Power Electronics

Poly Phase Uncontrolled Rectifiers

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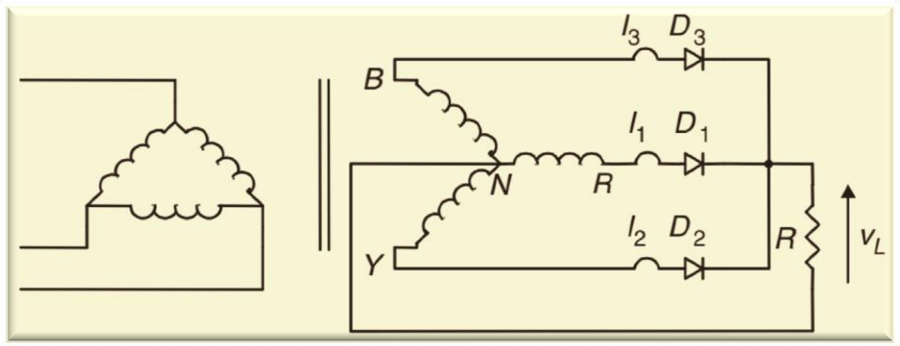
Three Phase Uncontrolled Half Wave Rectifiers

A basic three-phase half-wave rectifier circuit with resistive load is shown in Figure. The rectifier is fed from an ideal 3–phase supply through delta–star 3-phase transformer.

