Lecture # 8

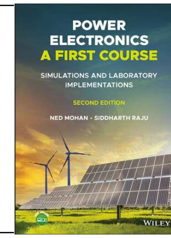
ECEN 438/738 Power Electronics

Spring 2025 Semester

Dr. Prasad Enjeti,
Electrical & Computer Engineering
Texas A&M University
http://enjeti.tamu.edu

1

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

2

ECEN 438/738 Power Electronics

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

Click Here to Access Book Chapters online and Download

3

DC-DC Buck Converter - DC-DC Boost Converter

DC-DC Buck Converter

1. $\boxed{V_o = D V_{in}}$

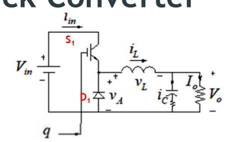
2. $\boxed{\Delta I_L = \frac{V_o (1-D) T}{L}}$

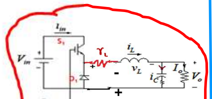
3. $\boxed{L_{min} = \frac{(1-D) R}{2f}}$

4. $\boxed{I_L = I_o = \frac{V_o}{R} \quad T = \frac{1}{f}}$

5. (Input Power) $V_{in} I_{in} = V_o \cdot I_o$ (output Power)
$I_{in} = \frac{V_o}{V_{in}} \cdot I_o = D \cdot I_o = D I_L$

6. $\boxed{C = \frac{(1-D)}{\left(\frac{\Delta V_o}{V_o}\right) * 8 * L * f^2}}$





$$V_o = \frac{V_{in} * D}{1 + \frac{r_L}{R}}$$

$$\eta = \frac{1}{1 + \frac{r_L}{R}}$$

DC-DC Boost Converter

$$\boxed{V_o = \frac{V_{in}}{1 - D}}$$

$$\boxed{\Delta I_L = \frac{V_{in} * DT}{L}; \quad L = \frac{V_{in} * DT}{\Delta I_L} = \frac{V_{in} * D}{f * \Delta I_L}}$$

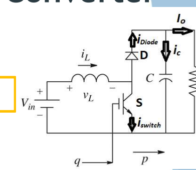
$$\boxed{L_{min} = \frac{D * (1-D)^2 * R}{2 * f}}$$

$$V_{in} * I_L = V_o * I_o$$

$$I_{Diode} = I_o = \frac{V_o}{R}$$

$$I_{switch} = I_L * D$$

$$\boxed{C = \frac{I_o * DT}{\Delta V_o} = \frac{D}{R * \left(\frac{\Delta V_o}{V_o}\right) * f}}$$



$$\boxed{C = \frac{I_o * DT}{\Delta V_o} = \frac{D}{R * \left(\frac{\Delta V_o}{V_o}\right) * f}}$$

$$\boxed{\frac{V_o}{V_{in}} = \left(\frac{1}{1-D}\right)\left(\frac{1}{1 + \frac{r_L}{R(1-D)^2}}\right)}$$

$$\boxed{\eta = \frac{1}{1 + \frac{r_L}{R(1-D)^2}}}$$

4

Question 2 10 pts

In the DC-DC buck converter shown in the figure, the input voltage V_{in} is varying from 6 V to 24 V, the output voltage V_o is regulated to 5 V. The power output power P_o is also variable and is in the range 27 watts to 52 watts. The switching frequency is 342 kHz. The inductor resistance $r_L = 0.16$ ohms. **Calculate the required minimum duty cycle D to regulate the output voltage at 5 V?**

(Assume: continuous conduction mode of operation)

6V to 24V

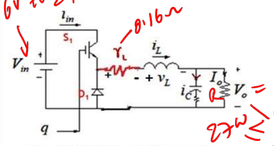


Fig. DC-DC Buck Converter

$L = xy\ \mu H$

$$\boxed{L_{min} = \frac{(1-D)R}{2f}}$$

D_{min} ?

$$D_{min} = \left(\frac{V_o}{V_{in}}\right)\left(1 + \frac{r_L}{R}\right)$$

$$\boxed{D_{min} = \frac{5}{24}\left(1 + \frac{0.16}{R_{max}}\right)}$$

$27W \leq P_o \leq 52\ W$

$$\boxed{\frac{V_o}{V_{in}} = \frac{D}{1 + \frac{r_L}{R}}}$$

$P_o = \frac{V_o^2}{R} \Rightarrow \boxed{R = \frac{V_o^2}{P_o}}$

$R_{max} = \frac{5^2}{27}$

5

Complex Power - ECEN 340

$v(t) = V_p \cos(\omega t + \theta_V)$

$i(t) = I_p \cos(\omega t + \theta_I)$

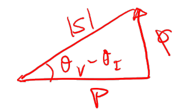
Since $\boxed{V_{RMS} = \frac{V_p}{\sqrt{2}}}$ $\boxed{I_{RMS} = \frac{I_p}{\sqrt{2}}}$

