بسمه تعالی

الکترونیک صنعتی

یکسوکننده های دیودی

DIODE RECTIFIERS

رضانژاد

پارامترهای کارایی

$$\eta = \frac{P_{dc}}{P_{ac}} \qquad P_{dc} = V_{dc} I_{dc} \;\; P_{ac} = V_{rms} I_{rms}$$

$$V_{ac} = \sqrt{V_{rms}^2 + V_{dc}^2}$$

$$FF = \frac{V_{rms}}{V_{dc}}$$

$$RF = \frac{V_{ac}}{V_{dc}} = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1} = \sqrt{FF^2 - 1}$$

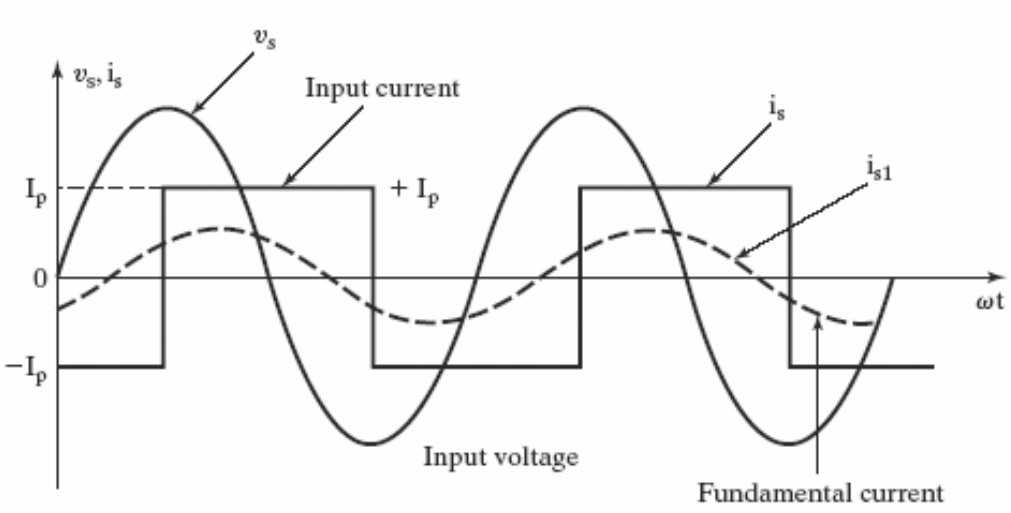
$$TUF = \frac{P_{dc}}{V_s I_s}$$

$$DF = \cos\phi$$

$$HF = \sqrt{\frac{I_s^2 - I_{s1}^2}{I_{s1}^2}} = \sqrt{\left(\frac{I_s}{I_{s1}}\right)^2 - 1}$$

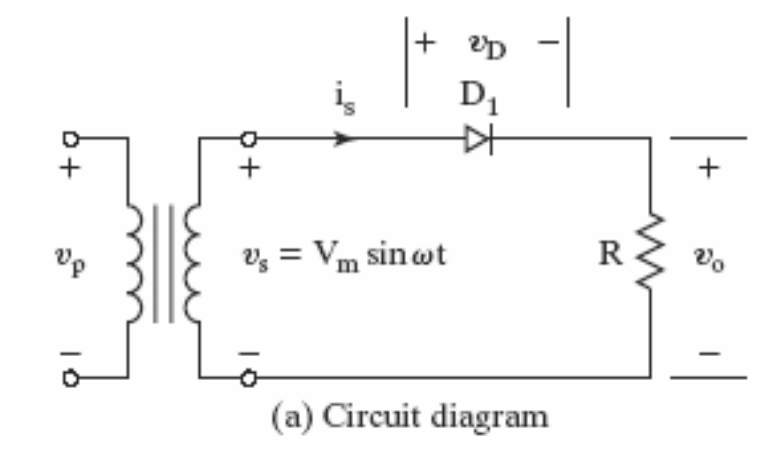
$$PF = \frac{V_s I_{S1}}{V_s I_S}\cos\phi = \frac{I_{S1}}{I_S}\cos\phi$$

$$CF = \frac{I_{S(peak)}}{I_S}$$



Single-Phase Half-wave Rectifier

یکسوساز تکفاز نیم موج



(a) Circuit diagram

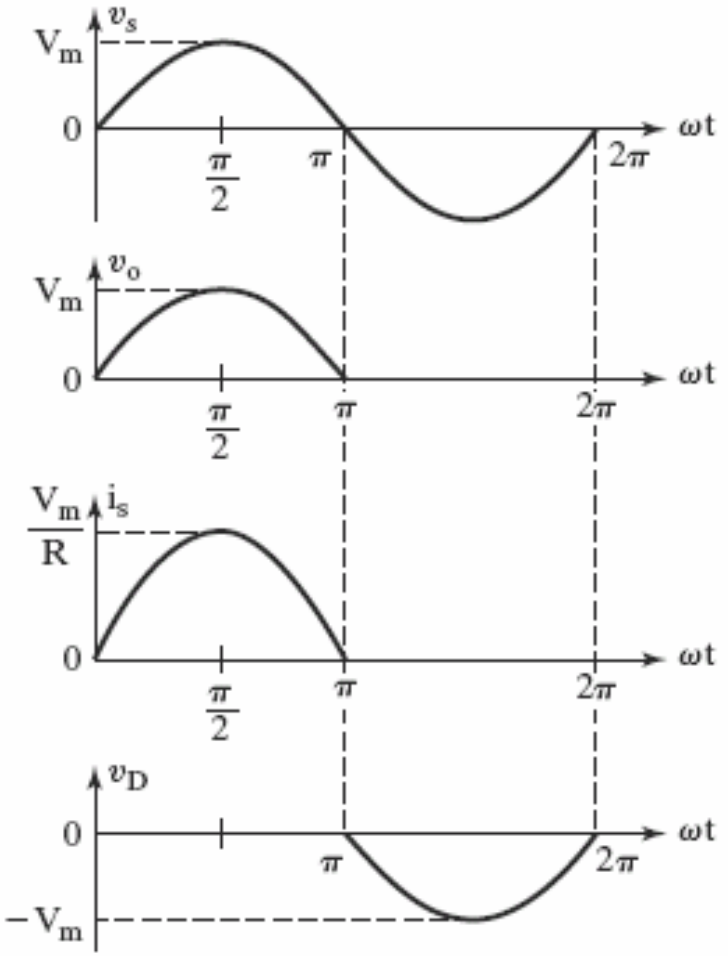
$$V_{dc} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin\theta d\theta = \frac{V_m}{\pi} = 0.318 V_m$$

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

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} V_m^2 \sin^2\theta d\theta} = \frac{V_m}{2}$$

$$I_{rms} = \frac{V_m}{2R}$$

$$\eta = \frac{P_{dc}}{P_{ac}} = 40.5\%$$



(b) Waveforms

Single-Phase Half-wave Rectifier

یکسوساز تکفاز نیم موج

$$FF = \frac{V_{rms}}{V_{dc}} = \frac{0.5\,V_m}{0.318 V_m} = 1.57$$

$$RF = \frac{V_{ac}}{V_{dc}} = \sqrt{1.57^2 - 1} = 1.21$$

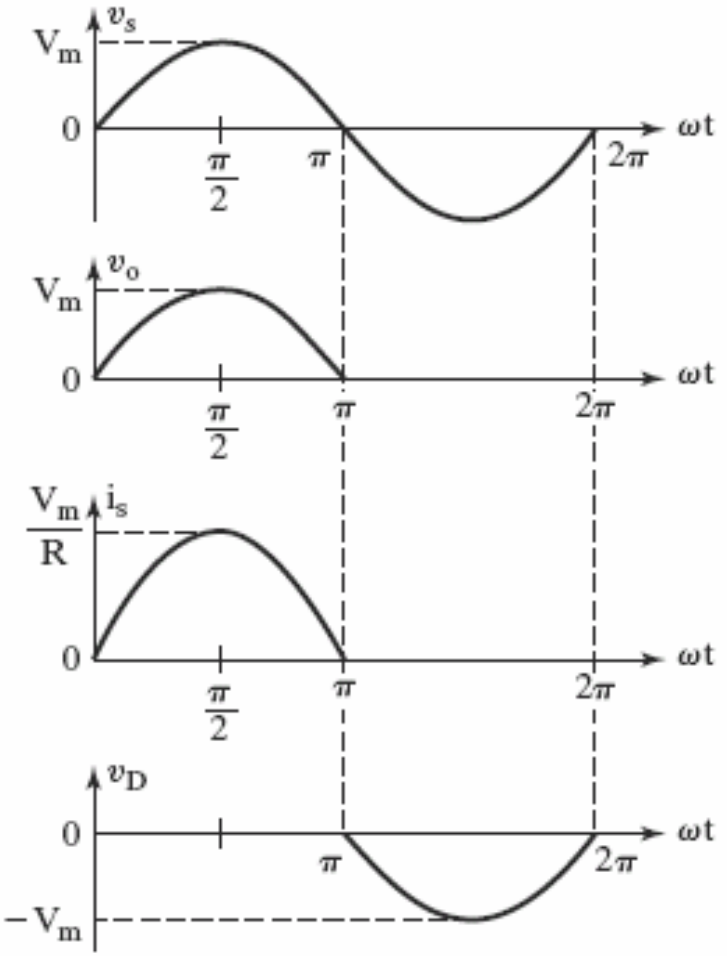
$$TUF = \frac{P_{dc}}{V_s . I_s}$$

$$V_s = \frac{V_m}{\sqrt{2}} \qquad \Rightarrow TUF = \frac{\frac{V_m}{\pi} \times \frac{V_m}{\pi R}}{\frac{V_m}{\sqrt{2}} \times \frac{0.5 V_m}{R}} = 0.286$$

