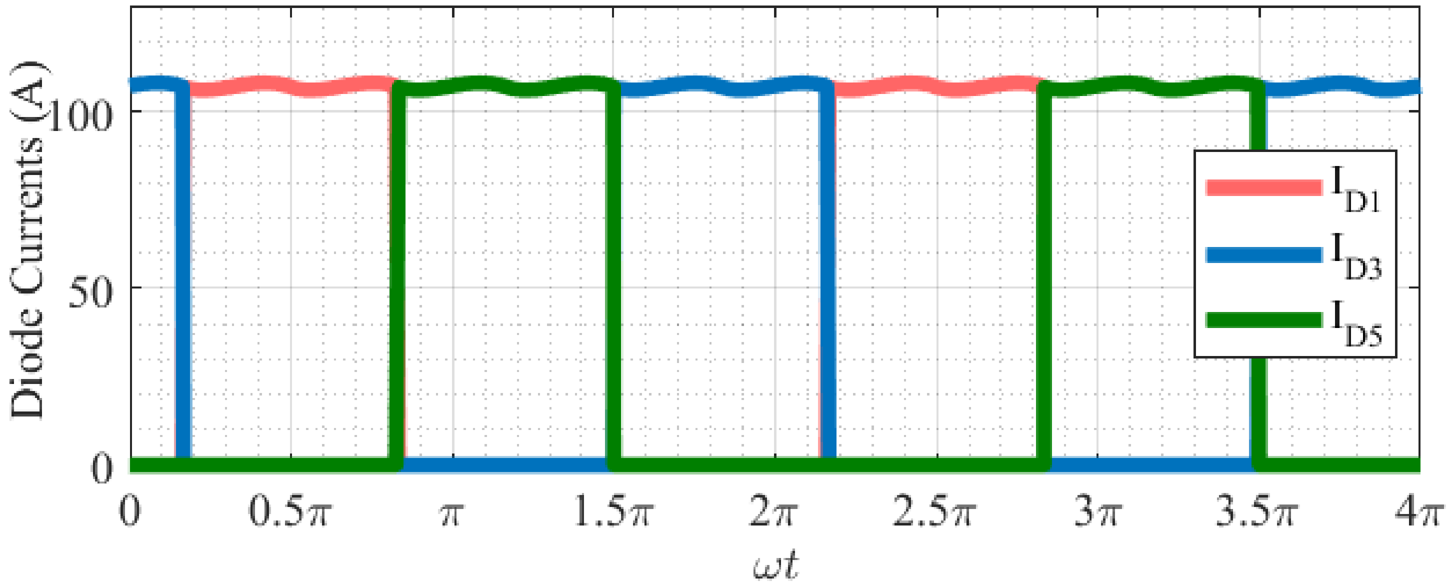


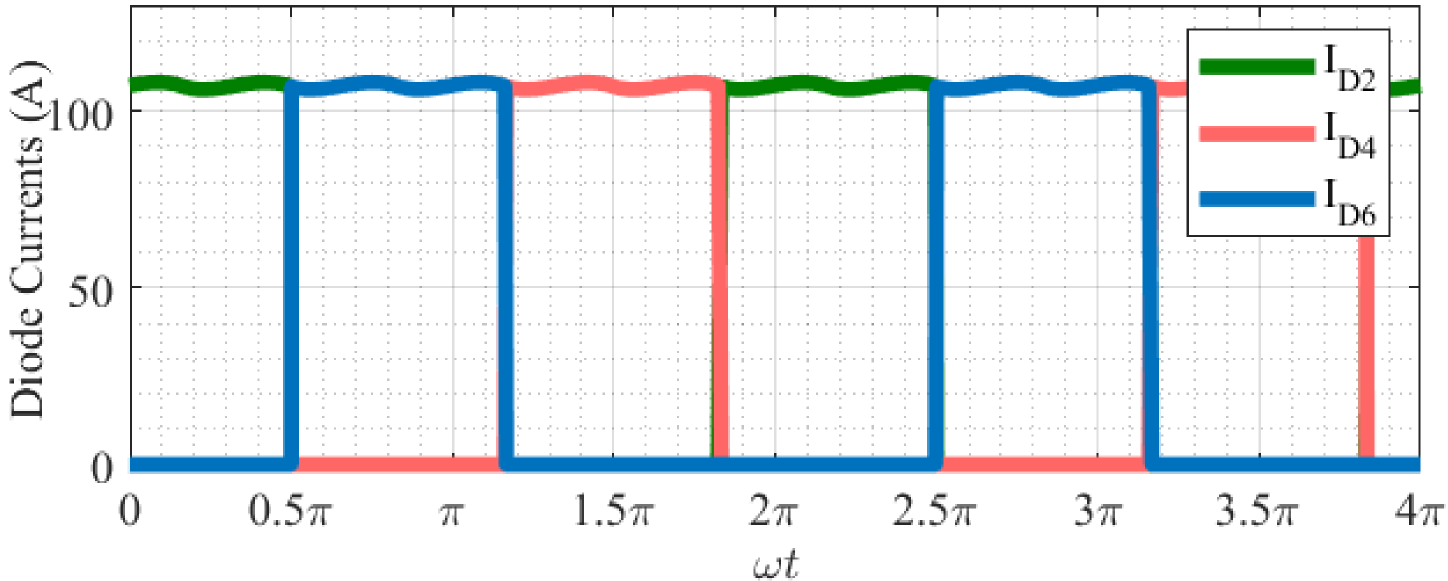






Diode Currents and Conduction Interval





Diode Currents and Conduction Interval

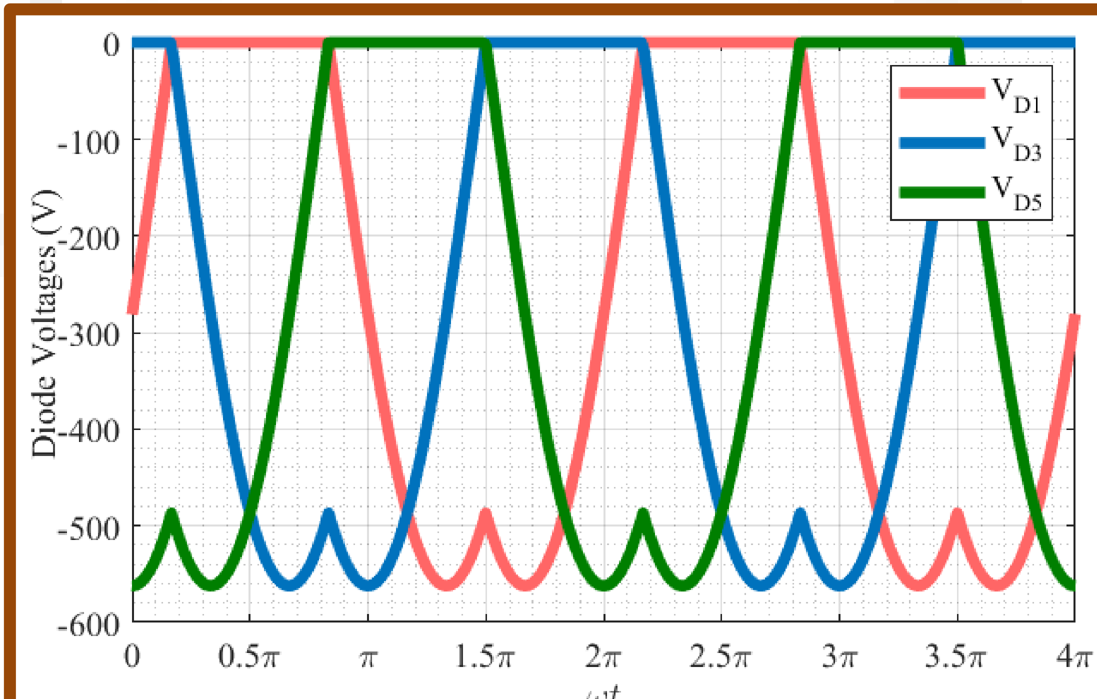
- The current in a conducting diode is the same as the load current.
- To determine the current in each phase of the source, Kirchhoff's current law is applied at nodes a, b, and c or R, S and T.