$\boxed{Where: \phi = \theta_V - \theta_I}$

$$P = \frac{V_p I_p}{2} \cos(\theta_V - \theta_I) \qquad Q = \frac{V_p I_p}{2} \sin(\theta_V - \theta_I)$$

$$P = V_{RMS} * I_{RMS} * \cos(\phi)$$

$$Q = V_{RMS} * I_{RMS} * \sin(\phi)$$



Representing $v(t)$, $i(t)$ as phasors, we have

$\bar{V} = V_{rms}\angle\theta_V$ **Complex Power** $S = \bar{V}\bar{I}^* = V_{rms}I_{rms}\angle(\theta_V - \theta_I)$

$\bar{I} = I_{rms}\angle\theta_I$

$$\boxed{S = \bar{V}\bar{I}^* = P + jQ}$$

6

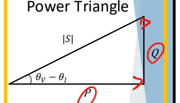
Complex Power - ECEN 340

Representing sinusoidal voltage and current $v(t)$, $i(t)$ *as phasors, we have*

$\bar{V} = V_{rms}\angle\theta_V$ $\boxed{S = \bar{V}\bar{I}^* = P + jQ}$

$\bar{I} = I_{rms}\angle\theta_I$

$(\phi) = \theta_V - \theta_I$



S: Complex power (VA, kVA, MVA)

$|S|$: Apparent power (VA, kVA, MVA) $= V_{rms} * I_{rms}$

P: Real power (W, kW, MW) $= V_{rms} * I_{rms} * \cos(\phi)$

Q: Reactive power (Var, kVar, Mvar) $= V_{rms} * I_{rms} * \sin(\phi)$

Power Factor (PF): $\cos(\phi)$

7

Conservation of Complex Power - ECEN 340

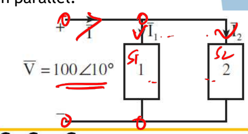
Suppose the two loads in Example # 1 and Example # 2 are connected in parallel.

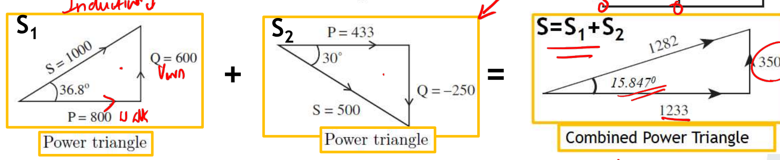
$\bar{S}_1 = 800 + j600$ VA $\bar{S}_2 = 433 - j250$ VA

The Total Power S is: $\bar{S} = \bar{S}_1 + \bar{S}_2 = (800 + 433) + j(600 - 250)$

$= 1233 + j350$ VA

Inductive





The Total Input current I : $\bar{I} = \frac{\bar{S}^*}{\bar{V}^*} = \frac{1233 - j350}{100\angle - 10°} = \frac{1282\angle - 15.847°}{100\angle - 10°} = 12.82\angle - 5.847°$ A

Same

From KVL, Input current: $\bar{I} = \bar{I}_1 + \bar{I}_2 = 10\angle - 26.8^0 + 5\angle 30^0 = 12.82\angle - 5.847^0$

This proves the conservation of complex power

8

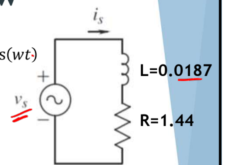
Power Factor / RMS - Fundamentals - Review

$I = \frac{V}{Z} = \frac{120∠0}{1.44 + j7.054} = 16.67\angle{-78.46^\circ}$

$v_s = \sqrt{2} * 120 * \cos(wt)$

$w = 2 * \pi * f = 2\pi \times 60$

$V = 377$



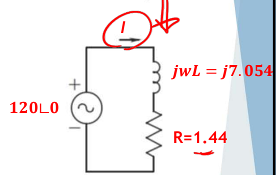
Complex Power

$S = V \cdot I^* = (120\angle 0)(16.67\angle{+78.46^\circ})$

$= 2000\angle 78.46$

$\boxed{S = 400 + j1959.6}$

78.46° I (lagging) the voltage



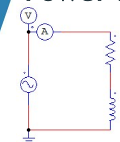
Real Power P = 400 W; Reactive Power Q = 1959.6 VAR

Power Factor: $PF = \frac{real\ power}{apparent\ power} = \frac{P}{V_{rms} * I_{rms}} = \frac{P}{|S|} = \frac{400}{2000} = 0.2$

$PF = \frac{V * I * \cos(\emptyset)}{V * I} = \cos(\emptyset) = \cos(78.46^0) = 0.2$

9

Power Factor / RMS - Fundamentals - PSIM Simulations



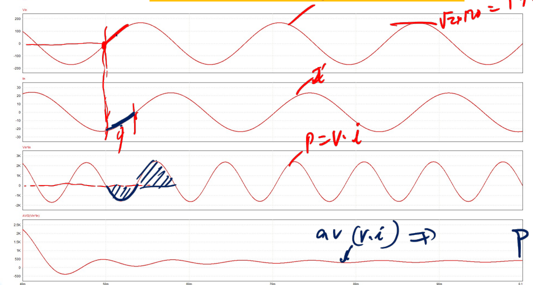
$P = V * I * \cos(\emptyset) = 400\ W$

$I = 16.67\ A$

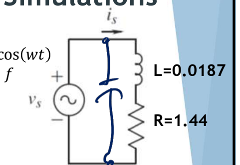
$v_s = \sqrt{2} * 120 * \cos(wt)$

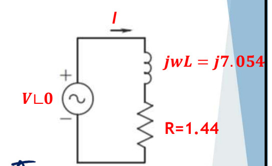
$w = 2 * \pi * f$

If PF = 1, i.e. Ø=0, then for V=120, we needs only I = 3.33 A for P = 400 Watts
Q - How can accomplish this??