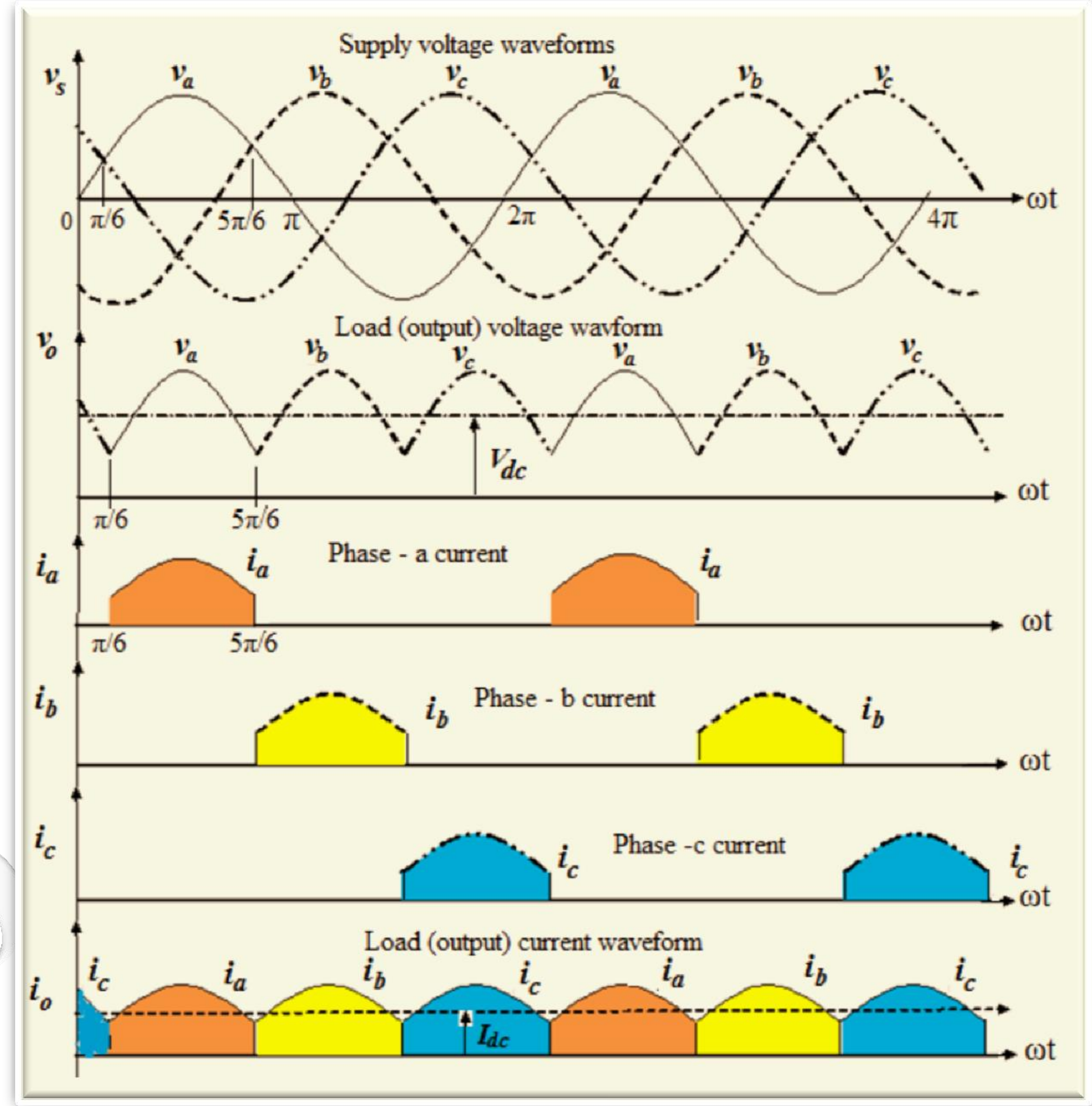


The principle of operation of this convertor can be explained as follows:

- The diode in a particular phase conducts during the period when the voltage on that phase is higher than that on the other two phases. For example: from π/6 to 5π/6, D_1 has a more positive voltage at its anode, in this period D_2 and D_3 are off. The neutral wire provides a return path to the load current.
- The conduction sequence is: D_1 ,D_2, D_3.

It is clear that, unlike the single-phase rectifier circuit, the conduction angle of each diode is 2π/3, instead of π.

Three Phase Uncontrolled Half Wave Rectifiers

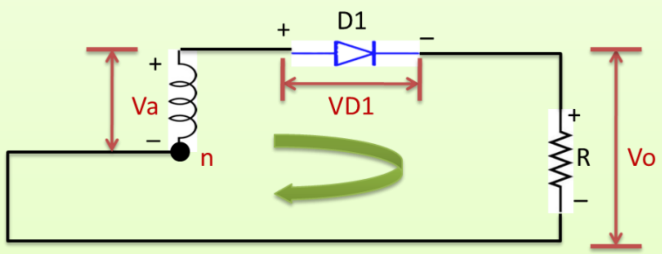


Three Phase Uncontrolled Half Wave Rectifiers

Variation of voltage across Diode D1

Voltage variation across diode D_1 can be obtained by applying KVL to the loop consisting of diode D_1, Phase 'a' winding and load R.

So, $-V_{D1} - V_o + V_a = 0$ or $V_{D1} = V_a - V_o$



When Diode D1 conduct:

$V_o = V_a$

Therefore , $V_{D1} = V_a - V_a = 0$

When diode D_2 conduct :

$V_o = V_b$

Therefore , $\boldsymbol{V_{D1} = V_a - V_b}$

At $\omega t = 180^0$, $V_b = 0.866V_{mp}$, $V_a = 0$ $V_{D1} = -0.866V_{mp}$

At $\omega t = 210^0$, $V_b = V_{mp}$, $V_a = -0.5V_{mp}$ $V_{D1} = -1.5V_{mp}$

At $\omega t = 240^0$, $V_b = 0.866V_{mp}$, $Va = -0.866V_{mp}$ $V_{D1} = -\sqrt{3}V_{mp}$

At $\omega t = 270^0$, $V_b = 0.5V_{mp}$, $Va = -V_{mp}$ $V_{D1} = -1.5V_{mp}$

Three Phase Uncontrolled Half Wave Rectifiers

Variation of voltage across Diode D1

When Diode D3 conducts :