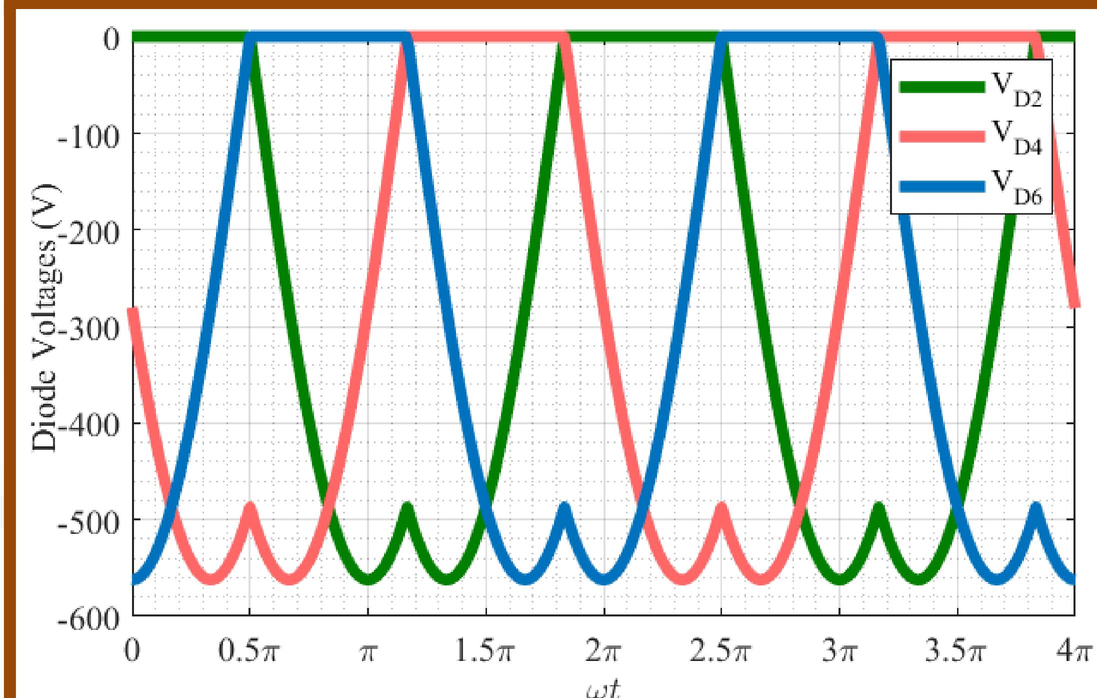
$$i_a = i_{D_1} - i_{D_4}$$
$$i_b = i_{D_3} - i_{D_6}$$
$$i_c = i_{D_5} - i_{D_2}$$

