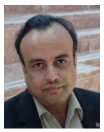
Lecture # 17

ECEN 438/738 Power Electronics

Spring 2025 Semester



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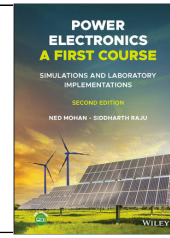
ECEN 438/738 Power Electronics



Power Electronics
A First Course: 2nd Edition

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

Chapter 7

Magnetic Circuit Concepts

Exam # 2 on 3/25/2025

- Topics covered: Lecture # 8, 9, 10, 11, 12, 13, 14 and 15 ONLY
- One sided formula sheet
- Exam # 2 will have a multiple choice questions with many parts
- Bring a calculator, Formula sheet and be prepared to scan and upload your work sheets on the Assignment Section of CANVAS
- Don't leave the exam without handing over the following: formula sheet + copy of your work

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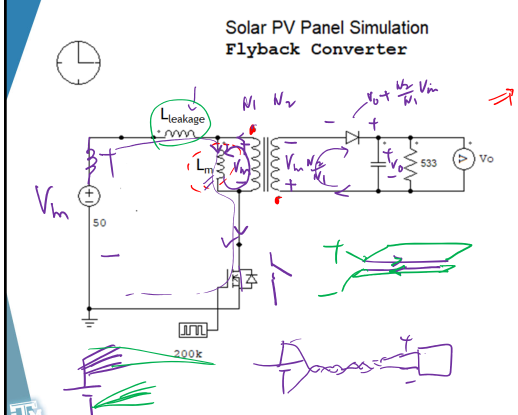
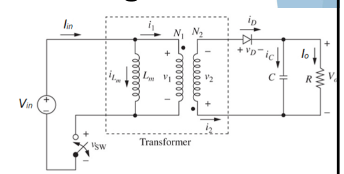
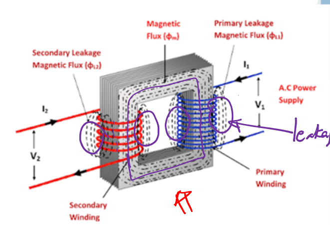
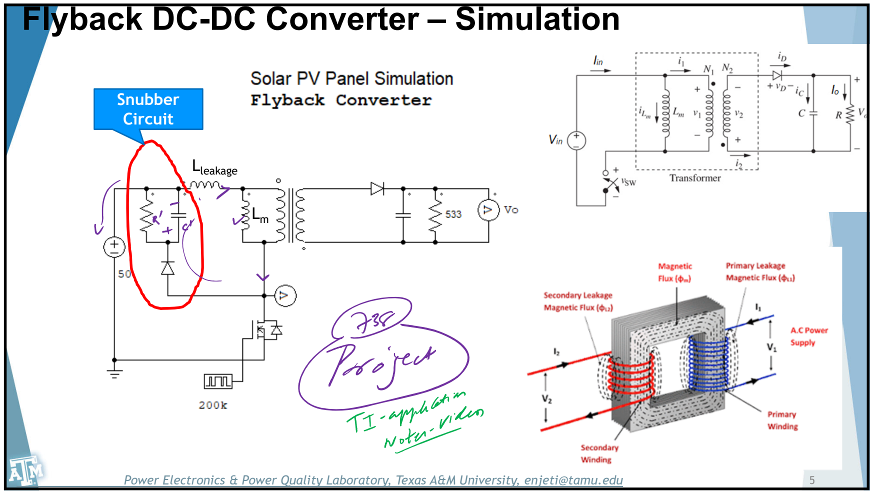
Flyback DC-DC Converter – with Leakage Inductance









Flyback DC-DC Converter – Simulation
Solar PV Panel Simulation
Flyback Converter
Snubber Circuit
L_leakage
L_m
533
Vo
50
200k
Transformer
Magnetic Flux (Φm)
Primary Leakage Magnetic Flux (Φ_L1)
Secondary Leakage Magnetic Flux (Φ_L2)
A.C Power Supply
Primary Winding
Secondary Winding
Project
TI - application notes-video
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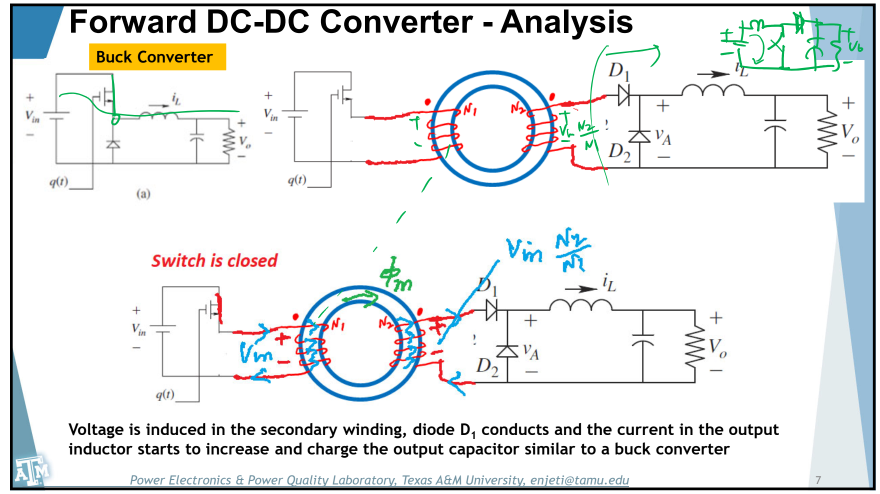