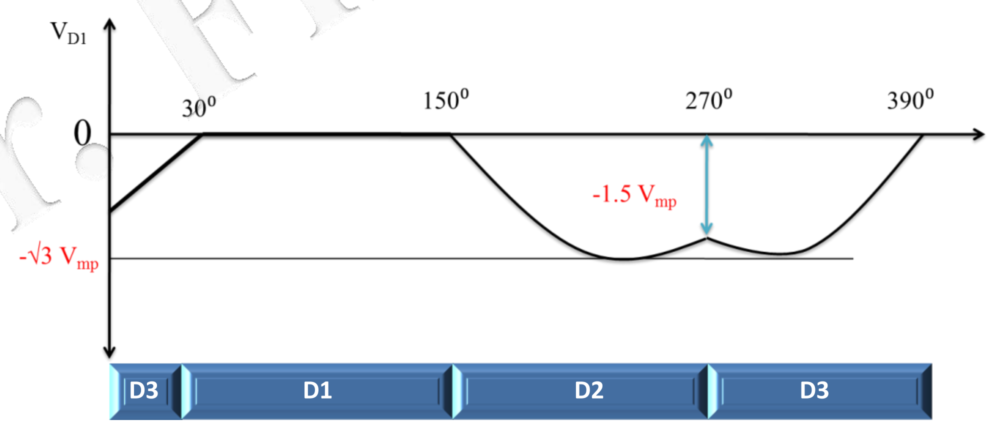
$$V_{D1} = V_a - V_c$$

At $\omega t = 300^0$, $V_a = -0.866\,V_{mp}$, $V_c = 0.866V_{mp}$ $\quad V_{D1} = -\sqrt{3}V_{mp}$

At $\omega t = 330^0$, $V_a = -0.5V_{mp}$, $V_c = V_{mp}$ $\quad V_{D1} = -1.5V_{mp}$

At $\omega t = 360^0$, $V_a = 0$, $V_c = 0.866V_{mp}$ $\quad V_{D1} = -0.866V_{mp}$

At $\omega t = 390^0$, $V_a = 0.5V_{mp}$, $V_c = 0.5V_{mp}$ $\quad V_{D1} = 0$



Three Phase Uncontrolled Half Wave Rectifiers

Let

$V_{an} = V_m \sin\omega t$ $\quad$ $V_{bn} = V_m \sin(\omega t\text{-}2\pi/3)$ $\quad$ $V_{bn} = V_m \sin(\omega t\text{-}4\pi/3)$

The <u>dc component</u> of the output voltage is the average value, and load current is the resistor voltage divided by resistance.

$$V_{dc} = \frac{3}{2\pi}\int_{\pi/6}^{5\pi/6} V_m sin\omega t\ d\omega t = \frac{3\sqrt{3}V_m}{2\pi} = 0.827V_m$$

$$I_{dc} = \frac{3\sqrt{3}V_m}{2\pi R} = \frac{0.827V_m}{R}$$

The *rms* value of the output voltage and current are

$$V_{rms} = \sqrt{\frac{3}{2\pi}\int_{\pi/6}^{5\pi/6} (V_m sin\omega t)^2\ d\omega t} = 0.84V_m$$

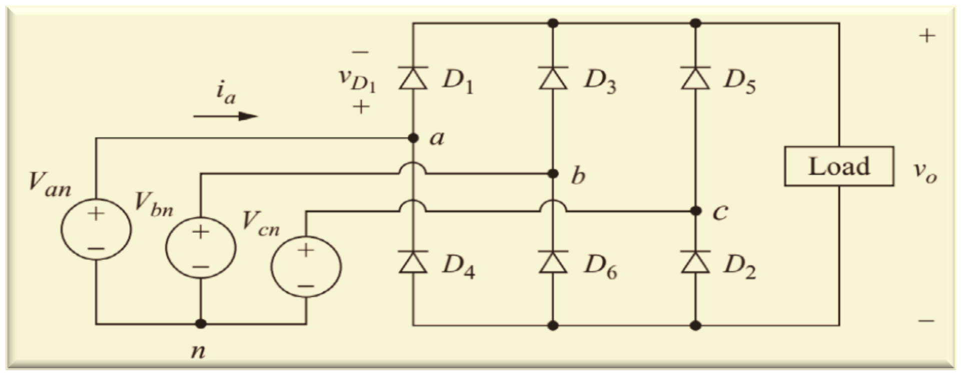
$$I_{rms} = \frac{0.84V_m}{R}$$

The *rms* current in each transformer secondary winding can also be found as

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_{\pi/6}^{5\pi/6} (I_m sin\omega t)^2\ d\omega t} = 0.485I_m$$

Three Phase Full-Wave Uncontrolled Bridge Rectifier

Three-phase rectifiers are commonly used in industry to produce a dc voltage and current for large loads. The three-phase voltage source is balanced and has phase sequence a-b-c.



