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ENM061 - Power Electronic Converters 7.5 ECTS, 2017

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Lecture outline

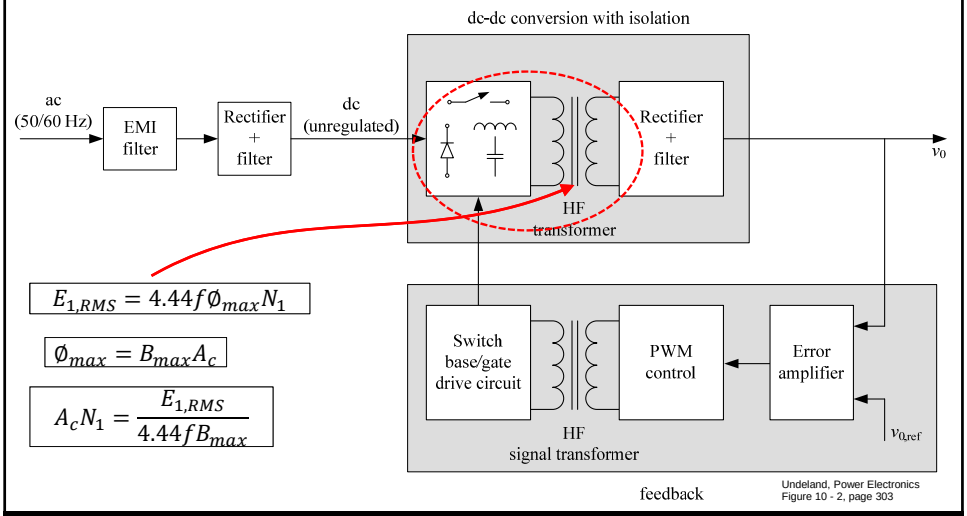
The flyback converter

- DC/DC converters with electrical isolation
- The fly back converter
  - ❖ Continuous conduction mode (CCM)
  - ❖ Discontinuous conduction mode (DCM)
  - ❖ Load voltage limitation and purpose of a third winding
- Alternative fly back converter configurations
- Brief description of the Tutorial, PSpice and Practical exercises
- Summary

Learning outcomes

- Fourier components and total harmonic distortion (THD) for basic waveforms.
- Operating principles of the most common active components (e.g. diode, thyristor, IGBT, and MOSFET) and passive components (e.g. capacitors, transformers and inductors).
- Operation of a pulse width modulation (PWM), the purpose of controlling the desired quantity and the need for a controller circuit within the power electronic converter.
- Analysis of ideal DC/DC converters (e.g. buck, boost, buck-boost, flyback, the forward, the push-pull, half-bridge and full-bridge converters) in CCM and DCM operation.
- Operating principles of single-phase and three-phase AC/DC inverters with different modulation strategies (e.g. PWM and square wave operation).
- Operation of multilevel converters (e.g. NPC, flying capacitor and MMC topologies) using current and voltage waveform analysis. Pros and Cons of the converter in terms of harmonics and losses.
- Operation of single- and three-phase diode rectifiers operating with voltage-stiff and current-stiff DC-side. Investigating the impact of line impedance within the converter circuit for current commutation.
- Operation of single- and three-phase thyristor rectifiers operating with a current-stiff DC-side and the impact of line impedance for current commutation. Investigating the use of 6/12-pulse configurations.
- Identify simple power electronic converter schematics. Recognizing the different parts in a physical circuit on which basic wave-shape and efficiency measurements is performed.
- Loss calculation in passive and active components. Evaluating the temperature rise in the active components and choosing an appropriate heat-sink. Gaining a basic understanding of component life time.
- Utilizing the software Cadence PSpice to simulate basic power electronic circuits and the practical labs to have a firsthand experience of how real DC/DC converters operate.

Switch-mode power supply with electrical Isolation



$$E_{1,RMS} = 4.44 f \emptyset_{max} N_1$$

$$\emptyset_{max} = B_{max} A_c$$

$$A_c N_1 = \frac{E_{1,RMS}}{4.44 f B_{max}}$$

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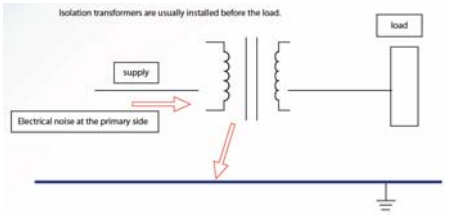
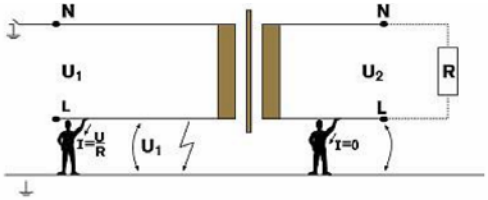
Figure 10 - 2, page 303