$$I_s = \frac{V_{rms}}{R} = \frac{0.5 V_m}{R}$$

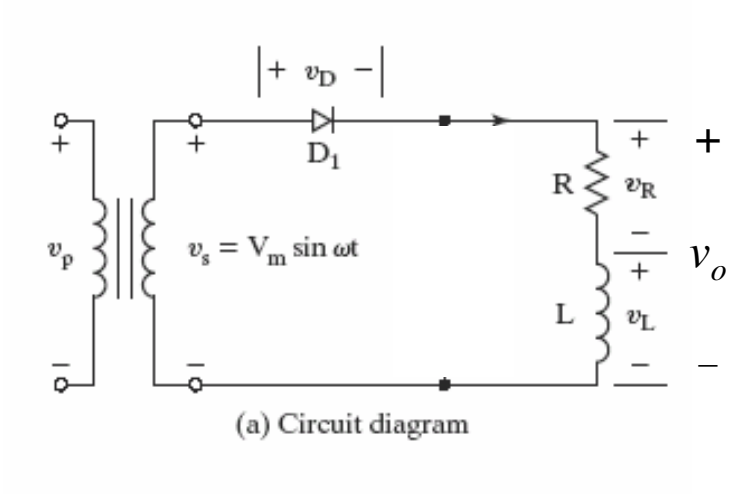
$$PIV = V_m$$

$$CF = \frac{I_{s(peak)}}{I_s} = \frac{V_m / R}{V_{rms} / R} = 2$$

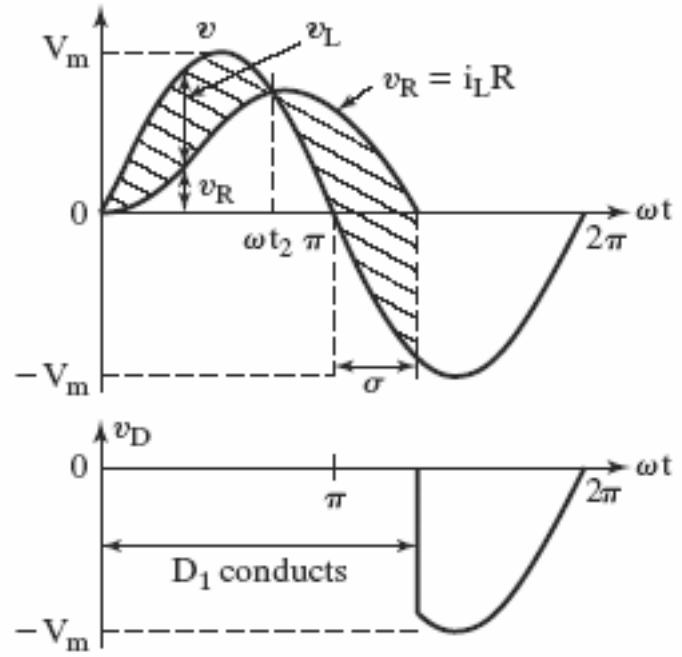


(b) Waveforms

یکسوساز تکفاز نیم موج با بار RL



(a) Circuit diagram



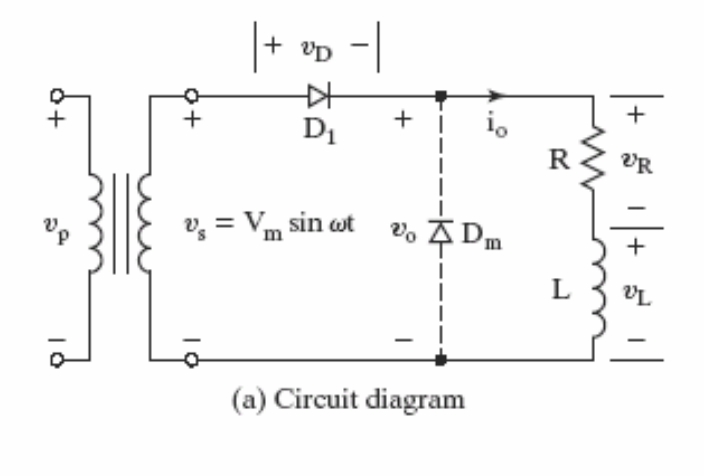
(b) Waveforms

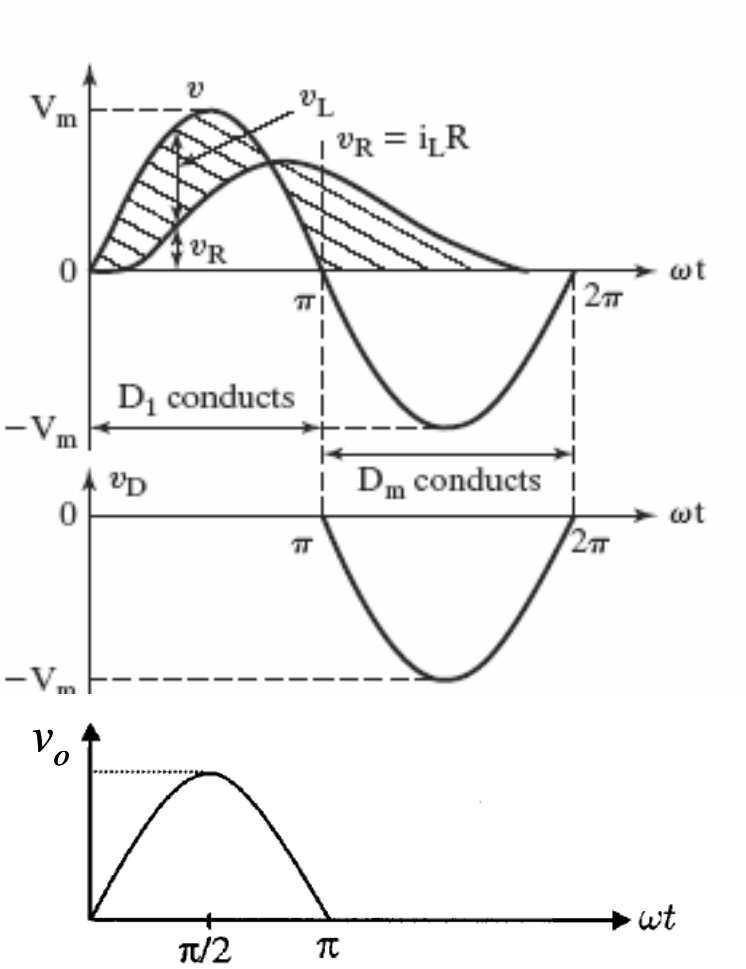
$$V_{o(dc)} = \frac{1}{2\pi}\int_0^{\pi+\sigma} V_m \sin\theta d\theta = \frac{V_m}{2\pi}\left[1-\cos(\pi+\sigma)\right]$$

$$V_{o(dc)} = V_{R(dc)} + V_{L(dc)} \qquad V_{L(dc)} = 0 \quad ?$$

$$I_{o(dc)} = \frac{V_m}{2\pi R}\left[1-\cos(\pi+\sigma)\right]$$

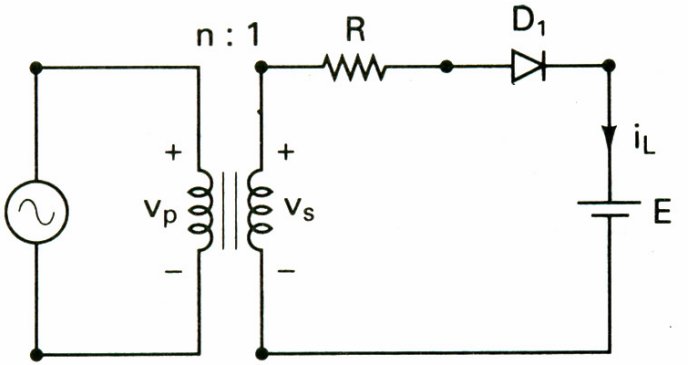
یکسوساز تکفاز نیم موج با بار RL

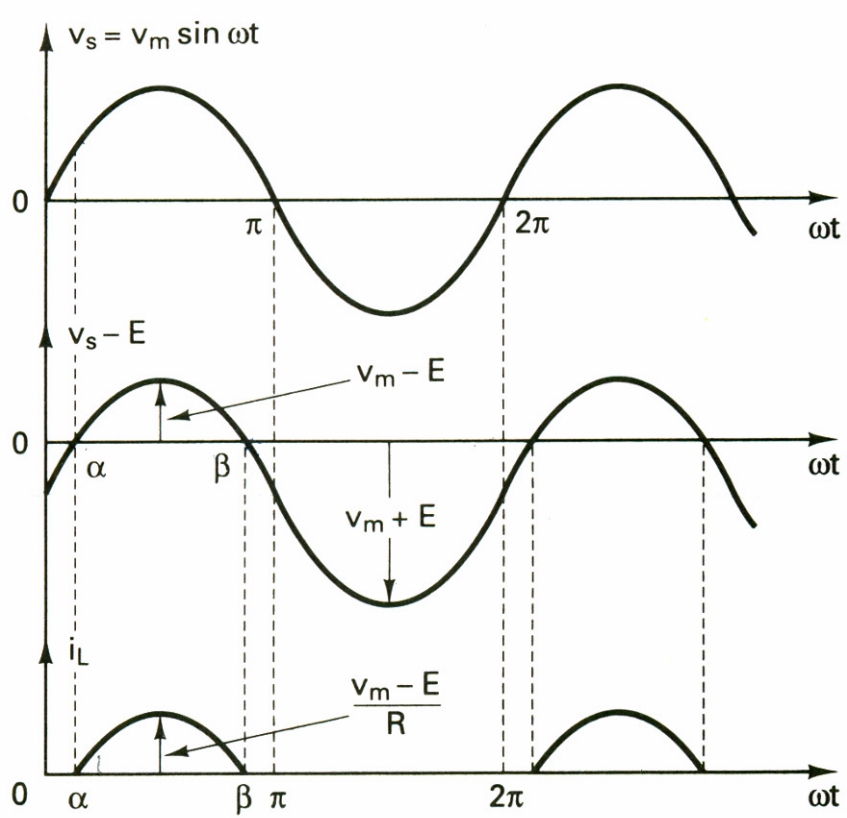




$$V_{dc} = \frac{1}{2\pi}\int_0^{\pi} V_m \, Sin\, \omega t \, d(\omega t) = \frac{V_m}{\pi}$$

یکسوساز نیم موج بعنوان شارژر (با محدودکننده جریان مقاومتی)





$$if\ \ v_s - E > 0 \ \Rightarrow\ \ D:on \quad \alpha = Sin^{-1}\frac{E}{V_m}$$

$$if\ \ v_s - E < 0 \ \Rightarrow\ \ D:off \quad \beta = \pi - \alpha$$

$$i_L = \frac{v_s - E}{R}$$

مثال: ولتاژ باتری در شکل ۳–۱۷ الف برابر است با $E=12$ V و ظرفیت آن 100 W-h است. جریان شارژکننده متوسط باید برابر $I_{dc}=5$ A باشد. ولتاژ ورودی اولیه 60 Hz و $V_p=120$ V و نسبت سیم‌پیچهای ترانسفورماتور $n=2:1$ است. محاسبه کنید الف) زاویه هدایت دیود δ ب) مقاومت محدودکننده جریان R

حل: $V_s=V_p/n=120/2=60$ V، $V_p=120$ V، $E=12$ V و $V_m=\sqrt{2}V_s=\sqrt{2}\times60=84.85$ V.

