Lecture # 11

ECEN 438/738 Power Electronics

Spring 2025 Semester

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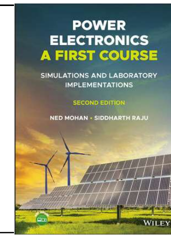
ECEN 438/738 Power Electronics



Power Electronics
A First Course: 2nd Edition

Free Textbook Online Access Link: https://go.oreilly.com/TAMU/library/view/-/9781119818564/?ar

Chapter 5
RECTIFICATION OF UTILITY INPUT USING DIODE RECTIFIERS

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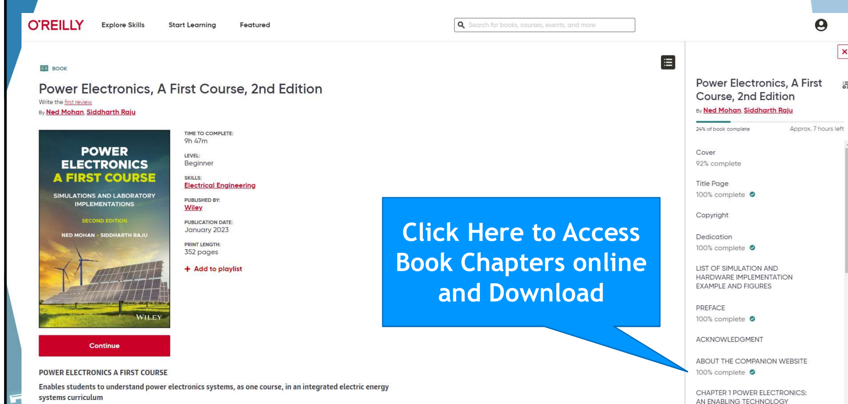
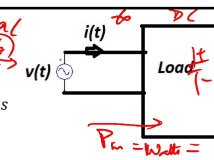


Total Harmonics - THD - PF - DF

(120V, 60Hz / 240V, 50Hz) ac



$$v(t) = \sqrt{2}V * \sin(wt) \quad Volts$$

$$i(t) = \sqrt{2}I_1 \sin(wt - \emptyset_1) + \sqrt{2}I_3 \sin(3wt + \emptyset_3) + \sqrt{2}I_5 \sin(5wt + \emptyset_5) \quad Amps$$

harmonic

$$THD = \frac{rms\ of\ the\ harmonic\ components}{rms\ of\ the\ fundamental\ component}$$

$$DF = \frac{I_1}{I_{rms}}$$

Note: $I_{rms} = \sqrt{I_1^2 + I_3^2 + I_5^2}$ *Therefore rms of the harmonic components* $= \sqrt{I_3^2 + I_5^2}$

Not: $\sqrt{I_3^2 + I_5^2} = \sqrt{I_{rms}^2 - I_1^2}$

$$Therefore\ THD = \frac{\sqrt{I_3^2 + I_5^2}}{I_1} = \frac{\sqrt{I_{rms}^2 - I_1^2}}{I_1} = \sqrt{\frac{I_{rms}^2}{I_1^2} - 1} = \sqrt{\frac{1}{DF^2} - 1}$$

$$\boxed{THD = \sqrt{\frac{1}{DF^2} - 1}}$$

Single Phase Diode Rectifier

$\frac{\Delta V_o}{V_o} = \%$

$V_m = \sqrt{2} V_s$

Note: as C increases α decreases and ΔV_o decreases

The RC discharge equation is $v_o(t) = V_m * e^{\frac{-t}{RC}}$

Also note that input current flows ONLY when diodes conduct i.e. power is supplied during the conduction α only

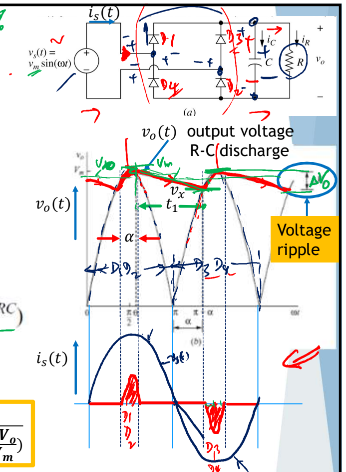
Now $v_x(t) = V_m * e^{\frac{-t_1}{RC}}$ As C is large $t_1 \to \frac{\pi}{w}$