Some basic observations about the circuit are as follows:

- Kirchhoff's voltage law around any path shows that only one diode in the top half of the bridge may conduct at one time (D_1, D_3, or D_5). The diode that is conducting will have its anode connected to the phase voltage that is highest at that instant.
- Kirchhoff's voltage law also shows that only one diode in the bottom half of the bridge may conduct at one time (D_2, D_4, or D_6). The diode that is conducting will have its cathode connected to the phase voltage that is lowest at that instant.
- D_1 and D_4 cannot conduct at the same time. Similarly, D_3 and D_6 cannot conduct simultaneously, nor can D_5 and D_2.

Three Phase Full-Wave Uncontrolled Bridge Rectifier

Some basic observations about the circuit are as follows:

- The output voltage across the load is one of the line-to-line voltages of the source. For example, when D_1 and D_2 are ON, the output voltage is v_{ac}. Furthermore, the diodes that are ON are determined by which line-to-line voltage is the highest at that instant. For example, when v_{ac} is the highest line-to-line voltage, the output is v_{ac}.

- 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 6ω, where ω is the frequency of the three-phase source.

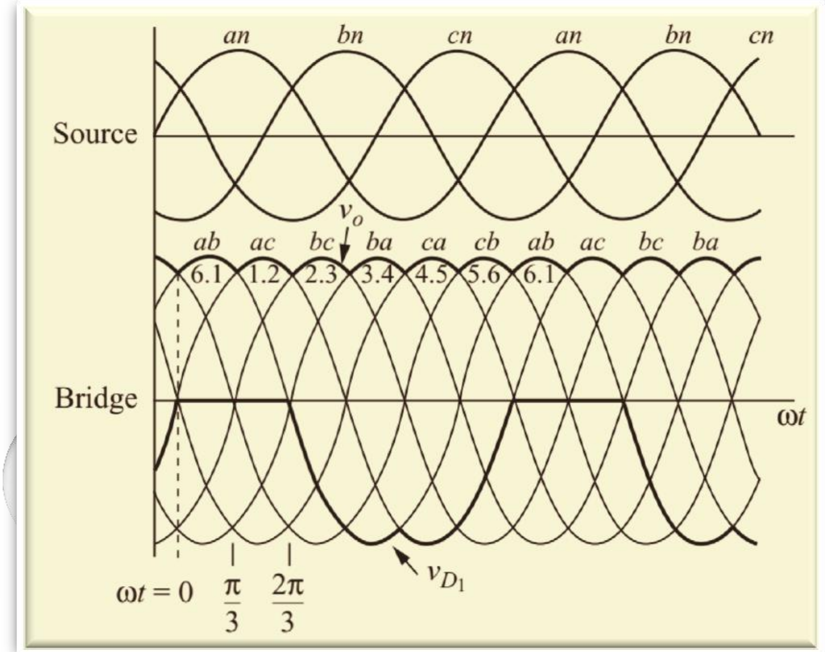
Three Phase Full-Wave Uncontrolled Bridge Rectifier