الف) از رابطه ۳–۵۸ داریم: $\alpha=\sin^{-1}(12/84.85)=8.13°$ یا 0.1419 rad و $\beta=180-8.13=171.87°$. زاویه هدایت برابر است با

$$\delta=\beta-\alpha=171.87-8.13=163.74°$$

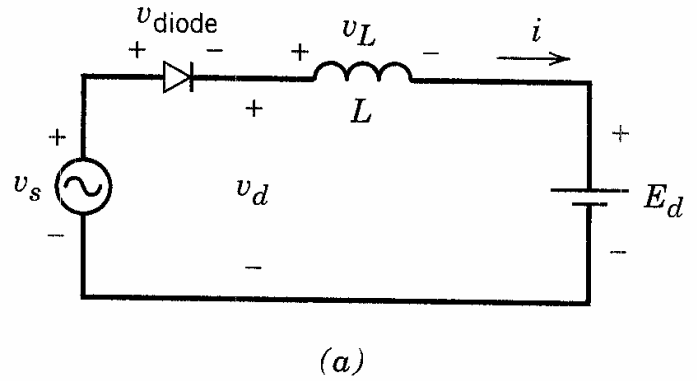
ب) مقدار متوسط جریان شارژکننده I_{dc} برابر خواهد بود با

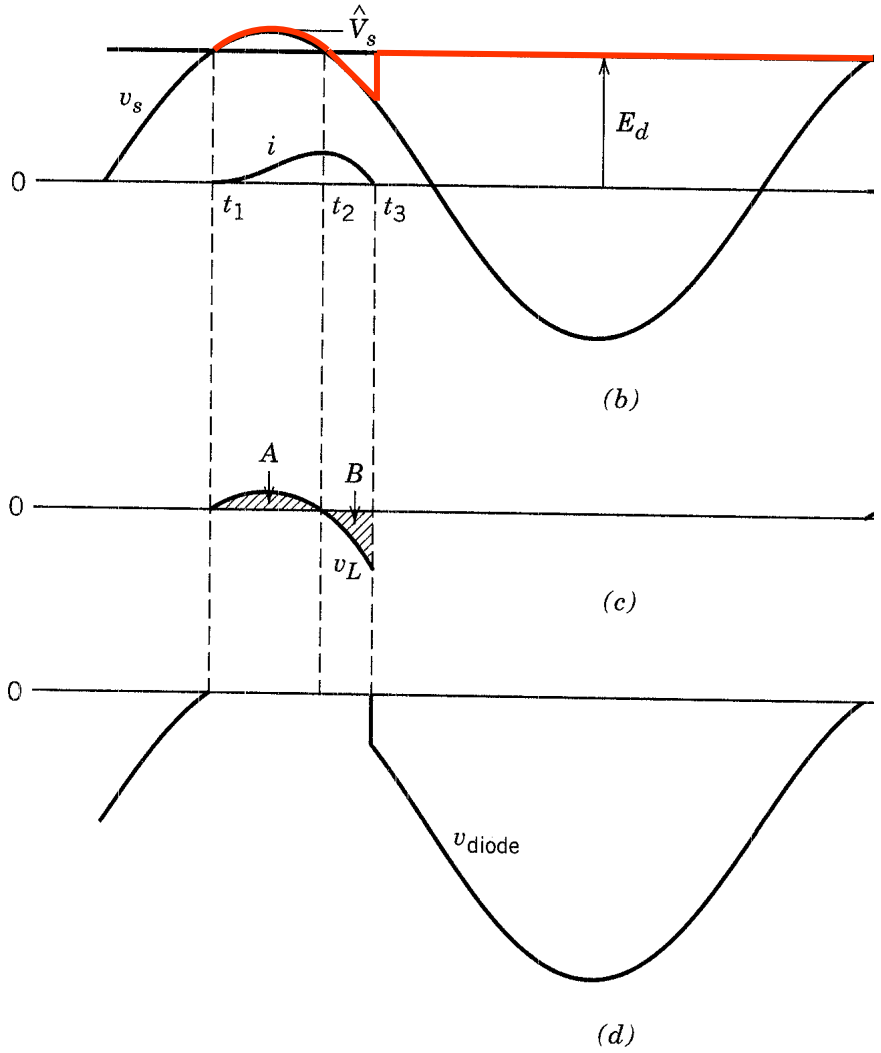
$$I_{dc}=\frac{1}{2\pi}\int_{\alpha}^{\beta}\frac{V_m\sin\omega t-E}{R}\,d(\omega t)=\frac{1}{2\pi R}(2V_m\cos\alpha+2E\alpha-\pi E),\qquad \beta=\pi-\alpha$$

$$R=\frac{1}{2\pi I_{dc}}(2V_m\cos\alpha+2E\alpha-\pi E)$$

$$=\frac{1}{2\pi\times5}(2\times84.85\times\cos8.13°+2\times12\times0.1419-\pi\times12)=4.26\ \Omega$$

یکسوساز نیم موج با بار سلفی و ولتاژ dc داخلی





مثال: یکسوکننده نیم موج تکفاز با بار مقاومتی به یک منبع 60 Hz و $V_s = 120\ V$ متصل است. سری فوریه ولتاژ خروجی را بدست آورید.

$$v_L(t) = a_0 + \sum_{n=1}^{\infty} (a_n Cos\, n\omega t + b_n Sin\, n\omega t)$$

$$a_0 = V_{dc} = \frac{1}{2\pi}\int_0^{2\pi} V_m\, Sin\, \omega t\, d(\omega t) = \frac{V_m}{\pi}$$

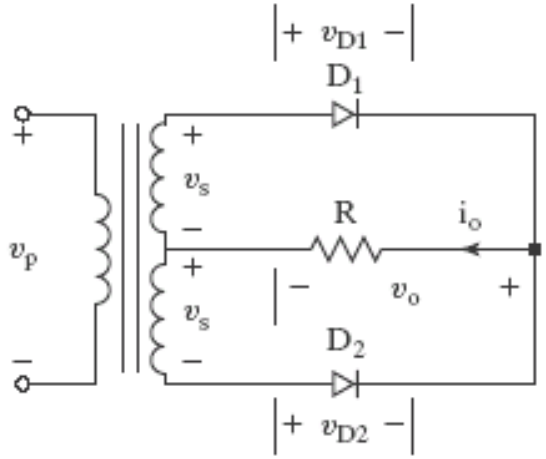
$$a_n = \frac{1}{\pi}\int_0^{2\pi} v_L(t).Cos\, n\omega t\, d(\omega t) = \frac{1}{\pi}\int_0^{\pi} V_m\, Sin\, \omega t.Cos\, n\omega t\, d(\omega t) = \begin{cases} \frac{1+(-1)^n}{1-n^2}\frac{V_m}{\pi} & n \geq 2 \\ 0 & n = 1 \end{cases}$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} v_L(t).Sin\, n\omega t\, d(\omega t) = \frac{1}{\pi}\int_0^{\pi} V_m\, Sin\, \omega t.Sin\, n\omega t\, d(\omega t) = \begin{cases} \frac{V_m}{2} & n = 1 \\ 0 & n \geq 2 \end{cases}$$

$$v_L(t) = \frac{V_m}{\pi} + \frac{V_m}{2} Sin\, \omega t - \frac{2V_m}{3\pi} Cos\, 2\omega t + \frac{2V_m}{15\pi} Cos\, 4\omega t - \frac{2V_m}{35\pi} Cos\, 6\omega t + \ldots$$

Full-Wave Rectifier (center-tapped)

یکسوساز تکفاز تمام موج با ترانس سر وسط



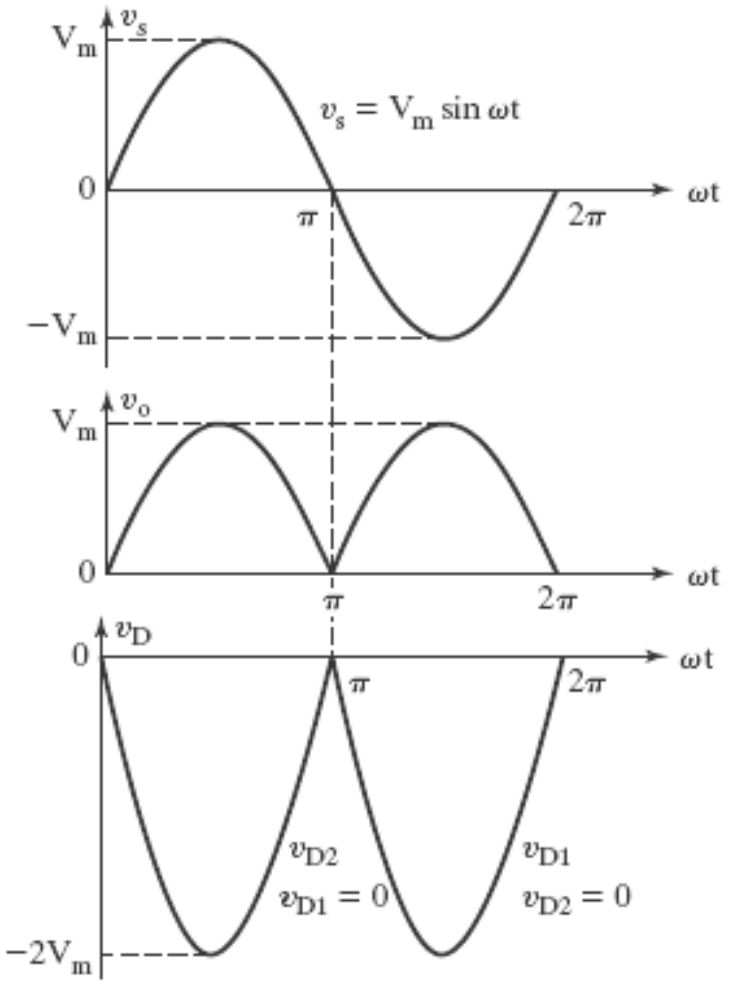
$$V_{o(dc)} = \frac{2}{2\pi}\int_0^{\pi} V_m \sin\theta d\theta = \frac{2V_m}{\pi}$$

$$V_{o(rms)} = \sqrt{\frac{2}{2\pi}\int_0^{\pi} V_m^2 \sin^2\theta d\theta} = \frac{V_m}{\sqrt{2}}$$

