Lecture # 14

ECEN 438/738 Power Electronics

Spring 2025 Semester

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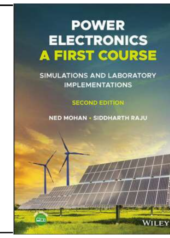

Power Electronics
A First Course: 2nd Edition

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Chapter 7

Magnetic Circuit Concepts

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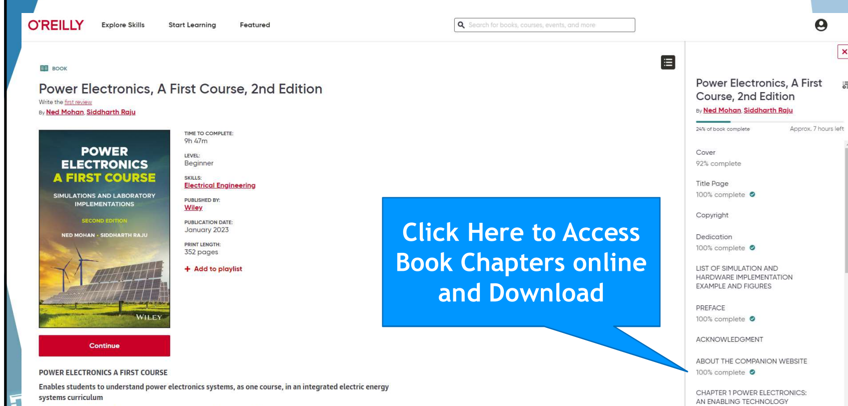

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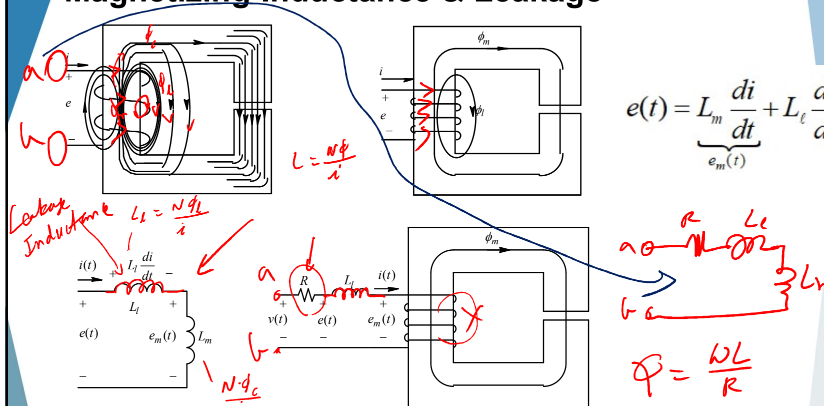
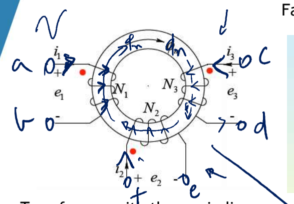
Magnetizing Inductance & Leakage



$$e(t) = \underbrace{L_m \frac{di}{dt}}_{e_m(t)} + L_\ell \frac{di}{dt}$$

Where R is the resistance of the coil & Rc is the core loss representation for hysteresis and eddy current losses

Transformers – Basics



Faraday's Law - a rate of change in flux results in induced voltage

$$e_1 = N_1\frac{d\phi_m}{dt}$$
$$e_2 = N_2\frac{d\phi_m}{dt}$$
$$e_3 = N_3\frac{d\phi_m}{dt}$$

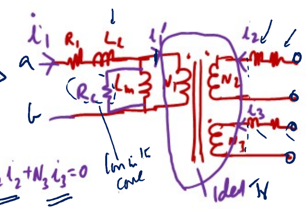
Therefore: $\frac{d\phi_m}{dt} = \frac{e_1}{N_1} = \frac{e_2}{N_2} = \frac{e_3}{N_3}$ $\Rightarrow \frac{e_1}{e_2} = \frac{N_1}{N_2}$; $\frac{e_3}{e_2} = \frac{N_3}{N_2}$

$$\Rightarrow \quad \phi_m = \frac{1}{N_1}\int e_1 dt = \frac{1}{N_2}\int e_2 dt = \frac{1}{N_3}\int e_3 dt$$

Transformer with three windings

Understand the dot convention

The equivalent circuit considering the Leakage flux is:



In many instances we neglect leakage inductance - assuming the coil is tightly wound - i.e. tightly coupled - hence no leakage

Choosing a core with high μ_r will result in high L_m therefore can be neglected.