Forward DC-DC Converter - Analysis
Buck Converter
(a)
Switch is closed
Vin N2/N1
Φm
Voltage is induced in the secondary winding, diode D1 conducts and the current in the output inductor starts to increase and charge the output capacitor similar to a buck converter
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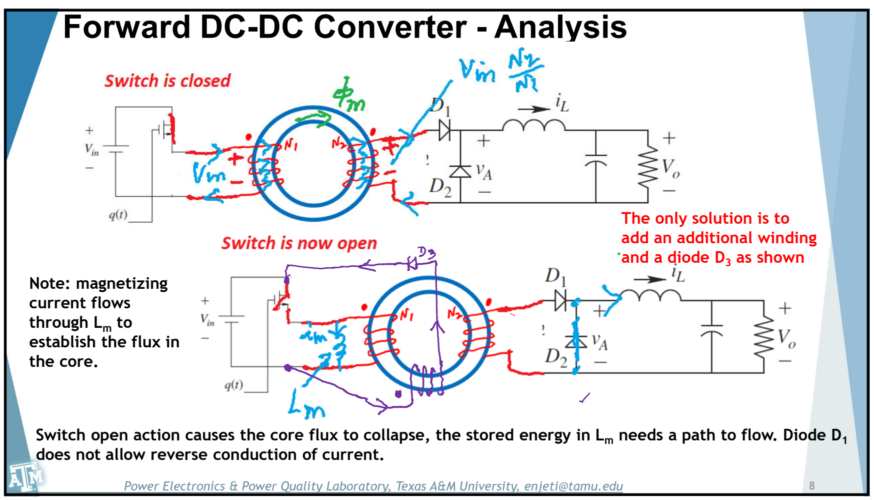

Forward DC-DC Converter - Analysis
Switch is closed
Vin N2/N1
Φm
Switch is now open
The only solution is to add an additional winding and a diode D3 as shown
Note: magnetizing current flows through Lm to establish the flux in the core.
Lm
Switch open action causes the core flux to collapse, the stored energy in Lm needs a path to flow. Diode D1 does not allow reverse conduction of current.
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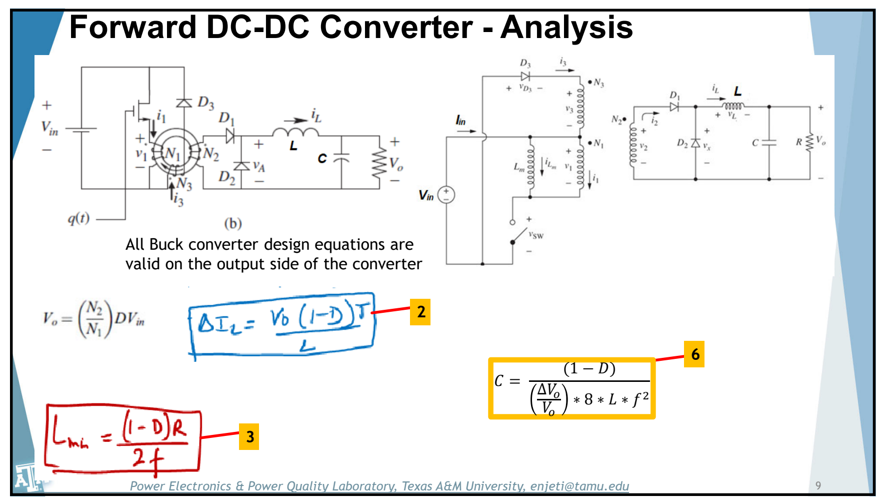

Forward DC-DC Converter - Analysis
(b)
All Buck converter design equations are valid on the output side of the converter
$V_o = \left(\frac{N_2}{N_1}\right) D V_{in}$
$\Delta I_L = \frac{V_o (1-D) T}{L}$
2
$C = \frac{(1-D)}{\left(\frac{\Delta V_o}{V_o}\right) * 8 * L * f^2}$
6
$L_{min} = \frac{(1-D)R}{2f}$
3
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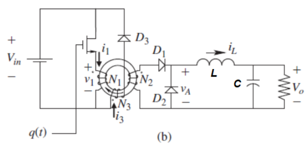
Forward DC-DC Converter - Analysis