$$\eta = \frac{P_{dc}}{P_{ac}} = 81\%$$

$$FF = \frac{V_{rms}}{V_{dc}} = 1.11$$

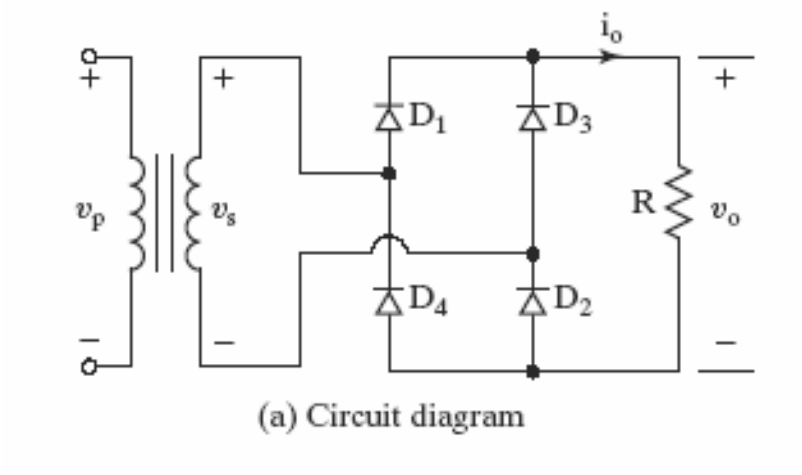
$$FF = \frac{V_{ac}}{V_{dc}} = 0.482$$



(b) Waveforms

Full-Wave Bridge Rectifier

یکسوساز تکفاز تمام موج با استفاده از پل دیود



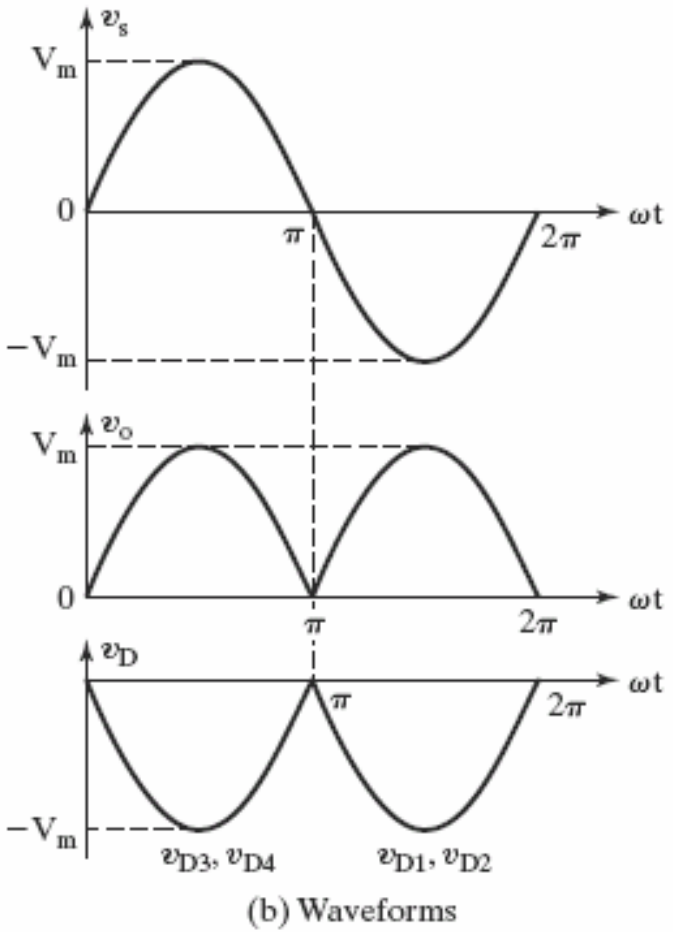
(a) Circuit diagram

$$V_{o(dc)} = \frac{2}{2\pi}\int_0^{\pi} V_m \sin\theta d\theta = \frac{2V_m}{\pi}$$

$$I_{o(dc)} = \frac{2V_m}{\pi R}$$

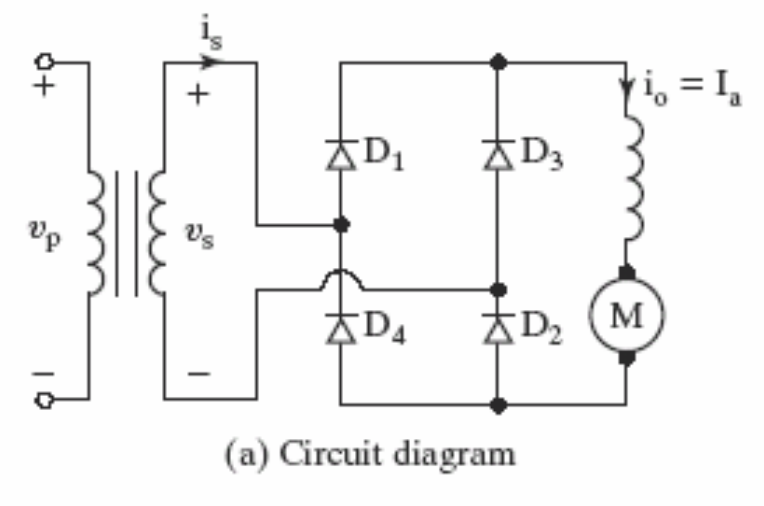
$$V_{o(rms)} = \sqrt{\frac{2}{2\pi}\int_0^{\pi} V_m^2 \sin^2\theta d\theta} = \frac{V_m}{\sqrt{2}}$$

$$I_{o(rms)} = \frac{V_m}{\sqrt{2}R}$$

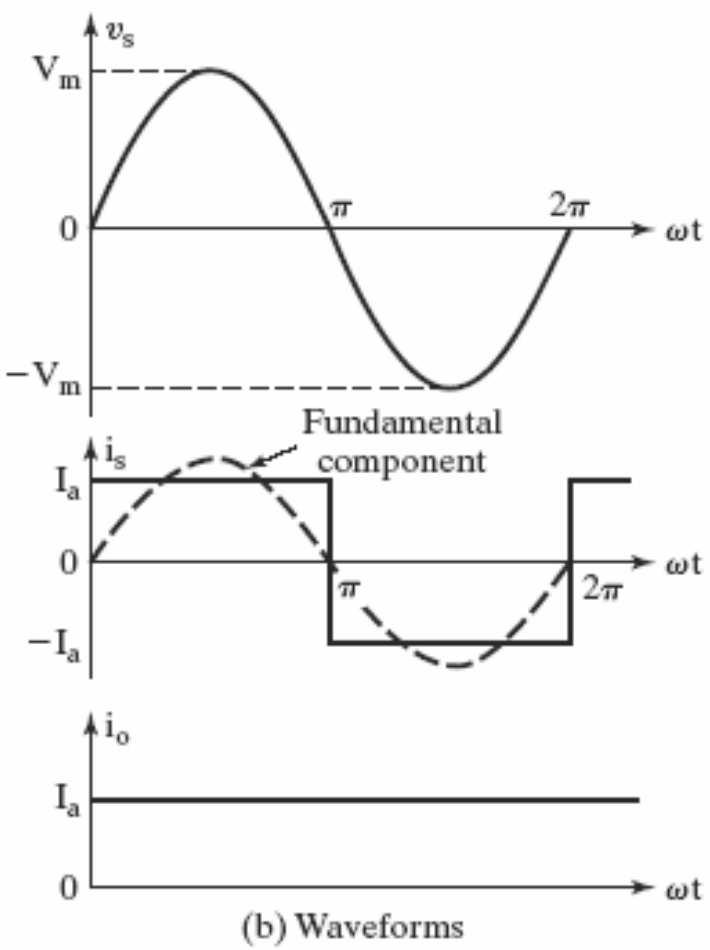


(b) Waveforms

پل تمام موج تکفاز با بار سلفی (موتور dc)



(a) Circuit diagram



(b) Waveforms

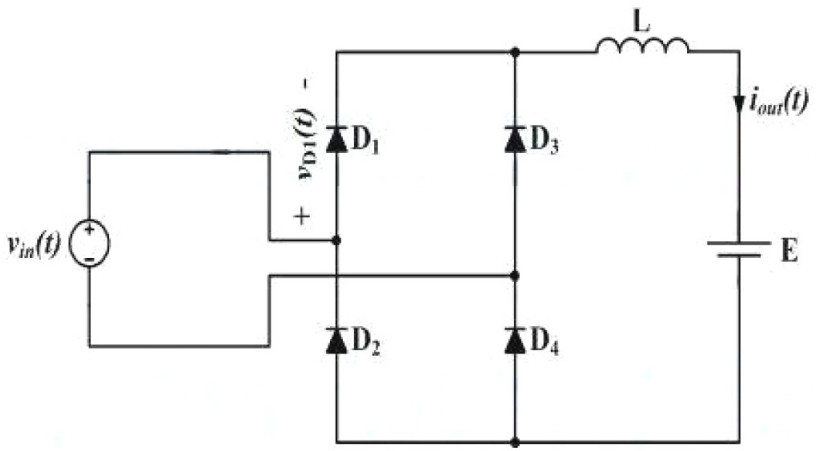
$$i_s(t) = \frac{4I_a}{\pi}\left(\frac{\sin\omega t}{1} + \frac{\sin 3\omega t}{3} + \frac{\sin 5\omega t}{5} + ...\right)$$

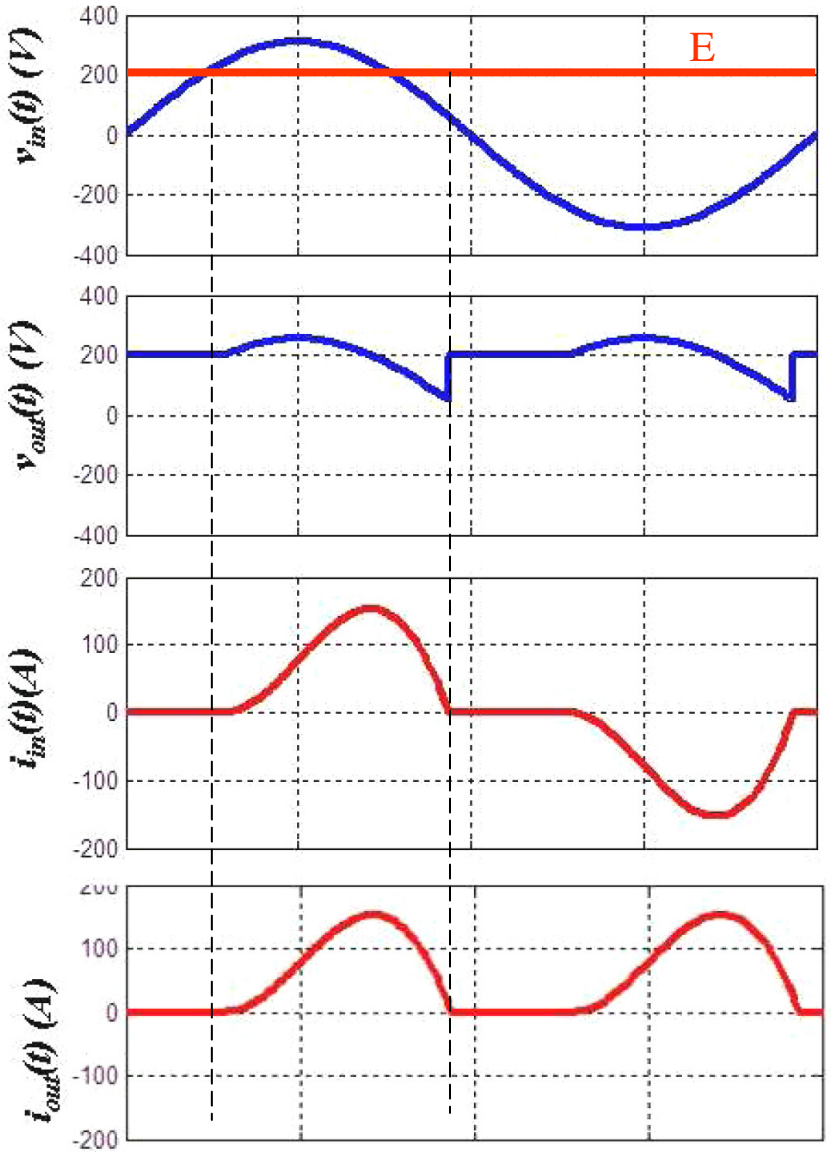
$$I_{s1} = \frac{4I_a}{\pi\sqrt{2}} = 0.90I_a$$