$$I_{D,\text{avg}} = \frac{1}{3} I_{o,\text{avg}}$$

$$I_{D,\text{rms}} = \frac{1}{\sqrt{3}} I_{o,\text{rms}}$$

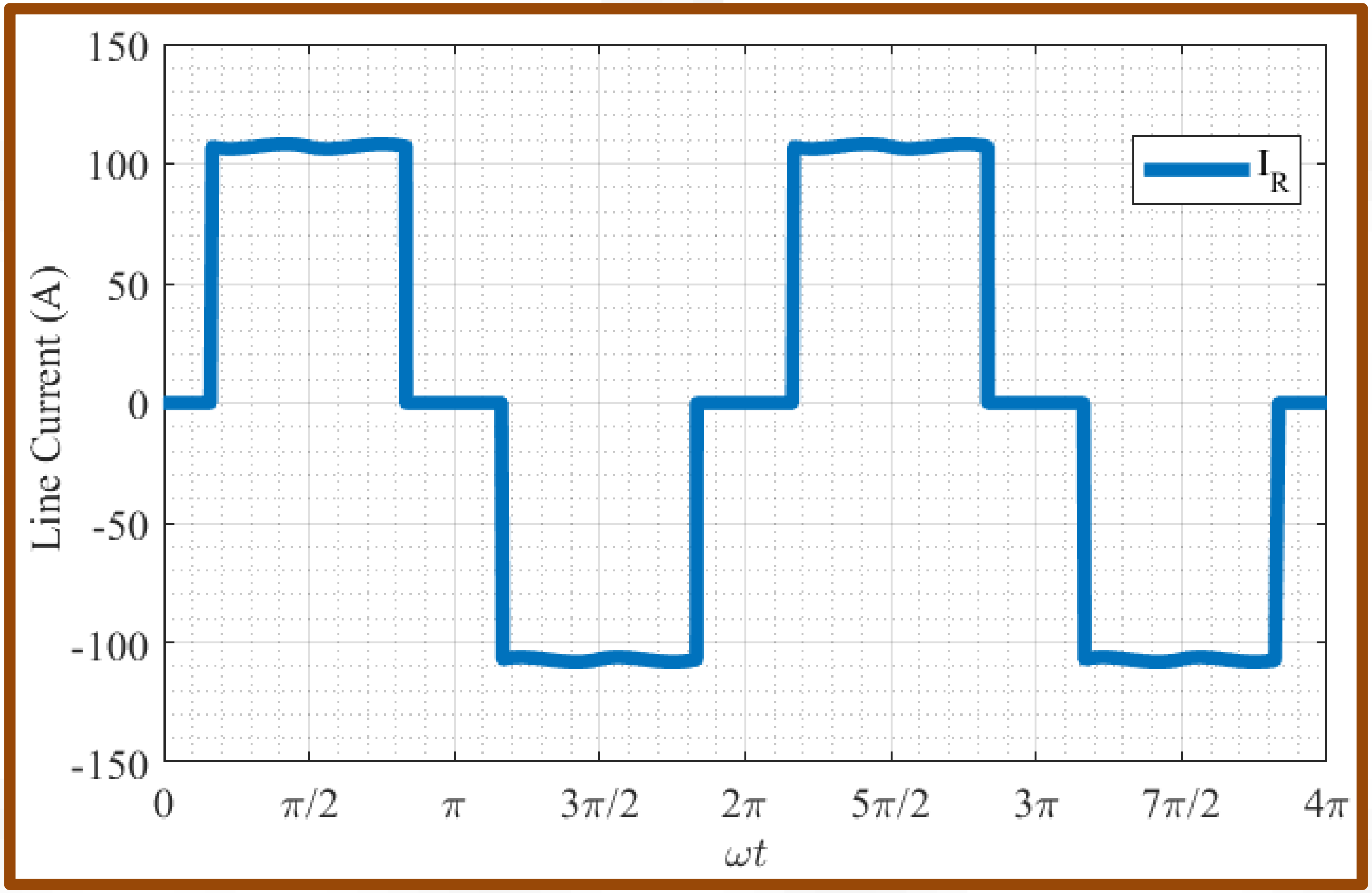
$$I_{s,\text{rms}} = \sqrt{\frac{2}{3}}\, I_{o,\text{rms}}$$