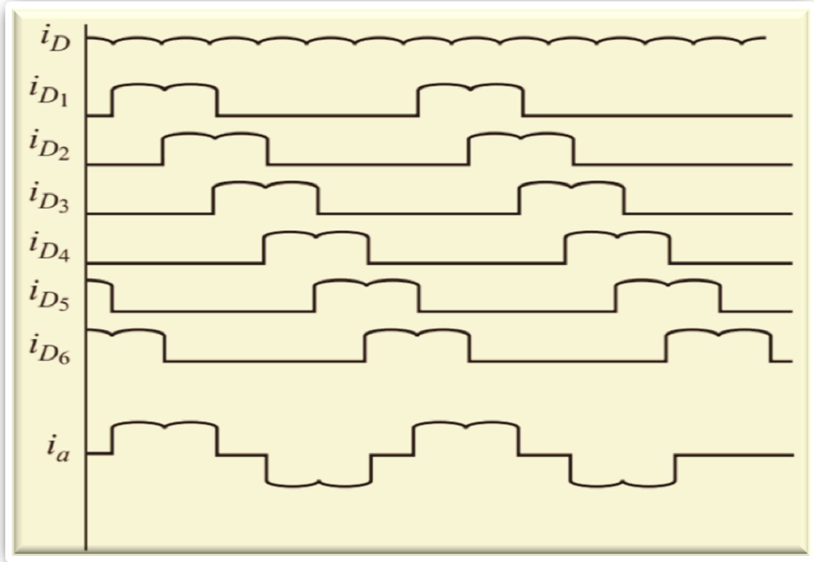
The figures shows the phase voltages and the resulting combinations of line-to-line voltages from a balanced three-phase source and the current in each of the bridge diodes for a resistive load.

The diodes conduct in pairs (6,1), (1,2), (2,3), (3,4), (4,5), (5,6), (6,1), ... Diodes turn on in the sequence 1, 2, 3, 4, 5, 6, 1, . . .

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,

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





Three Phase Full-Wave Uncontrolled Bridge Rectifier

Let

$V_{an} = V_m \sin\omega t$ $\quad V_{bn} = V_m \sin(\omega t - 2\pi/3)$ $\quad V_{bn} = V_m \sin(\omega t - 4\pi/3)$

$$V_{ab} = V_{an} - V_{bn} = \sqrt{3}V_m \sin(\omega t + \pi/6)$$

$$V_{bc} = V_{bn} - V_{cn} = \sqrt{3}V_m \sin(\omega t - \pi/2)$$

$$V_{ca} = V_{cn} - V_{an} = \sqrt{3}V_m \sin(\omega t - 7\pi/6)$$

The <u>dc component</u> of the output voltage is the average value, and load current is the resistor voltage divided by resistance.

$$V_{dc} = \frac{3}{\pi}\int_{\pi/6}^{\pi/2} \sqrt{3}V_m \sin(\omega t + \pi/6)\, d\omega t = \frac{3}{\pi}\int_{\pi/6}^{\pi/2} \sqrt{3}V_m (\sin\omega t \cos\pi/6 + \cos\omega t \sin\pi/6) d\omega t$$

$$V_{dc} = \frac{3}{\pi}\int_{\pi/6}^{\pi/2} \sqrt{3}V_m \left(\frac{\sqrt{3}}{2}\sin\omega t + \frac{1}{2}\cos\omega t\right) d\omega t = \frac{3\sqrt{3}V_m}{\pi} = 1.654V_m$$

$$I_{dc} = 1.654\frac{V_m}{R}$$

The average power is $\quad P_{dc} = V_{dc} I_{dc}$

Three Phase Full-Wave Uncontrolled Bridge Rectifier

The *rms* value of the output voltage is

$$V_{rms} = \sqrt{\frac{3}{\pi}\int_{\pi/6}^{\pi/2} (\sqrt{3}V_m \sin(\omega t - \pi/6))^2 \, d\omega t} = 1.655V_m$$

The *rms* current in each phase can also be found as

$$I_{(a,b,c)rms} = 0.78I_m$$

The *rms* current through a diode is:

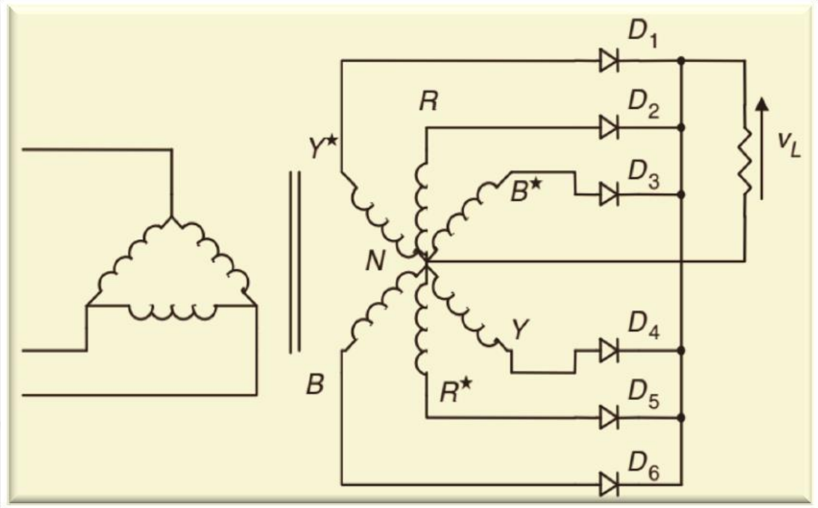
$$I_{(D)rms} = 0.552I_m$$

Where

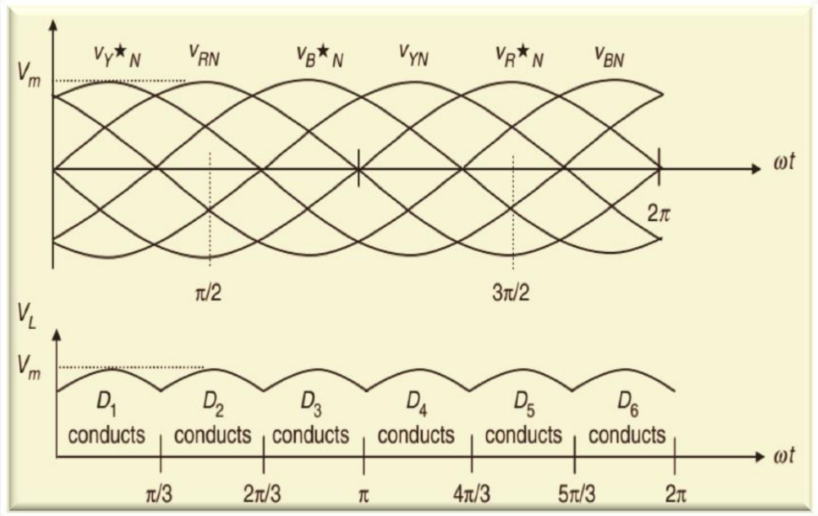
$$I_m = 1.73V_m/R$$

Six-phase Star Rectifier

The six-phase voltages on the secondary are obtained by means of a center-tapped arrangement on a star-connected three phase winding.



The diode in a particular phase conducts during the period when the voltage on that phase is higher than that on the other phases. The conduction angle of each diode is $\pi/3$.



Currents flow in only one rectifying element at a time, resulting in a low average current, but a high peak to an average current ratio in the diodes.

Six-phase star circuit is attractive in applications which require a low ripple factor and a common cathode or anode for the rectifiers.

Six-phase Star Rectifier

The average value of the output voltage can be found as

$$V_{dc} = \frac{6}{2\pi}\int_{\pi/3}^{2\pi/3} V_m \sin\theta d\theta = V_m \frac{6}{\pi}\frac{1}{2} = 0.955V_m$$

The *rms* of the output voltage can be found as

$$V_{rms} = \sqrt{\frac{3}{\pi}\int_{\pi/3}^{2\pi/3} (V_m \sin\omega t)^2 \, d\omega t} = V_m\sqrt{\frac{3}{\pi}(\frac{\pi}{6}+\frac{\sqrt{3}}{4})} = 0.956V_m$$

The *rms* current in each transformer secondary winding can also be found as

$$I_{rms} = I_m\sqrt{\frac{1}{2\pi}(\frac{\pi}{6}+\frac{\sqrt{3}}{4})} = 0.396I_m$$

Where

$$I_m = \frac{V_m}{R}$$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