$$I_s = I_a$$

$$THD = \sqrt{\left(\frac{1}{0.9}\right)^2 - 1} = 0.4843$$

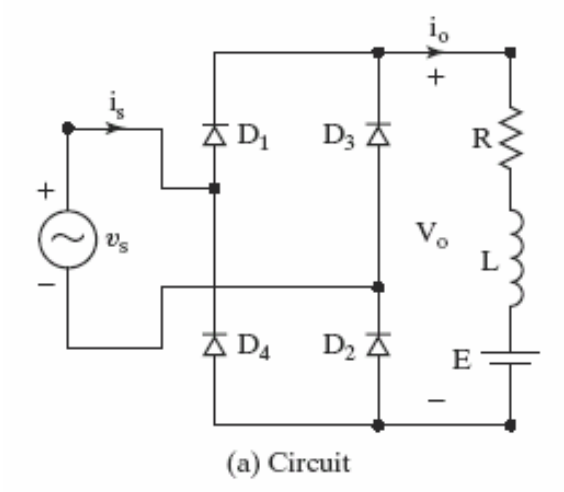
Single-phase full-wave battery charger with an inductor at the output side





Bridge Rectifier (RL load)

پل تمام موج تکفاز با بار اهمی- سلفی (RL)



(a) Circuit

$$L\frac{di_o}{dt} + Ri_o + E = \sqrt{2}V_s \sin\omega t \quad for\ i_o \geq 0$$

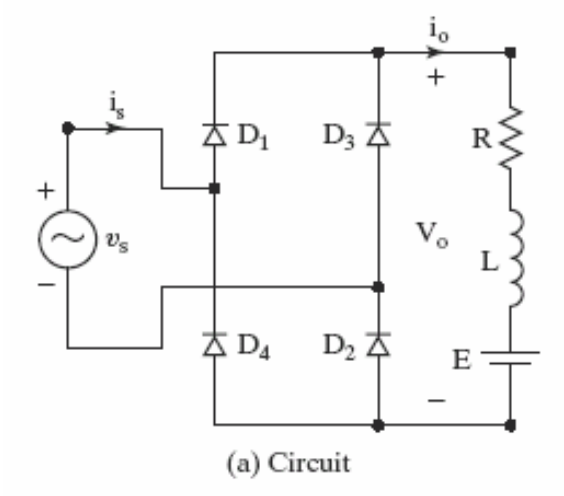
$$i_o = \frac{\sqrt{2}V}{Z}\sin(\omega t - \theta) + A_1 e^{-(R/L)t} - \frac{E}{R}$$

$$Z = \sqrt{R^2 + (\omega L)^2} \qquad \theta = \tan^{-1}(\omega L / R)$$

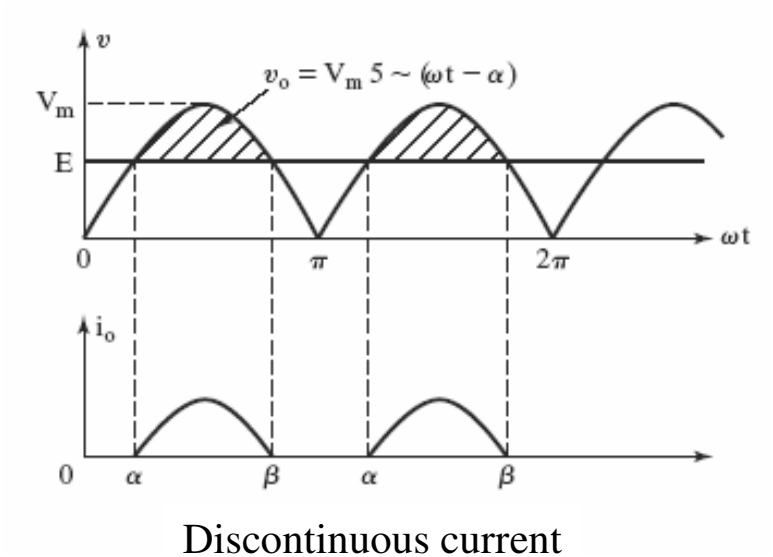
- Case 1: Continuous conduction, $i_o > 0$
- Case 2: Discontinuous conduction, $i_o = 0$

Bridge Rectifier (RL load)

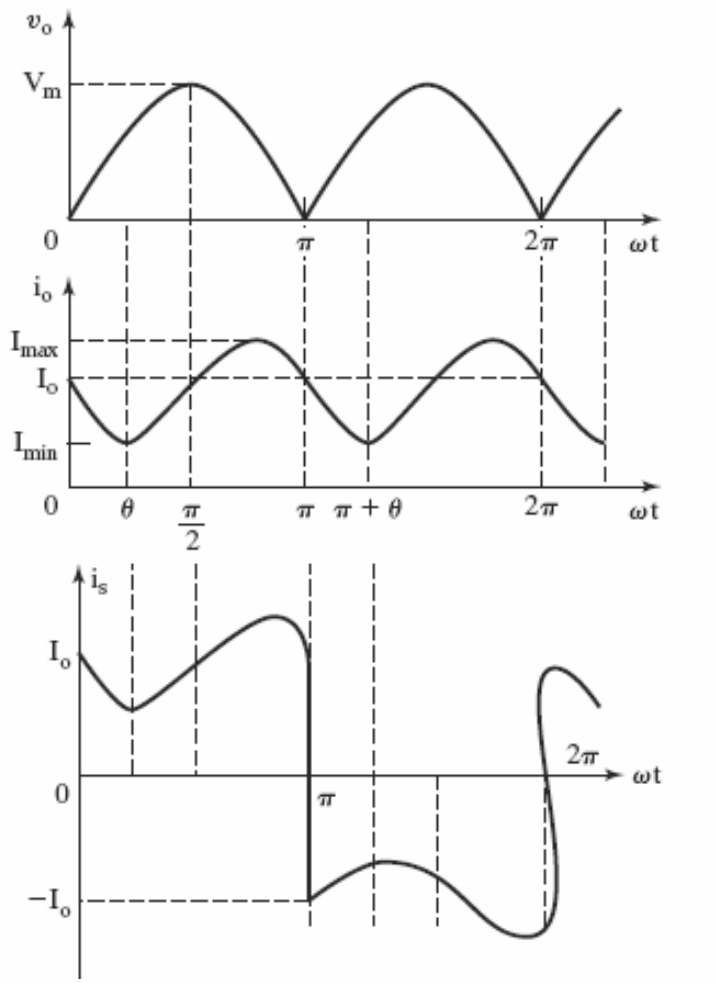
پل تمام موج تکفاز با بار اهمی- سلفی (RL)



(a) Circuit



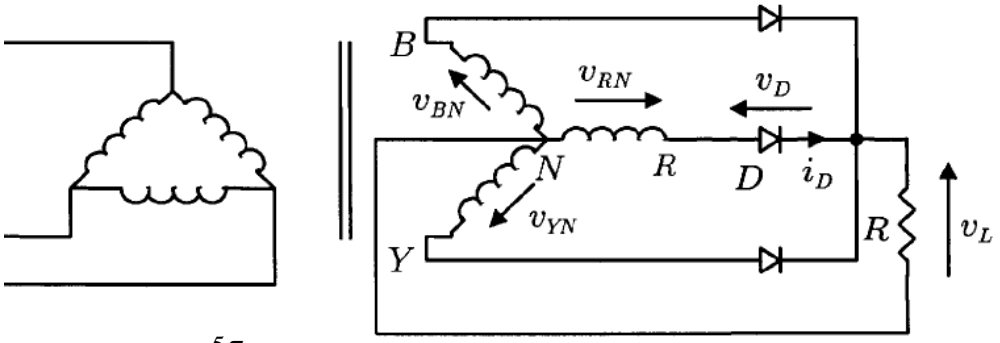
Discontinuous current



Continuous current

Three-Phase Star Rectifiers

یکسوکننده نیم موج سه فاز



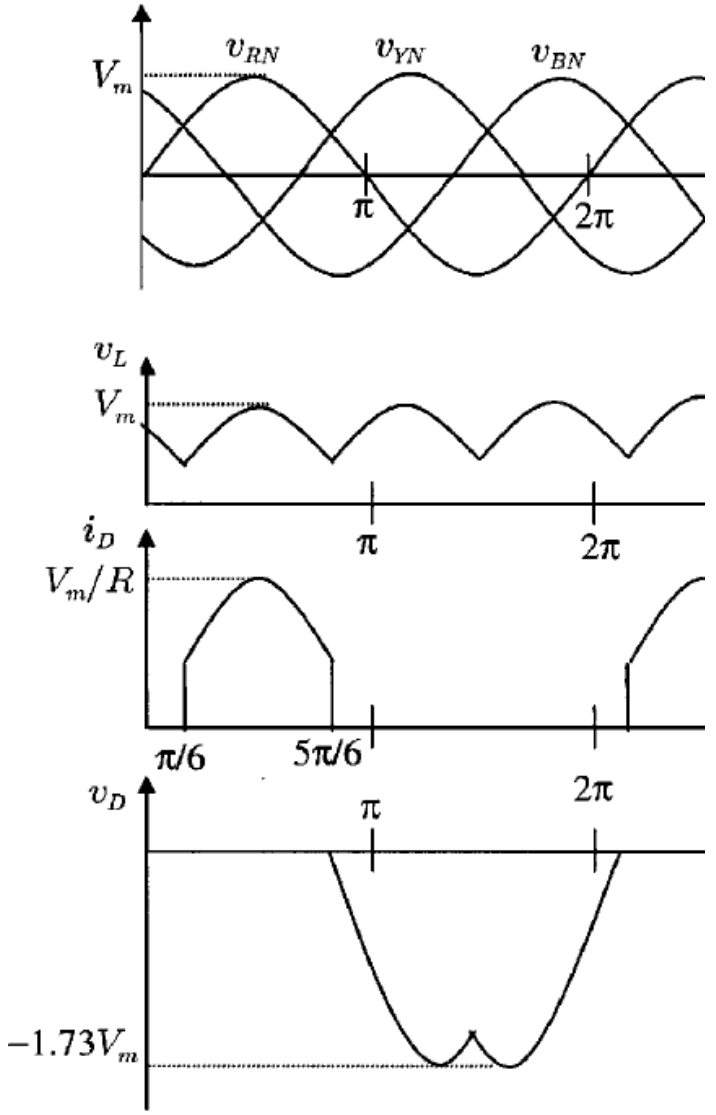
$$V_{dc} = \frac{3}{2\pi}\int_{\frac{\pi}{6}}^{\frac{5\pi}{6}} V_m \, Sin\,\omega t \, d(\omega t)$$