$N_1 i_1' + N_2 i_2 + N_3 i_3 = 0$

l_m in core

Ideal Tr

Transformers – Continued

A three-winding transformer with N1=10 turns, N2=5 turns, and N3=5 turns uses a magnetic core that has the following properties: Am=0.639 cm^2, the magnetic path length l_m = 3.12 cm, and the relative permeability of the material μ_r=5000

A square-wave voltage of ±30V amplitude at a frequency of 100kHz is applied to winding 1. Windings 2 and 3 are open. Ignore the leakage inductance. Calculate and draw the magnetizing current waveforms and the voltages induced in the open windings 2 and 3

$\frac{e_1}{N_1} = \frac{e_2}{N_2} = \frac{e_3}{N_3}$; $e_2 = \frac{N_2}{N_1}e_1$; $e_3 = \frac{N_3}{N_1}e_1$

$e_2 = \pm 15V$; $e_3 = \pm 15V$

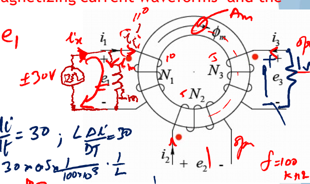
$$L_m = \frac{N^2}{R_e} = \frac{N^2}{\left(\frac{l}{\mu_0\mu_r A}\right)}$$

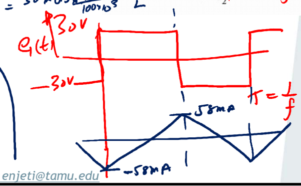
$$= \frac{100}{\frac{3.12\times10^{-2}}{4\pi\times10^{-7}\times5000\times6.639\times10^{-4}}} = 1.29\ mH$$