Therefore $V_x = V_m * e^{\frac{-\pi}{wRC}}$

$\Delta V_o = V_m - V_x = V_m - V_m * e^{\frac{-\pi}{wRC}} = V_m(1 - e^{-\pi/\omega RC})$

From Math, $e^{-\pi/\omega RC} \approx 1 - \frac{\pi}{\omega RC}$

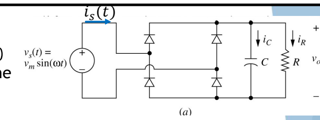
Therefore $\boxed{\Delta V_o \approx \frac{V_m \pi}{\omega RC} = \frac{V_m}{2fRC}}$ and $\boxed{C = \frac{1}{2 * f * R * (\frac{\Delta V_o}{V_m})}}$



Single Phase Diode Rectifier

60 Hz

For a single phase diode rectifier shown in figure, $v_s = 120\ V\ (rms)$ R = 500 ohms, C = 100 uF, a) Calculate the voltage ripple b) Find the capacitance C to limit the voltage ripple to 1%



Note $\boxed{C = \frac{1}{2 * f * R * (\frac{\Delta V_o}{V_m})}}$

a) Voltage ripple $\frac{\Delta v_o}{V_m} = 0.167\ or\ 16.7\%$

b) For a voltage ripple $\frac{\Delta v_o}{V_m} = 0.01$, $we\ have\ C = 1670\ uF$

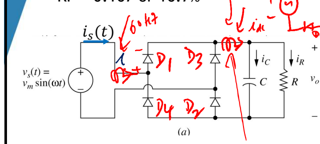
Attendance

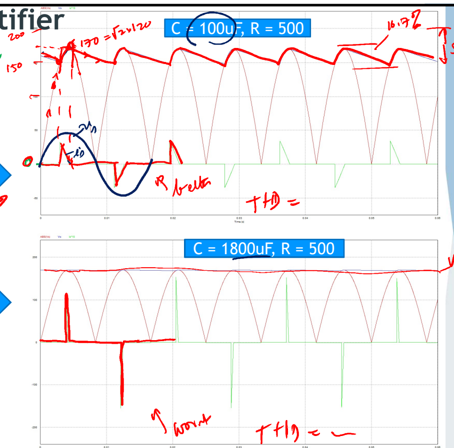
Current Sensor

Single Phase Diode Rectifier

Example: Vs = 120 rms,
R=500 ohms, C = 100uF
RF = 0.167 or 16.7%

$\frac{\Delta V_o}{V_o}$ = RF ripple Factor





Example: Vs = 120 rms,
R=500 ohms, C = 1800uF
RF = 0.01 or 1%

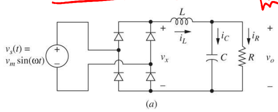
Note: As C is increased RF decreases. However input current peak increases & quality deteriorates

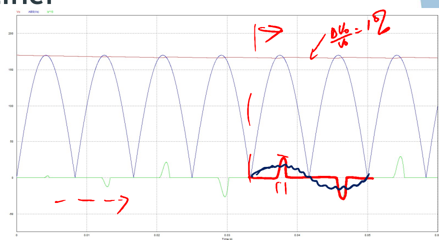
Solution: Add an Inductor to limit the current peak

Single Phase Diode Rectifier

Example: Vs = 120 rms,
R=500 ohms,
L= 1mH, C = 1800uF
RF = 0.01 or 1%

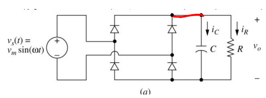
with inductor

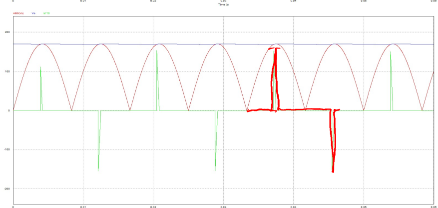




Example: Vs = 120 rms,
R=500 ohms,
L= 0, C = 1800uF
RF = 0.01 or 1%

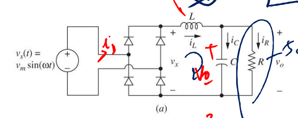
without Inductor

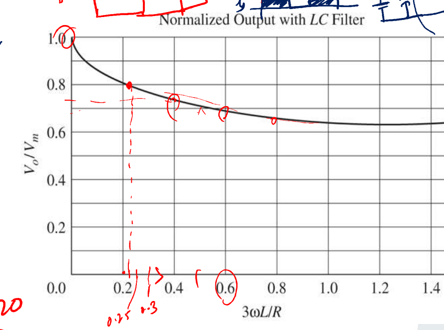




Single Phase Diode Rectifier

Example: Vs = 120 rms,
R=5 ohms, 60Hz
L= 1mH, C = 1800uF
RF = 0.01 or 1%





$$\frac{3\omega L}{R} = \frac{3\times 2\pi f\times 1\times 10^{-3}}{5} = 0.226 \approx 0.23$$