$$= \frac{2}{\frac{2\pi}{3}}\int_0^{\frac{\pi}{3}} V_m \, Cos\,\omega t \, d(\omega t) = \frac{3\sqrt{3}V_m}{2\pi} = 0.827 V_m$$

$$V_{rms} = \sqrt{\frac{2}{\frac{2\pi}{3}}\int_0^{\frac{\pi}{3}} V_m{}^2 \, Cos^2\,\omega t \, d(\omega t)} = 0.84 V_m$$

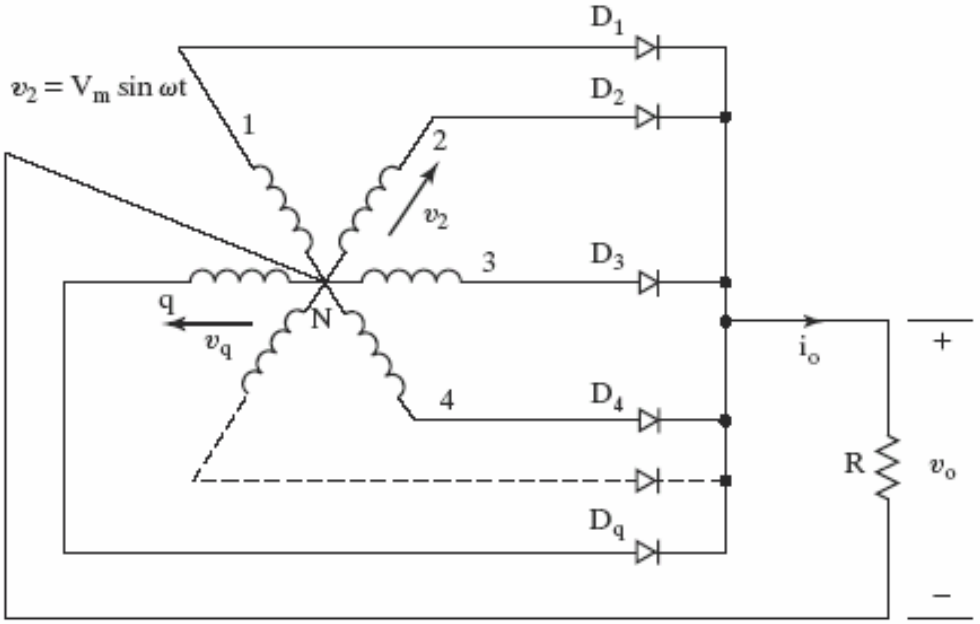
$$I_s = \sqrt{\frac{2}{2\pi}\int_0^{\frac{\pi}{3}} I_m{}^2 \, Cos^2\,\omega t \, d(\omega t)} = \frac{V_{rms}}{R\sqrt{3}} = \frac{I_{rms}}{\sqrt{3}}$$

$$\eta = \frac{P_{dc}}{P_{ac}} = 96.77\%$$

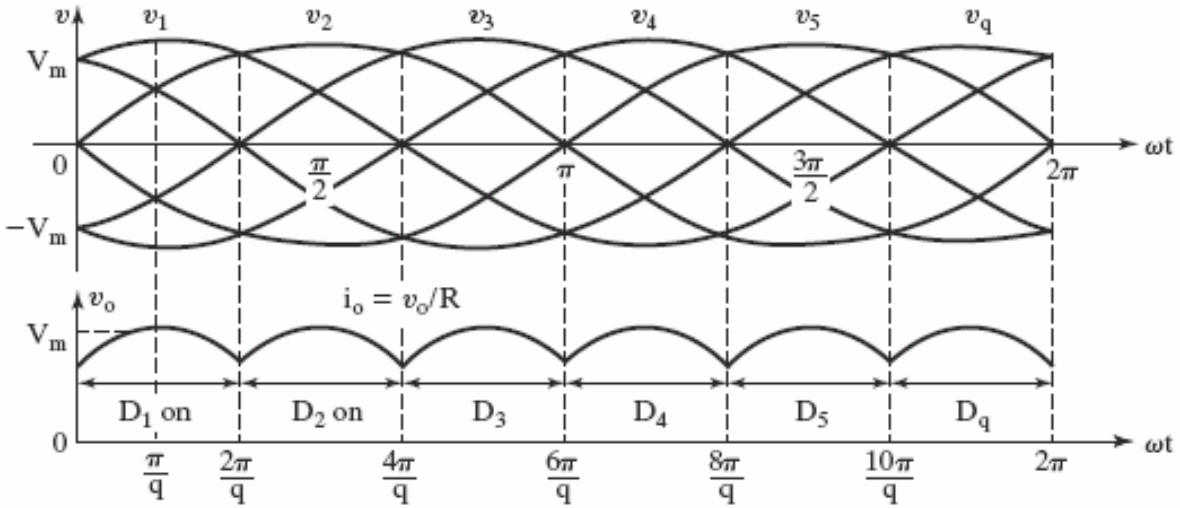


Multiphase Rectifiers

یکسوکننده نیم موج چندفاز



(a) Circuit diagram



(b) Waveforms

$$V_{dc} = \frac{2}{2\pi/q}\int_0^{\frac{\pi}{q}} V_m \, Cos\, \omega t \, d(\omega t)$$

$$= V_m \frac{q}{\pi} Sin \frac{\pi}{q}$$

$$V_{rms} = \sqrt{\frac{2}{2\pi/q}\int_0^{\frac{\pi}{q}} V_m^{\,2} \, Cos^2 \, \omega t \, d(\omega t)}$$

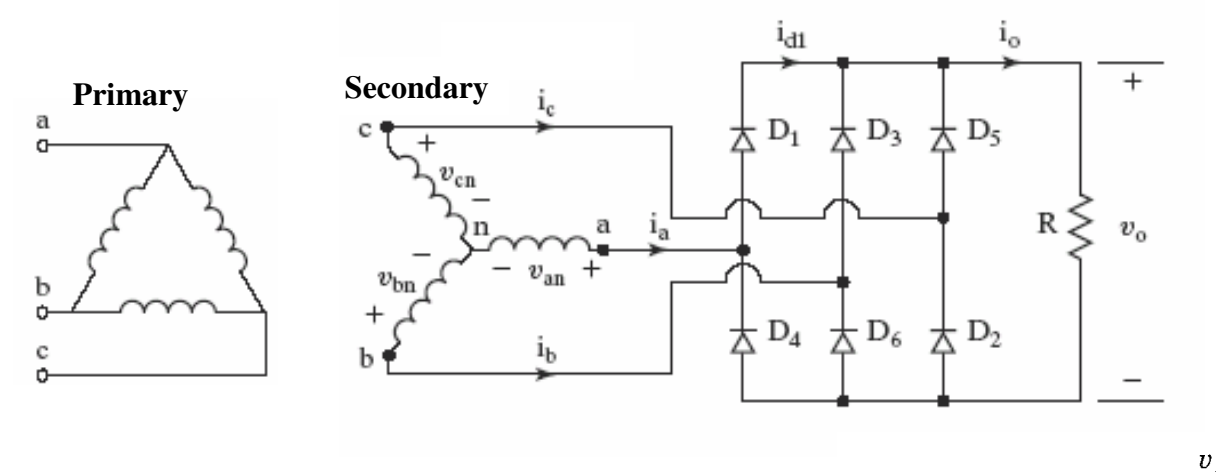
$$= V_m \sqrt{\frac{q}{2\pi}\left(\frac{\pi}{q} + \frac{1}{2} Sin \frac{2\pi}{q}\right)}$$

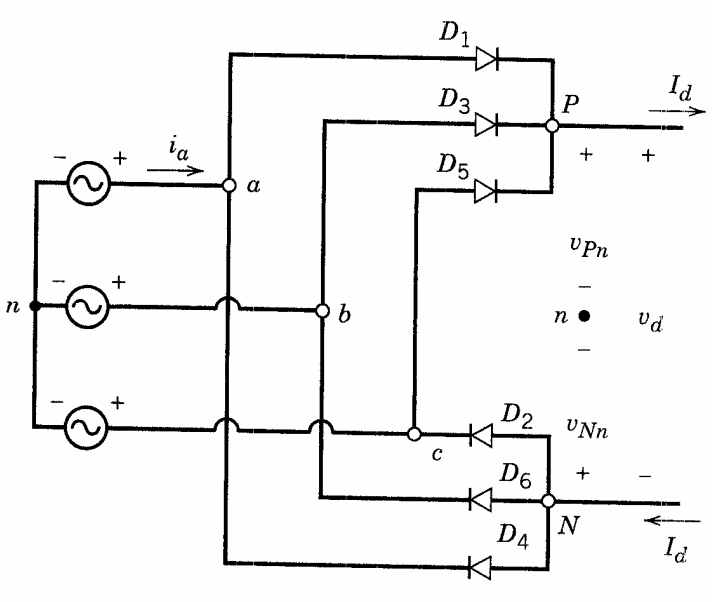
$$I_s = \sqrt{\frac{2}{2\pi}\int_0^{\frac{\pi}{q}} I_m^{\,2} \, Cos^2 \, \omega t \, d(\omega t)}$$