$L\frac{di}{dt} = 30$; $L\frac{\Delta i}{\Delta T} = 30$

$\Delta I = 30\times0.5\times\frac{1}{100\times10^3}\cdot\frac{1}{L}$

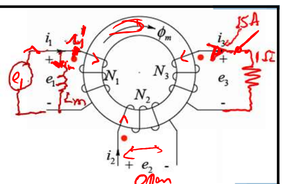
$\boxed{\Delta I = 116\ mA}$

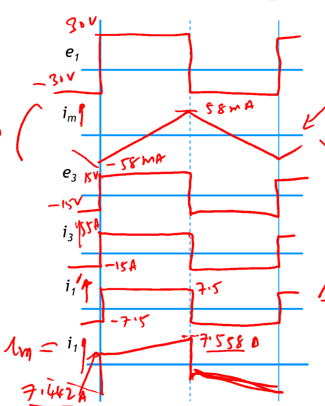




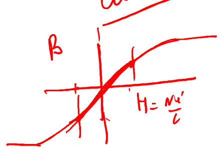
Transformers – Continued

Now a 1Ω resistance is connected to e_3





Magnetizing current



$i_1' + i_m = i_1$

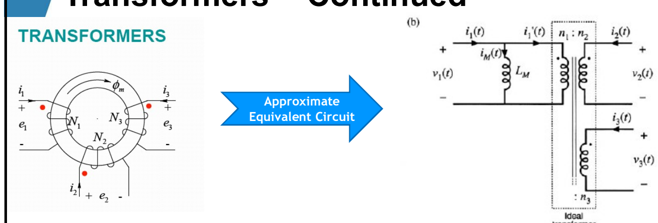
$N_1 i_1' + N_3(-i_3) = 0$

$N_1 i_1' = N_3 i_3$

$i_1' = \frac{N_3}{N_1}\cdot i_3$

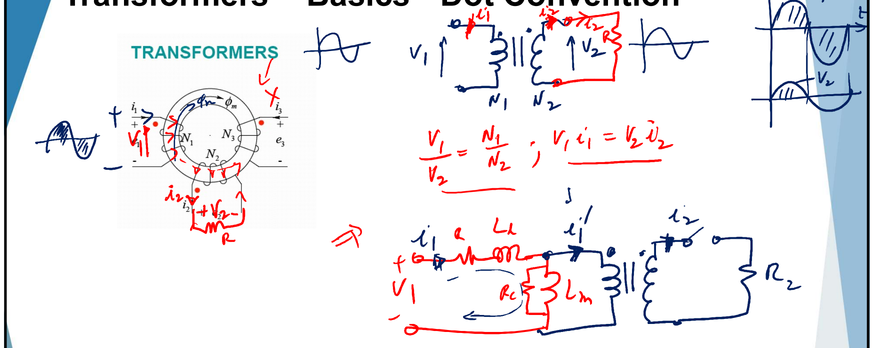
$= \frac{5}{10}(\pm 15A)$

Transformers – Continued

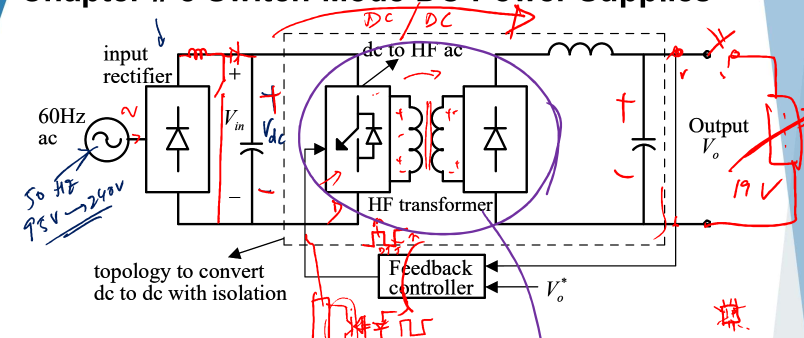


- Transformer provides isolation, its size & weight vary inversely with frequency
- When a large step-up or step-down conversion ratio is required, the use of a transformer can allow better converter optimization.
- By proper choice of transformer turns ratio, the voltage or current stresses imposed on the transistors and diodes can be minimized, leading to improved efficiency and lower cost
- Multiple dc outputs can also be obtained in an inexpensive manner, by adding multiple secondary windings and converter secondary side circuits.