$$\frac{V_o}{V_m} = 0.8$$

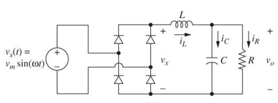
$$V_o = 0.8\times\sqrt{2}\times 120$$

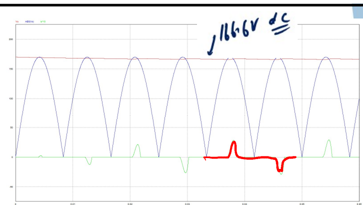
$$\boxed{V_o = 135.8V}$$

$$P_o = \frac{V_o^2}{R} = \frac{(135.8)^2}{5} = 3.68\ kW$$

Single Phase Diode Rectifier

Example: Vs = 120 rms,
R=500 ohms,
L= 1mH, C = 1800uF
RF = 0.01 or 1%





166.6V dc

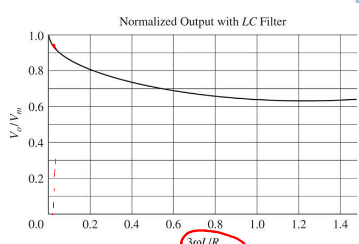
$$\frac{3\omega L}{R} = \frac{3\times 2\pi f\times 1\times 10^{-3}}{500} = 0.0023$$

Graph is different to read

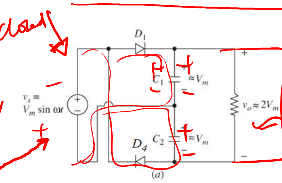
$$\frac{V_o}{V_m} \simeq 0.98$$

$$V_o = 0.98\times 120\sqrt{2} = 166.6V$$

$$P_o = \frac{(V_o)^2}{R} = \frac{(166.6)^2}{500} = 55\ watt$$

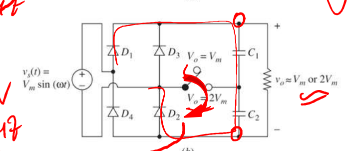


Single Phase Diode Rectifier - Voltage doubler



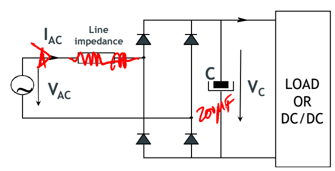
120V 60Hz

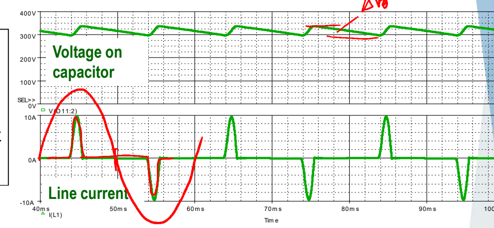
240V 50Hz



Single Phase Diode Rectifier --- and - Neutral Current

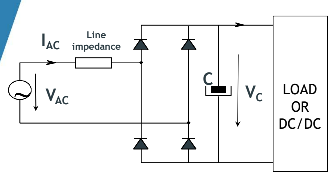
- AC mains: 230V and 50Hz
- Line impedance: 0.4Ω and 800μH
- For 300W and 10% voltage ripple: C= 200μF

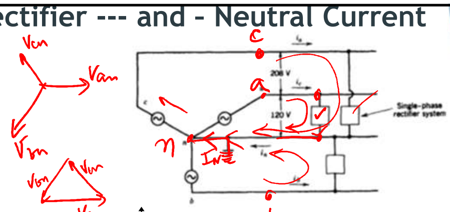


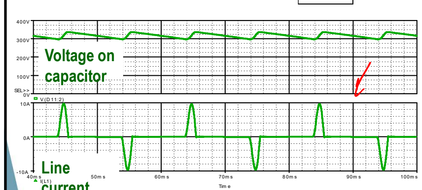


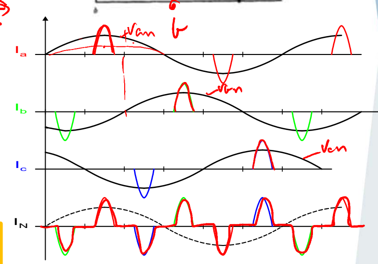
➢ Current only flows during the center portion of the input sine wave