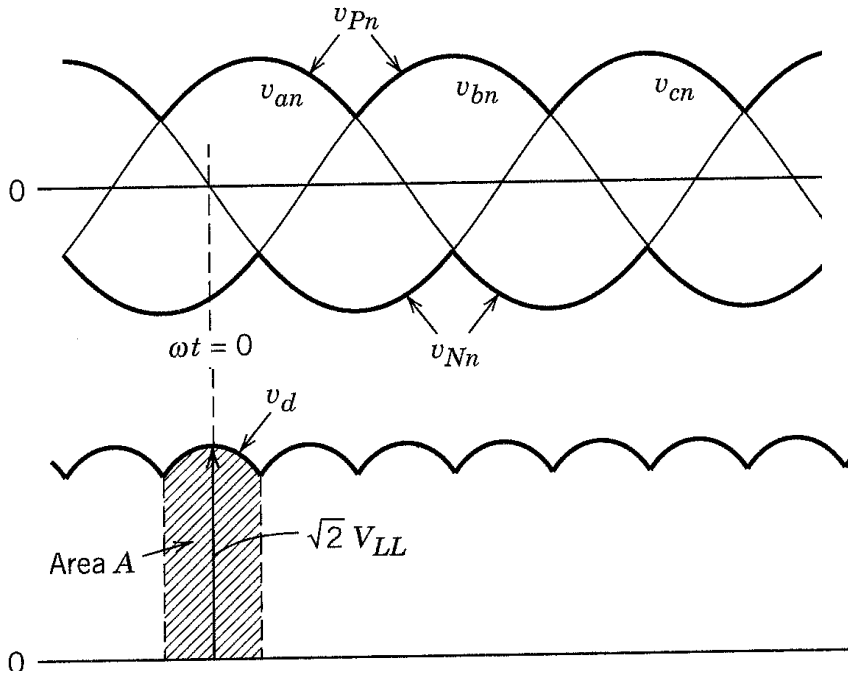
$$= \frac{V_{rms}}{R\sqrt{q}} = \frac{I_{rms}}{\sqrt{q}}$$

Three-Phase Bridge Rectifier

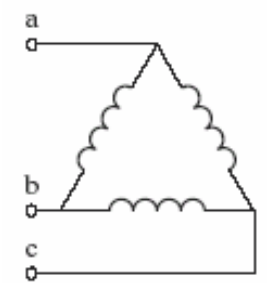
یکسوکننده پل سه فاز





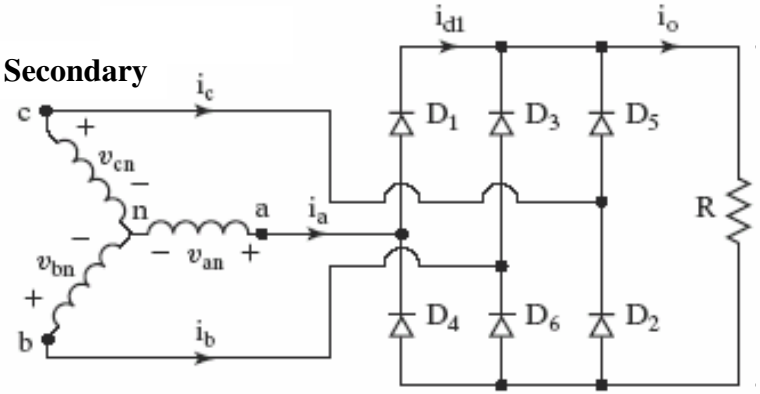


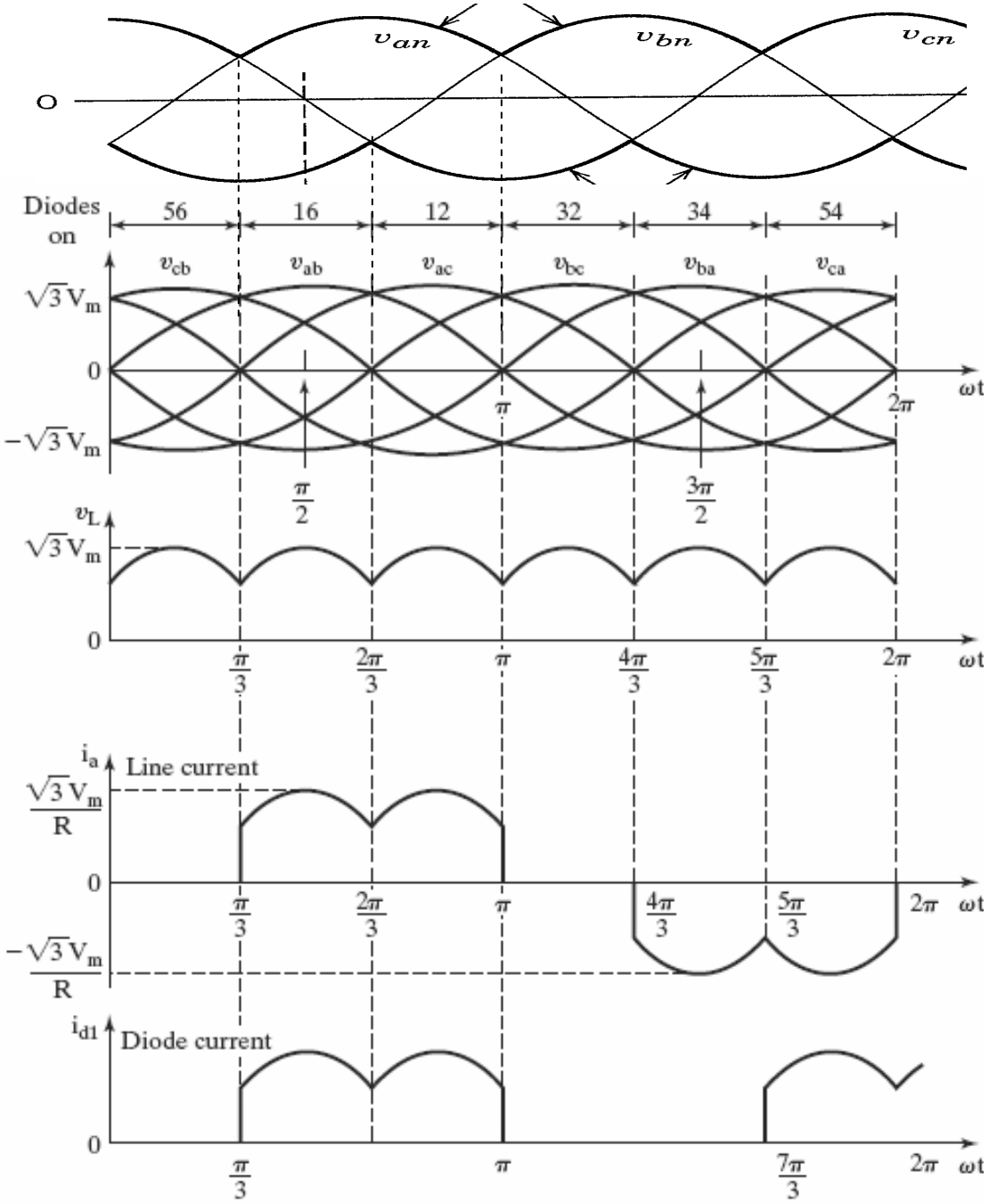
Three-Phase Bridge Rectifier



Primary

Secondary





$$V_{dc} = \frac{6\times 2}{2\pi}\int_0^{\frac{\pi}{6}} \sqrt{3}V_m Cos\,\omega t\, d(\omega t) = \frac{3\sqrt{3}V_m}{\pi} = 1.6539 V_m$$

$$\Rightarrow \quad \eta = \frac{P_{dc}}{P_{ac}} = 99.83\%$$

$$V_{rms} = \sqrt{\frac{2}{\frac{2\pi}{6}}\int_0^{\frac{\pi}{6}} 3{V_m}^2 Cos^2\,\omega t\, d(\omega t)} = 1.6554 V_m$$

$$I_{rms} = \sqrt{\frac{6\times 2}{2\pi}\int_0^{\frac{\pi}{6}} {I_m}^2 Cos^2\,\omega t\, d(\omega t)} = 0.9557\, I_m = \frac{V_{rms}}{R}$$

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

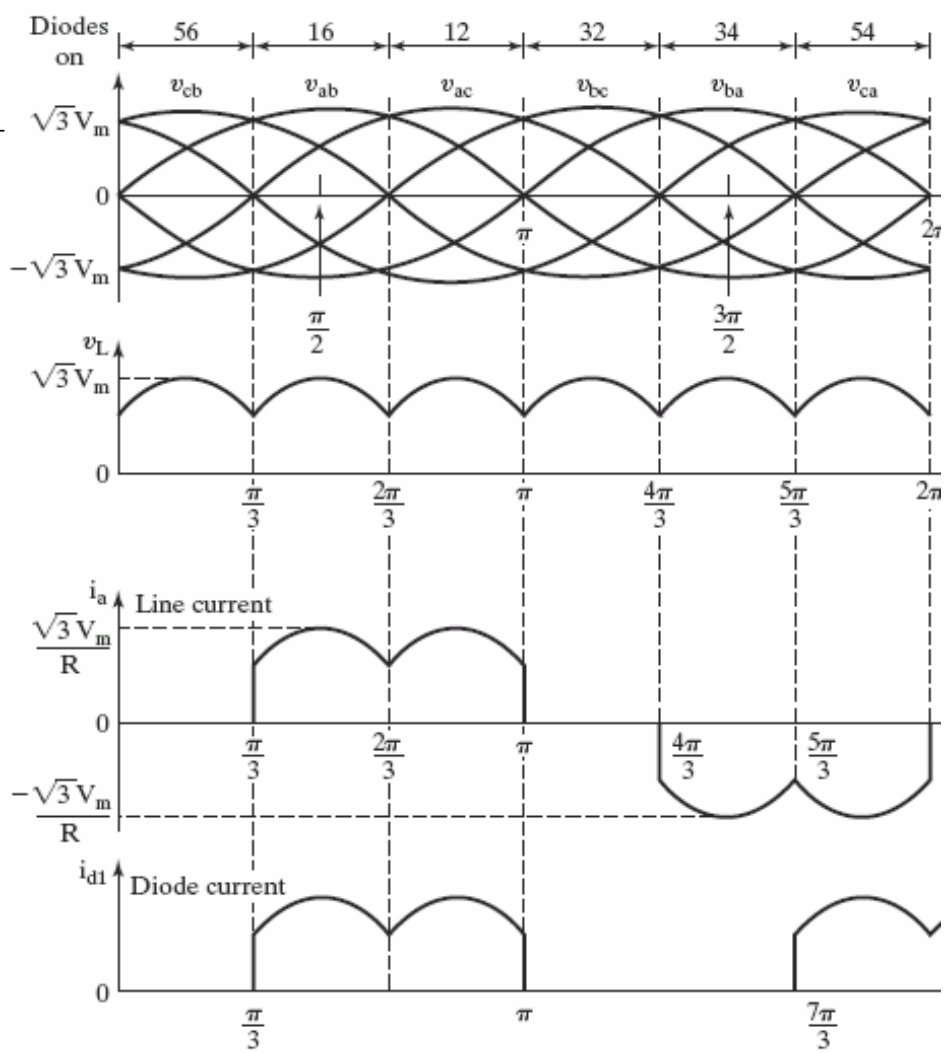
$$I_s = \sqrt{\frac{4\times 2}{2\pi}\int_0^{\frac{\pi}{6}} {I_m}^2 Cos^2\,\omega t\, d(\omega t)} = 0.7804\, I_m$$

$$I_r = \sqrt{\frac{2\times 2}{2\pi}\int_0^{\frac{\pi}{6}} {I_m}^2 Cos^2\,\omega t\, d(\omega t)} = 0.5518\, I_m$$

$$I_d = \frac{2\times 2}{2\pi}\int_0^{\frac{\pi}{6}} I_m Cos\,\omega t\, d(\omega t) = \frac{I_m}{\pi} = 0.318 V_m$$