Diode Voltages

Line Currents

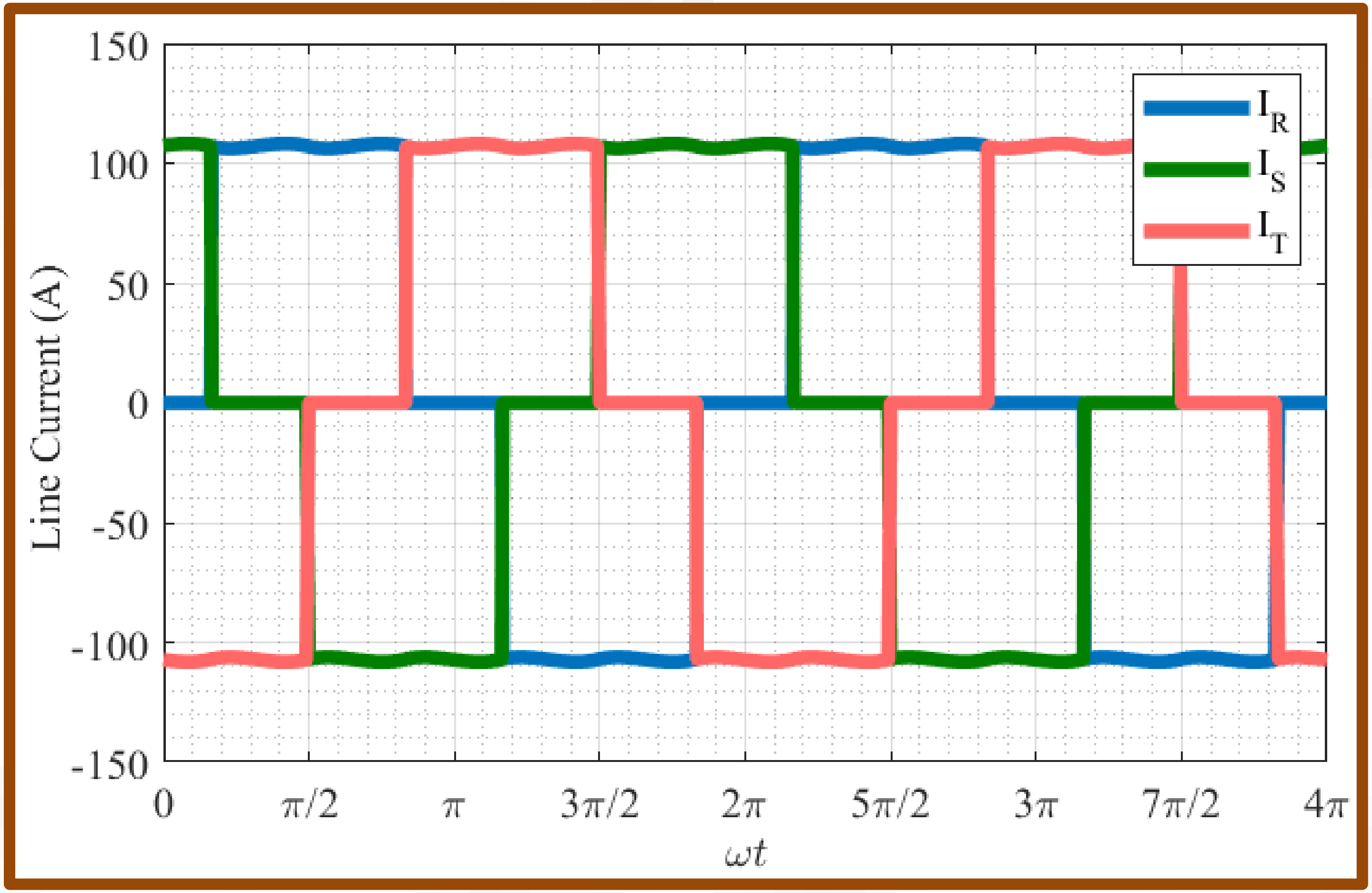


RMS current of line

$$I_s = I_m\sqrt{\frac{2}{\pi}\left(\frac{\pi}{6}+\frac{\sqrt{3}}{4}\right)} = 0.78\ I_m$$

$$I_m = \frac{\sqrt{3}V_m}{R} = 1.73V_m$$

Line Currents



RMS current through a diode $I_D = I_m\sqrt{\frac{1}{\pi}\left(\frac{\pi}{6}+\frac{\sqrt{3}}{4}\right)} = 0.552\ I_m$