Single Phase Diode Rectifier --- and - Neutral Current





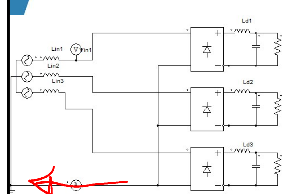


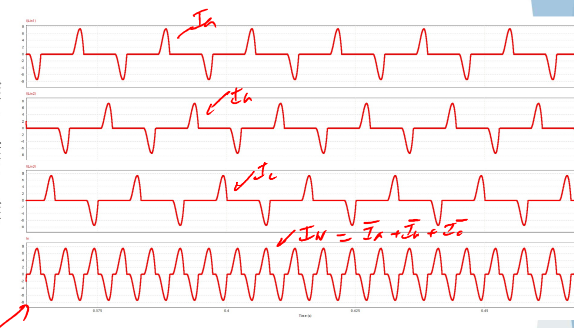


$$I_{N,rms} = \sqrt{I_{a,rms}^2 + I_{b,rms}^2 + I_{c,rms}^2}$$

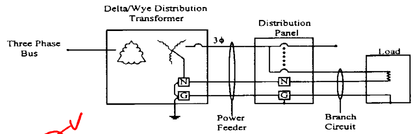
$$I_{N,rms} = \sqrt{3} * I_{phase,rms}$$

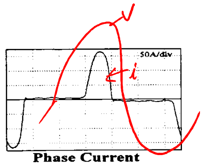
Single Phase Diode Rectifier --- and - Neutral Current



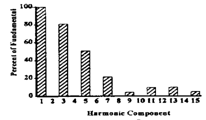


Single Phase Diode Rectifier --- and - Neutral Current

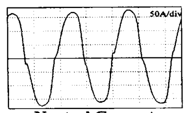




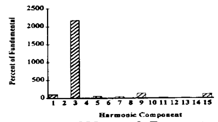
Phase Current



FFT of Phase Current



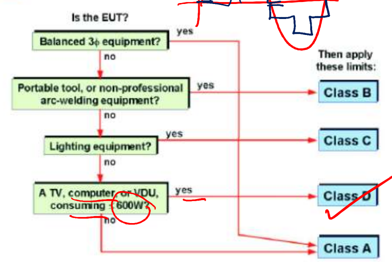
Neutral Current



FFT of Neutral Current

	WITH THIRD HARMONIC	WITHOUT THIRD HARMONIC
APPARENT POWER	≅ 48kVA	≅ 40kVA
POWER FACTOR	≅ .73	≅ .89
CREST FACTOR	≅ 2.36	
K RATING	≅ 5.8	≅ 5.34

Harmonic Current Limits - IEC 1000-3-2 (EN6 1000-3-2)



The emissions limits in EN 61000-3-2 Ed.2:2000
Relaxations for transitory emissions are specified in the standard

Harmonic order 'n'	Max current Class A	Max current Class B	Max current Class C (% of fundamental current)	Max current Class D (but no more than Class A)
2	1.08 Amps	1.62 A	2%	not specified
3	2.30 A	3.45 A	30λ %	3.4 mA/Watt
4	0.43 A	0.645 A	not specified	not specified
5	1.14 A	1.71 A	10%	1.9 mA/Watt
6	0.30 A	0.45 A	not specified	not specified
7	0.77 A	1.155 A	7%	1.0 mA/Watt
$8 \leq n \leq 40$ (even)	0.23 (8/n) A	0.345 (8/n) A	not specified	not specified
9	0.40 A	0.6 A	5%	0.5 mA/Watt
11	0.33 A	0.495 A	3%	not specified
13	0.21 A	0.315 A	3%	0.35 mA/Watt
$15 \leq n \leq 39$ (odd)	0.15 (15/n) A	0.225 (15/n) A	3%	(3.85/n) mA/Watt

(λ is the circuit power factor)

https://www.emcstandards.co.uk/files/61000-3-2_mains_harmonics.pdf