Transformers – Basics - Dot Convention



Chapter # 8 Switch-Mode DC Power Supplies



Electrical isolation provides safety & is needed

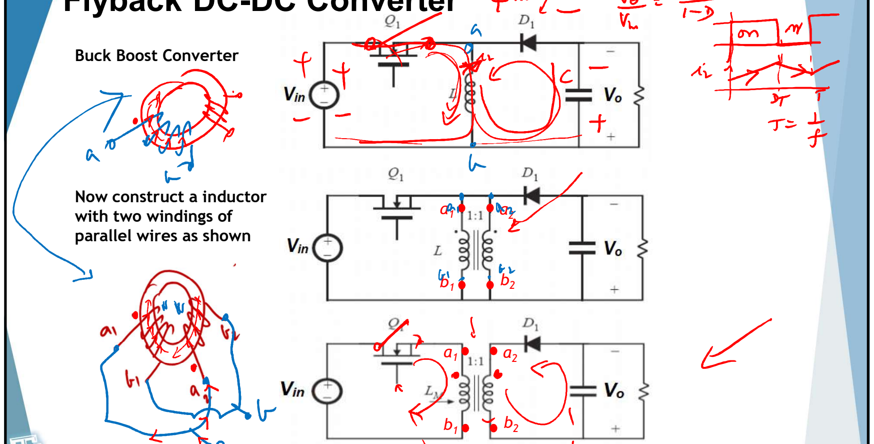
DC / DC

It is achieved via transformer isolation

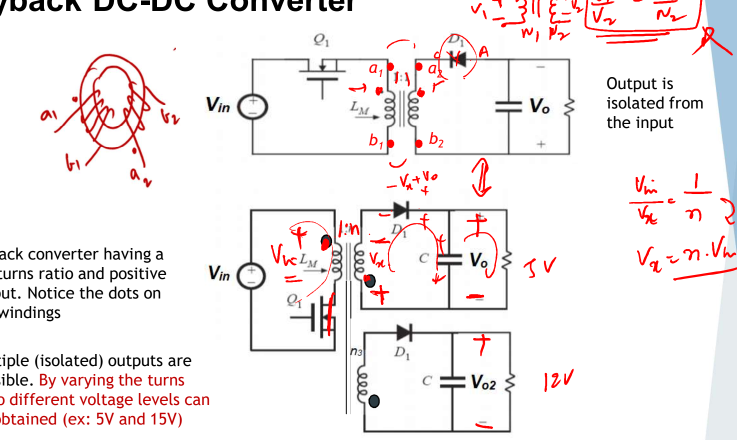
Flyback DC-DC Converter

Buck Boost Converter

Now construct a inductor with two windings of parallel wires as shown



Flyback DC-DC Converter



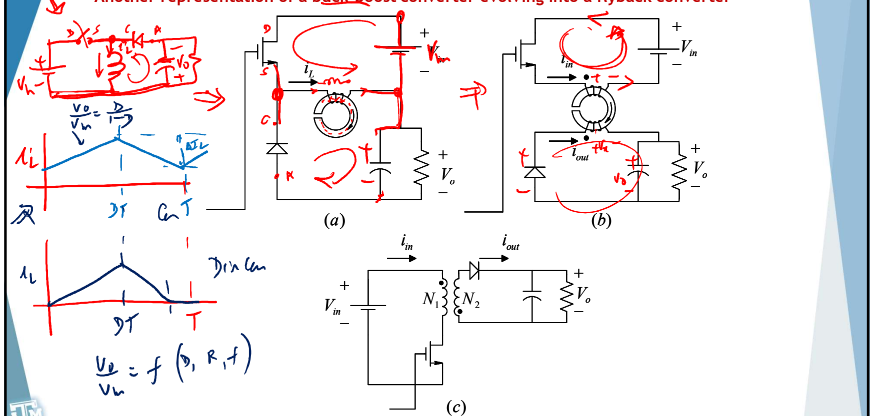
Output is isolated from the input

Flyback converter having a 1:n turns ratio and positive output. Notice the dots on the windings

Multiple (isolated) outputs are possible. By varying the turns ratio different voltage levels can be obtained (ex: 5V and 15V)

Flyback DC-DC Converter

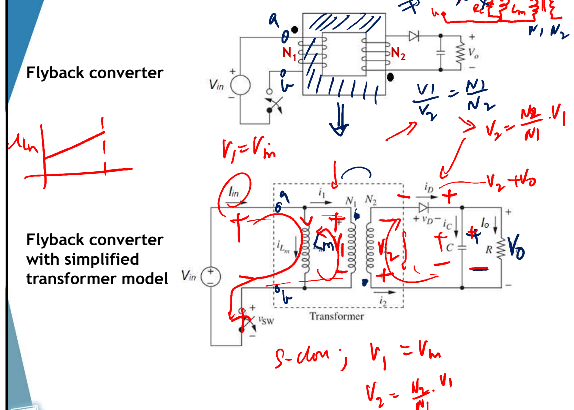
Another representation of a buck-boost converter evolving into a flyback converter



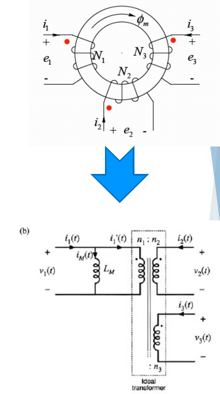
Flyback DC-DC Converter

Flyback converter

Flyback converter with simplified transformer model



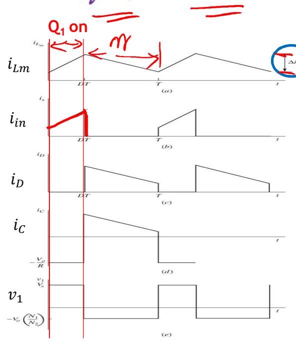
TRANSFORMERS

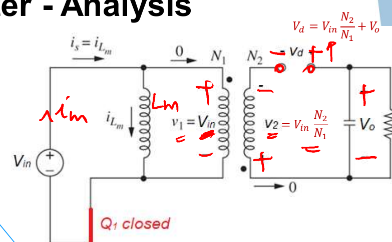


Flyback DC-DC Converter - Analysis

Switch Q_1 is Closed for DT

$\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow V_2 = V_1 \cdot \frac{N_2}{N_1}$





$$v_1 = V_{in} = L_m \frac{di_{Lm}}{dt}$$

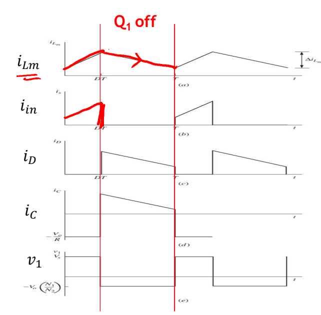
$$\frac{di_{Lm}}{dt} = \frac{\Delta i_{Lm}}{DT} = \frac{V_{in}}{L_m} \qquad L_m = \frac{V_{in} * DT}{\Delta i_{Lm}}$$