The apparent power from the three-phase source is

$$S = \sqrt{3}V_{L-L\,(RMS)}I_{S\,(RMS)}$$

The periodic output voltage is defined as

$$V_{m,L-L}\sin(\omega t)\ \text{for}\ \frac{\pi}{3} \leq \omega t \leq \frac{2\pi}{3}$$

Fourier series for the output voltage to be expressed as

$$\vartheta_o(t) = V_o + \sum_{n=6,12,18\ldots}^{\infty} V_n \cos(n\omega_o t + \pi)$$

$$V_n = \frac{6V_{m,L-L}}{\pi(n^2 - 1)} \qquad n = 6, 12, 18, \ldots$$

Line Currents

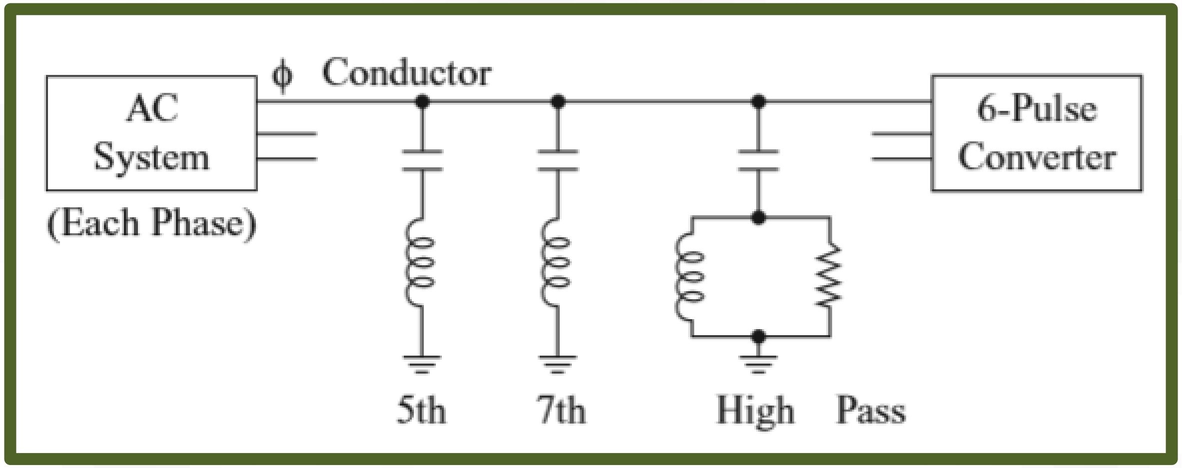
- In many applications, a load with series inductance results in a load current that is essentially dc.
- The Fourier series of the currents in phase a of the ac line is:

$$i_a(t) = \frac{2\sqrt{3}}{\pi} I_o \left(\cos \omega_0 t - \frac{1}{5} \cos 5\omega_0 t + \frac{1}{7} \cos 7\omega_0 t - \frac{1}{11} \cos 11\omega_0 t + \frac{1}{13} \cos 13\omega_0 t - \cdots \right)$$

- Because these harmonic currents may present problems in the ac system, filters are frequently necessary to prevent these harmonics from entering the ac system.

Input Filter

- A typical filtering scheme is shown in Figure.



- Resonant filters are used to provide a path to ground for the fifth and seventh harmonics, which are the two lowest and are the strongest in amplitude.

- Higher-order harmonics are reduced with the high-pass filter.

- These filters prevent the harmonic currents from propagating through the ac power system.