$P = \frac{1}{T}\int v \cdot i \cdot dt$

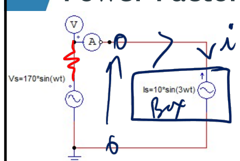


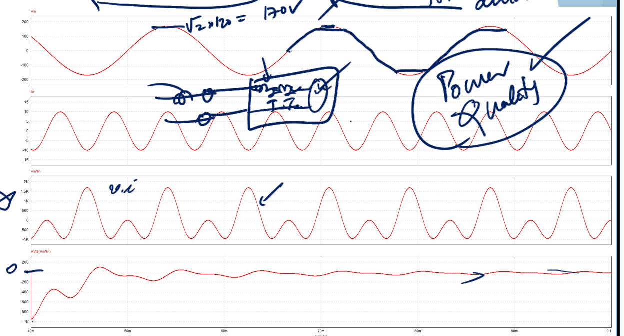


10

Power Factor / RMS - Harmonics - THD - DF

Total harmonic distortion





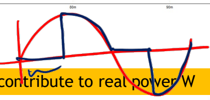
v(t) = 170 * cos(wt) V

i(t) = 10 * cos(3wt) V

Instantaneous Power
p(t) = v(t) * i(t)

Average Power

$P = \frac{1}{2\pi}\int_0^{2\pi} 170 * \cos(wt) * 10 * \cos(3wt)\, d(wt)$ = **0 (from calculus)**



Therefore voltage and current of different frequencies do not contribute to real power W

12

Definition of rms

if $v(t) = V_1 * \sin(\omega_1 t) + V_2 * \sin(\omega_2 t)$ + - - - -

$v(t) = V_1 \sin \omega t + V_2 \sin 3\omega t$

Then V_{rms} is

$V_{rms} = \sqrt{\frac{1}{T}\int_0^T (v_1 + v_2)^2\, dt}$

$= \sqrt{\frac{1}{T}\int_0^T (v_1^2 + 2v_1v_2 + v_2^2)\, dt}$

$= \sqrt{\frac{1}{T}\int_0^T V_1^2 \sin^2\omega t + \frac{1}{T}\int 2V_1V_2 \sin\omega t \cdot \sin 3\omega t\, dt + \frac{1}{T}\int_0^T V_2^2 \sin^2 3\omega t\, dt}$

$V_{rms} = \sqrt{\left(\frac{V_1}{\sqrt{2}}\right)^2 + \left(\frac{V_2}{\sqrt{2}}\right)^2}$

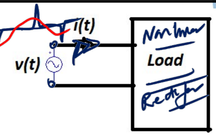
Therefore V_{rms} is

$V_{rms} = \sqrt{\left(\frac{V_1}{\sqrt{2}}\right)^2 + \left(\frac{V_2}{\sqrt{2}}\right)^2}$

13

Total Harmonics - THD - PF - DF

Power Factor: $PF = \dfrac{Real\ Power\ (watts)}{Apparent\ Power\ (volt.amps)}$



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

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

Real Power "P" =

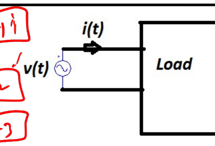
odd

even

14

Total Harmonics - THD - ~~PF~~ - ~~DF~~

Power Factor: $PF = \dfrac{Real\ Power\ (watts)}{Apparent\ Power\ (volt.amps)}$



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

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

Note: $I_{rms} = \sqrt{I_1^2 + I_3^2 + I_5^2}$

Watts

Real Power "P" $= VI_1 * Cos(\emptyset_1)$

Apparent Power $= V * I_{rms}$

Power Factor: $PF = \dfrac{Real\ Power\ (watts)}{Apparent\ Power\ (volt.amps)} = \dfrac{VI_1 * Cos(\emptyset_1)}{V * I_{rms}} = \dfrac{I_1 * Cos(\emptyset_1)}{I_{rms}}$

$I_{rms} > I_1$

Power Factor: $PF = \dfrac{I_1}{I_{rms}} * Cos(\emptyset_1)$

Distortion Factor (DF) $= \dfrac{I_1}{I_{rms}}$

$0 < DF \leq 1$

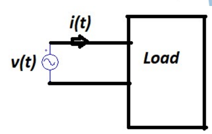
Displacement Factor (DPF) = $Cos(\emptyset_1)$

Power Factor: $PF = DF * DPF$

15

Total Harmonics - THD - PF - DF

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



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

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

$\leftarrow DF = \dfrac{I_1}{I_{rms}}$

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: $\sqrt{I_3^2 + I_5^2} = \sqrt{I_{rms}^2 - I_1^2}$

But THD $\equiv 0$

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

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

16