All Buck converter design equations are valid on the output side of the converter

$V_o = \left(\frac{N_2}{N_1}\right) D V_{in}$

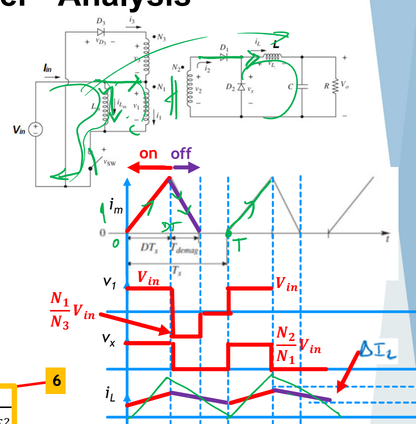
$V_{in} = 200V, \; V_o = 5V$

$5 = \left(\frac{N_2}{N_1}\right) D \cdot 200$

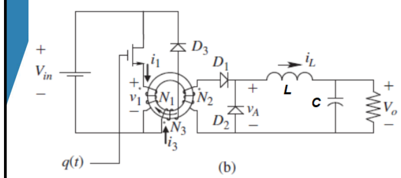
$\Delta I_L = \frac{V_o(1-D)T}{L}$ 2

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

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



Forward DC-DC Converter - Analysis



Note: when the **switch is closed**, core flux is established - this can be imagined as magnetizing current to flow through inductor L_m.

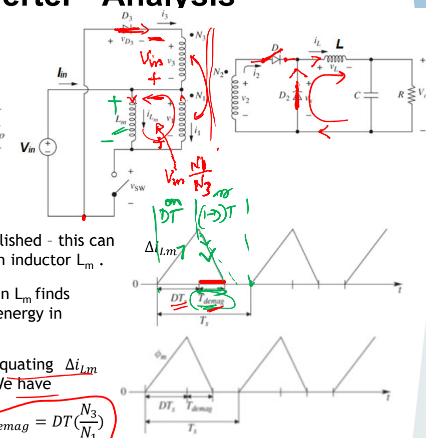
When the **switch is open** the magnetizing current in L_m finds a path via diode D_3 and winding N_3 and the stored energy in L_m is returned to input battery (source).

Switch is on, we have $L_m \frac{\Delta i_{Lm}}{DT} = V_{in}$;

Switch is off, we have $L_m \frac{\Delta i_{Lm}}{T_{demag}} = V_{in}\frac{N_1}{N_3}$

Equating Δi_{Lm}
We have

$T_{demag} = DT\left(\frac{N_3}{N_1}\right)$



Forward DC-DC Converter - Analysis

Note: $T_{demag} = DT\left(\frac{N_3}{N_1}\right)$

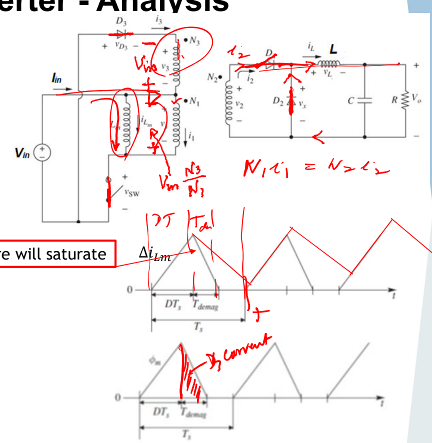
Also: $DT + T_{demag} < T$

i.e. $DT + DT\left(\frac{N_3}{N_1}\right) < T$

or $D\left(1 + \frac{N_3}{N_1}\right) < 1$

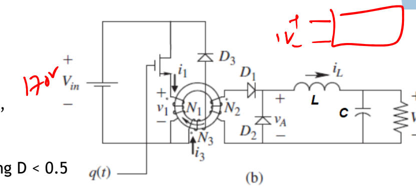
if $\frac{N_3}{N_1} = 1$; *we have* $D < 0.5$

if $D > 0.5$ - core will saturate



Forward DC-DC Converter - Analysis

Design a Forward converter for the following specifications:
V_{in} = 170V
V_o = 5V ; Output power P_o = 25W
f = 300kHz
The output voltage ripple must not exceed 2%, choose transformer turns ratios, duty ratio D