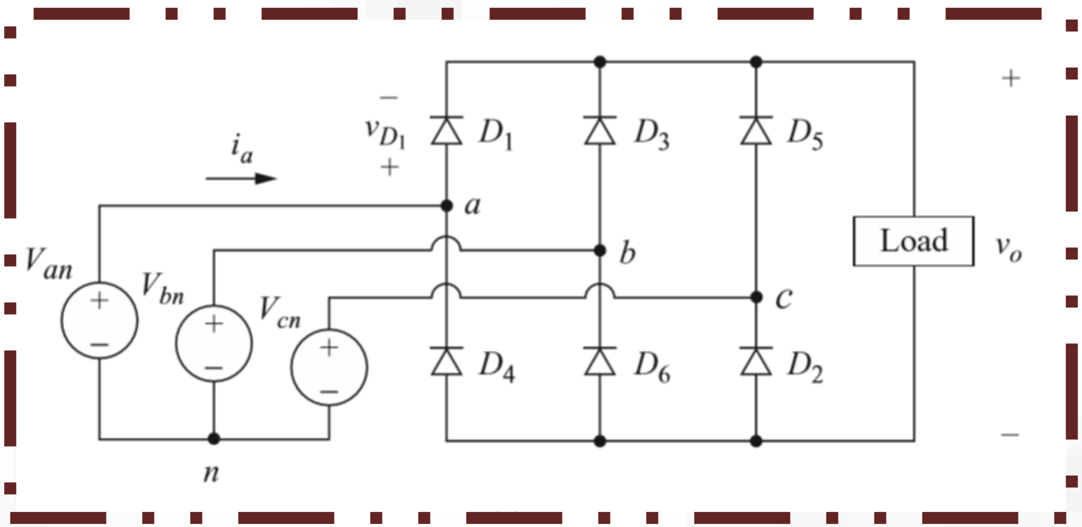
- Filter components are chosen such that the impedance to the power system frequency is large.

Summary

- The dc output voltage is slightly lower than the peak line voltage
- The Peak Repetitive Reverse Voltage (VRRM) rating of the employed diodes is 1.05 times the dc output voltage, and
- the Peak Repetitive Forward Current (IFRM) rating of the employed diodes is 0.579 times the dc output current.
- Therefore, this three-phase bridge rectifier is very efficient and popular wherever both dc voltage and current requirements are high.
- In many applications, no additional filter is required because the output ripple voltage is only 4.2%.
- Even if a filter is required, the size of the filter is relatively small because the ripple frequency is increased to six times the input frequency

Example-1

- The three-phase has a three-phase source of 480 Vrms line-to-line, and the load is a 25-Ω resistance in series with a 50-mH inductance. Determine
  - (a) the dc level of the output voltage,
  - (b) the dc and first ac term of the load current,
  - (c) the average and rms current in the diodes,
  - (d) the rms current in the source, and
  - (e) the apparent power from the source.



$$\frac{3V_{m,L-L}}{\pi} = \frac{3\sqrt{2}\,(480)}{\pi} = 648\text{V}$$

Example-1

The average load current is

$$I_o = \frac{V_o}{R} = \frac{648}{25} = 25.9 \text{ A}$$

$$I_6 = \frac{V_6}{Z_6} = \frac{0.0546V_m}{\sqrt{R^2 + (6\omega L)^2}} = \frac{0.0546\sqrt{2}(480)}{\sqrt{25^2 + [6(377)(0.05)]^2}} = \frac{37.0 \text{ V}}{115.8\ \Omega} = 0.32 \text{ A}$$

$$I_{6,\text{rms}} = \frac{0.32}{\sqrt{2}} = 0.23 \text{ A}$$

$$I_{D,\text{avg}} = \frac{I_o}{3} = \frac{25.9}{3} = 8.63 \text{ A}$$

$$I_{D,\text{rms}} = \frac{I_{o,\text{rms}}}{\sqrt{3}} \approx \frac{25.9}{\sqrt{3}} = 15.0 \text{ A}$$

$$I_{s,\text{rms}} = \left(\sqrt{\frac{2}{3}}\right) I_{o,\text{rms}} \approx \left(\sqrt{\frac{2}{3}}\right) 25.9 = 21.2 \text{ A}$$

$$S = \sqrt{3}(V_{L-L,\text{rms}})(I_{s,\text{rms}}) = \sqrt{3}\,(480)(21.2) = 17.6 \text{ kVA}$$