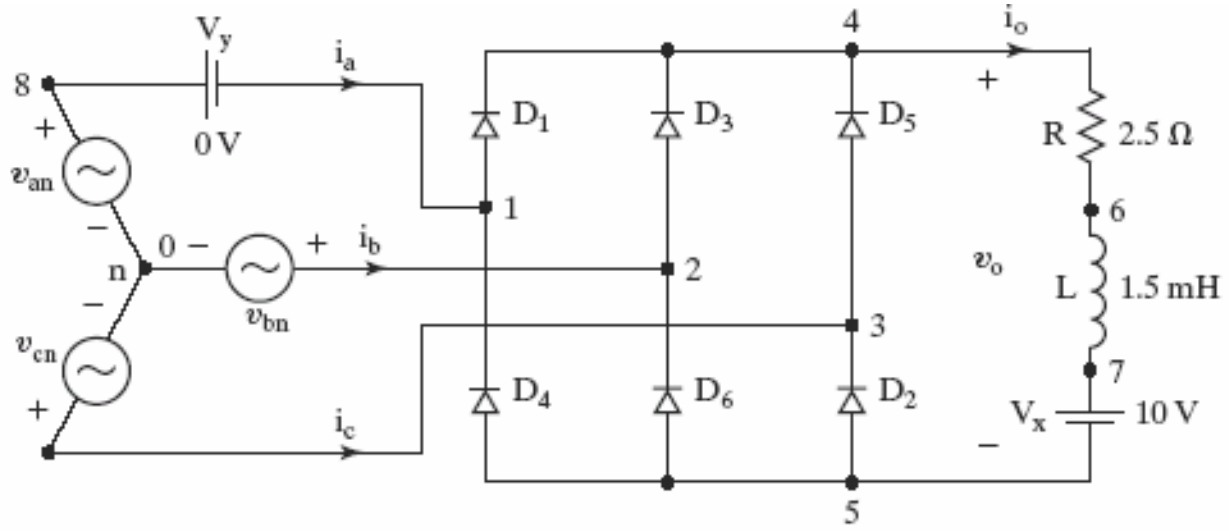
$$I_{dc} = \frac{V_{dc}}{R} = 3 I_d$$

Inductive load?



3-Phase Bridge Rectifier (RL Load)

یکسوکننده پل سه فاز با بار اهمی- سلفی

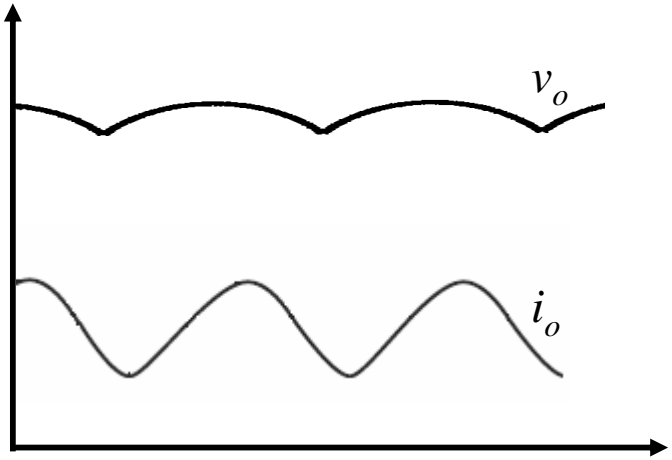


$$v_{ab} = \sqrt{2}V_{ab}\sin\omega t \quad for \quad \frac{\pi}{3} \le \omega t \le \frac{2\pi}{3}$$

$$L\frac{di_o}{dt} + Ri_o + E = \sqrt{2}V_{ab}\sin\omega t$$

$$i_o = \frac{\sqrt{2}V_{ab}}{Z}\sin(\omega t - \theta) + A_1 e^{-(R/L)t} - \frac{E}{R}$$

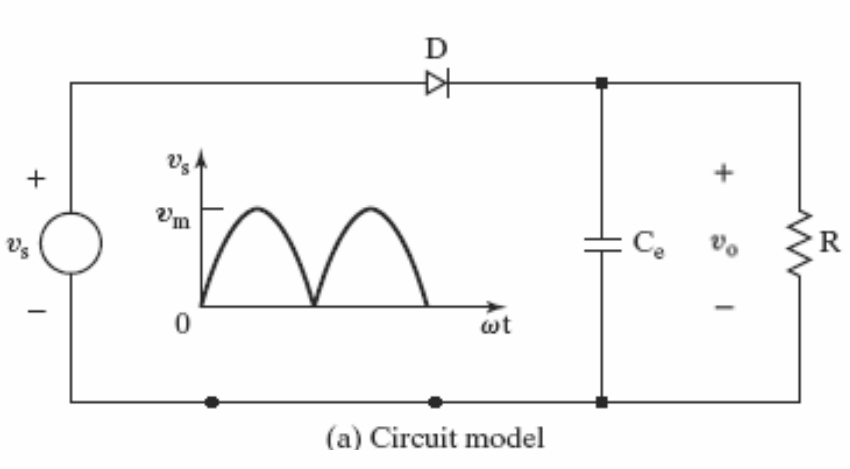
$$Z = \sqrt{R^2 + (\omega L)^2} \qquad \theta = \tan^{-1}(\omega L / R)$$



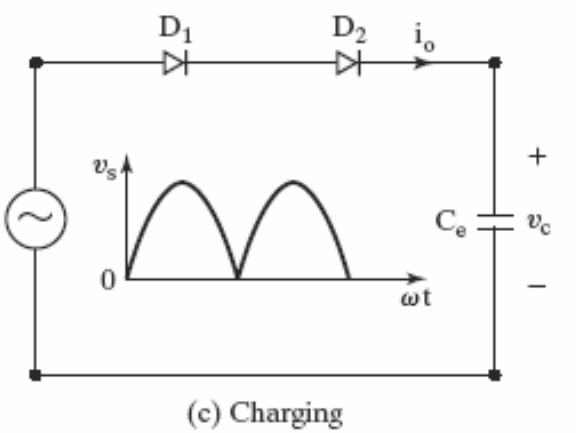
- Case 1: Continuous conduction, $i_o > 0$
- Case 2: Discontinuous conduction, $i_o = 0$

Single-Phase Rectifier with C-Filter

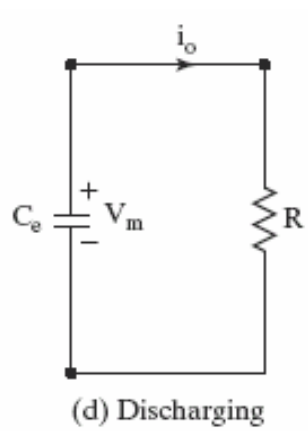
یکسوکننده پل تکفاز فاز با فیلتر C



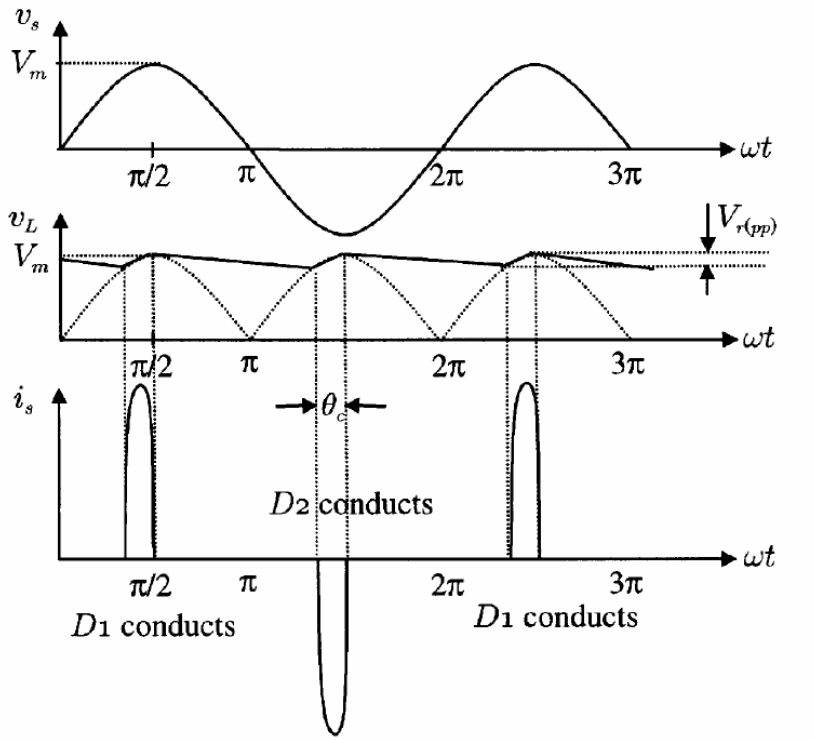
(a) Circuit model



(c) Charging



(d) Discharging



$$V_{o(dc)} = V_m - \frac{V_m}{4fRC_e}$$

$$V_{rms(ripple)} = \frac{V_{r(pp)}}{2\sqrt{2}} = \frac{V_m}{4\sqrt{2}fRC_e}$$

$$RF = \frac{V_{rms(ripple)}}{V_{o(dc)}} = \frac{1}{\sqrt{2}(4fRC_e - 1)}$$