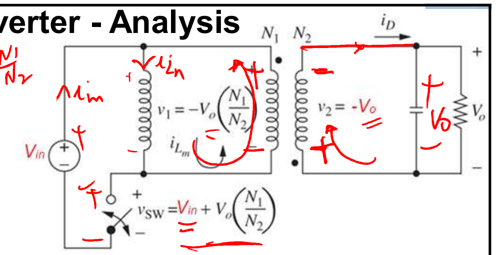
Diode voltage rating is: $V_d = V_{in}\frac{N_2}{N_1} + V_o$

Flyback DC-DC Converter - Analysis

Switch Q_1 is Open for (1-D)T

$\frac{V_1}{V_2} = \frac{N_1}{N_2}$





Volt-sec balance across the inductor L_m we have

$$V_{in} * DT + \left(-V_o\left(\frac{N_2}{N_1}\right)\right) * (1-D)T = 0$$

$$\boxed{\frac{V_o}{V_{in}} = \frac{D}{1-D} * \frac{N_2}{N_1}}$$

Voltage rating of the switch is: $V_{sw} = V_{in} + V_o\frac{N_1}{N_2}$

Flyback DC-DC Converter – Analysis - Summary

$$\frac{V_o}{V_{in}} = \frac{D}{1-D} * \frac{N_2}{N_1}$$

$$L_m = \frac{V_{in} * D}{\Delta i_{Lm} * f}$$

$$C = \frac{D}{R * f * (\frac{\Delta V_o}{V_o})}$$

Capacitor equation is same as buck-boost

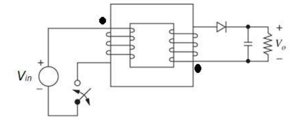
$$V_{in} * I_{in} = V_o * I_o$$

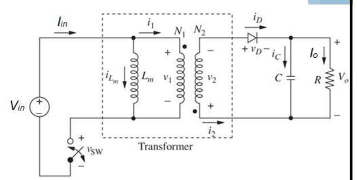
$$I_{in} = \frac{V_o}{V_{in}} I_o = \frac{D}{1-D} * \frac{N_2}{N_1} I_o$$

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

Voltage rating of the switch is: $V_{sw} = V_{in} + V_o \frac{N_1}{N_2}$

Diode voltage rating is: $V_d = V_{in} \frac{N_2}{N_1} + V_o$





V_{in}	V_o	D	$\frac{N_2}{N_1}$	V_{sw}	V_d
50 V	400 V	0.5	8	100 V	800 V
50 V	400V	0.8	2	250 V	500 V

Flyback DC-DC Converter - Analysis

A flyback converter is to be designed for the following specifications:
V_{in} = 48V ; V_o = 5V ; P_o = 30W ; f = 150kHz. It is desired that 0.3 < D < 0.5
Assume all losses are negligible

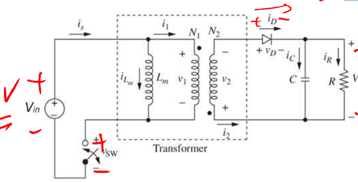
a) Find a suitable turns ratio N_1/N_2
b) Find the duty cycle D
c) Voltage & current ratings of the switch and diode
d) Output filter capacitor value for a 2% voltage ripple

$$\frac{V_o}{V_{in}} = \frac{D}{1-D} * \frac{N_2}{N_1}$$

$$V_d = V_{in} \frac{N_2}{N_1} + V_o$$

$$V_{sw} = V_{in} + V_o \frac{N_1}{N_2}$$

30W



If $D = 0.5$ we have

$\frac{N_1}{N_2} = 9.6$

Note: the turns ratio needs to be an integer

Choose: $\frac{N_1}{N_2} = 9$

$\frac{N_1}{N_2}$	D	V_{sw}	V_d
9	0.484	93 V	10.33 V
6	0.384	78 V	13 V
5	0.342	73 V	14.6 V
4	0.294	68 V	17 V

Choose N1/N2 = 5

$C = 136.8\ uF$

MOSFET = 150V
Diode = 30V