$V_o = \left(\frac{N_2}{N_1}\right) D V_{in}$

Substituting V_{in}, V_o and choosing D < 0.5 i.e. say D = 0.35, we have

$\frac{N_1}{N_2} = 11.9$; *say* = 12

Now recalculate D = 0.353

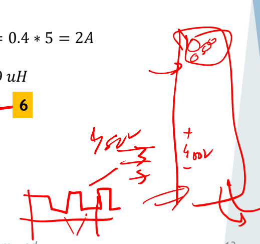
$\Delta I_L = \frac{V_o(1-D)T}{L}$ 2

Assume ΔI_L = 40% *of* $I_o = 0.4 * 5 = 2A$

From (2) we have $L = 5.39\ uH$

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

$C = 8.3\ uF$



Forward DC-DC Converter - Analysis

Design a Forward converter for the following specifications:
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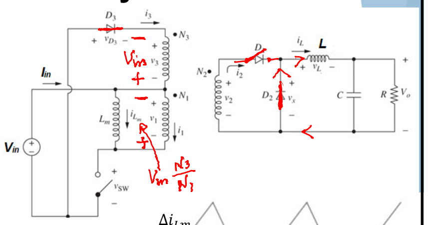
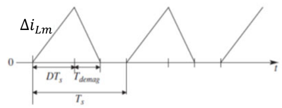


Find the switch and diode ratings



$Since\ V_{in} * I_{in} = V_o * I_o = P_o \quad ; I_{in} = 0.147\text{ A}$

$Also, \quad V_o * I_o = 25\ W \quad ; I_o = 5\text{ A}$

$For\ diode\ D_1; \ I_{D1} = D * I_o = 0.353 * 5 = 1.765\text{ A}$

$Voltage\ rating\ of\ diode\ D_1 is = \frac{N_2}{N_3} V_{in}; since\ N_3 = N_1; we\ have\ the\ rating\ as\ 14.17\ V$

$For\ diode\ D_2; \ I_{D2} = (1 - D) * I_o = (1 - 0.353) * 5 = 3.235\text{ A}$

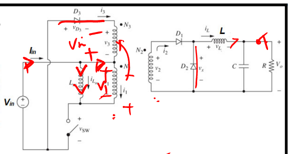
$Current\ rating\ of\ diode\ D_3\ is = \frac{1}{2} * \frac{T_{demag} * \Delta i_{Lm}}{T}$

$= \frac{1}{2} * \text{D} * \Delta i_{Lm}$

$Voltage\ rating\ of\ diode\ D_3\ is = 2 * V_{in}\ since\ N_3 = N_1$

Forward DC-DC Converter - Analysis

Example 8.2
In a Forward converter shown in Figure 8.4b, $V_{in} = 48$ V, $V_o = 5$ V, $N_1/N_2 = 3.5$, $N_1/N_3 = 1$, and the magnetizing inductance $L_{m1} = 150\ \mu$H. This converter is operating in equivalent CCM with a switching frequency $f_s = 200$ kHz and supplying an output load $P_o = 60$ W. Assume the filter inductor current i_L to be ripple-free. Assuming this converter to be lossless, calculate the waveforms associated with it.



$V_o = \left(\frac{N_2}{N_1}\right) D V_{in} \qquad Therefore\ \text{D} = 0.364$

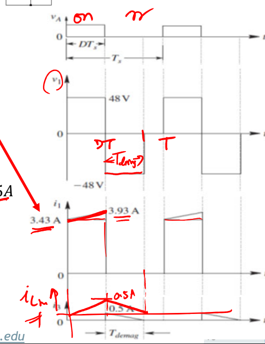
$Note: the\ output\ current\ I_o = I_L = \frac{60}{5} = 12\ A$

When switch is closed, input current on the primary winding i_1 is: $\quad i_1 = \frac{N_2}{N_1} * I_o = \frac{12}{3.5} = 3.43\ A$

$Switch\ is\ on, we\ have\ L_m \frac{\Delta i_{Lm}}{DT} = V_{in}; \ and\ \Delta i_{Lm} = \frac{V_{in} * DT}{L_m} = \frac{48 * 0.364}{200kHz * 150uH} = 0.5A$

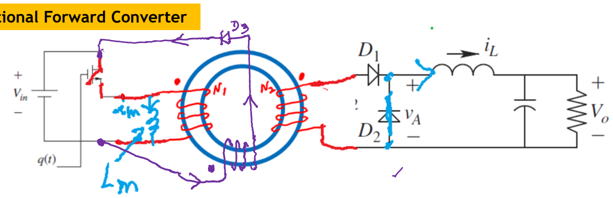
$Switch\ is\ off, we\ have\ L_m \frac{\Delta i_{Lm}}{T_{demag}} = V_{in} \frac{N_1}{N_3}$

$T_{demag} = DT \left(\frac{N_3}{N_1}\right) = 1.825\ micro - sec$



Two Switch Forward DC-DC Converter

Conventional Forward Converter



Two Switch Forward Converter