Electrical Isolation – The Reason for Isolated Converters

- Avoid circulating currents



- Safety reasons



- Multiple outputs and the possibility to have different turns ratios

Electrical Isolation – Power Supply Block Diagram

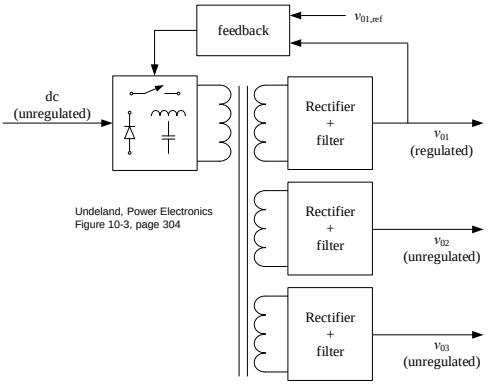


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Figure 10-3, page 304

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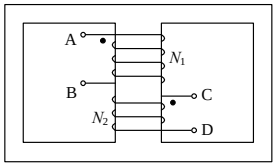
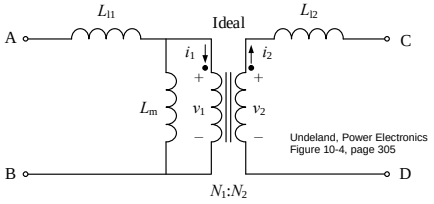
Figure 10 - 3, page 304

- Possible to implement multiple electrically isolated outputs from one converter. Only one output can be controlled though.
- Different turns ratio on the secondary windings

Electrical Isolation – Transformer Implementation

- For converter applications, a high frequency transformer is used which reduces size and weight compared with a 50Hz transformer

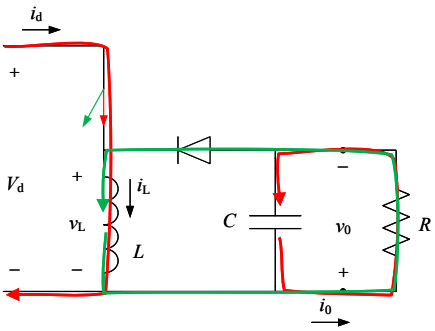




- Desirable to minimize the leakage inductance to reduce unwanted oscillations and therefore the need for snubber circuits
- In general it is desirable to maximize the magnetizing inductance to reduce the magnetizing current (except for the flyback)
- The core excitation can be either unidirectional or bidirectional
- When the current flows into the dot on the primary side – the current flows out of the dot on the secondary side

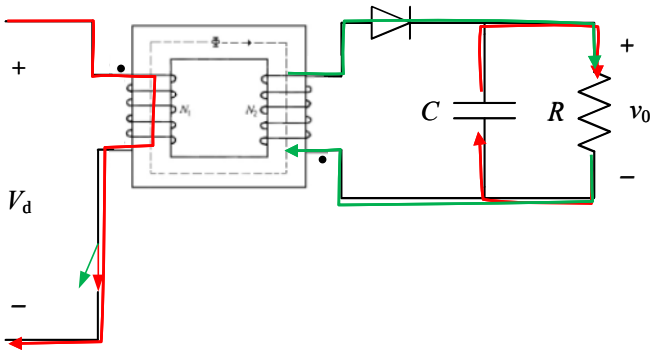
The Flyback – Derivation From the Buck/Boost Converter

- On: Energy is stored in the inductor
- Off: The energy stored in the inductor is transferred to the load

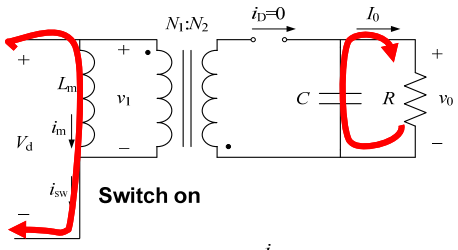


The Flyback – Derivation From the Buck/Boost Converter

- On: Energy is stored in the transformer
- Off: The energy stored in the transformer is transferred to the load



The Flyback – Current Paths with Equivalent Transformer Circuit



Switch on

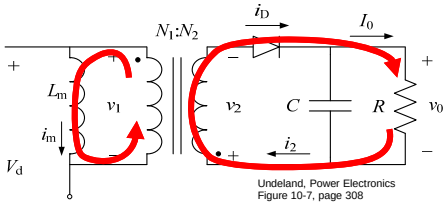


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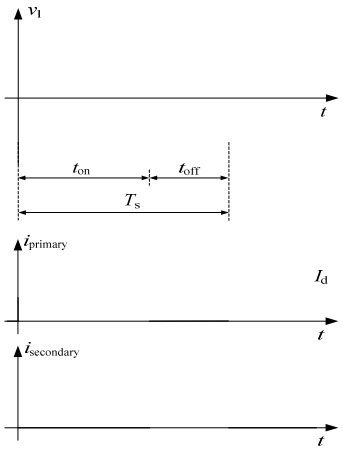
Figure 10-7, page 308

Switch off



Ex.: plot curves

The Flyback – Waveforms in CCM

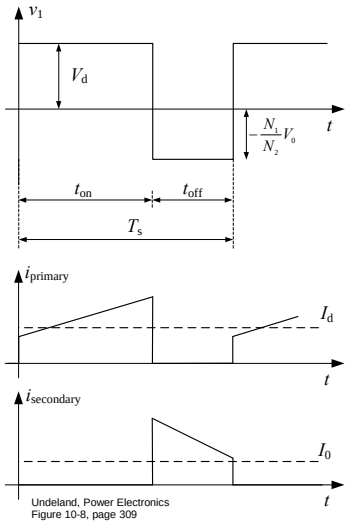


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Figure 10-8, page 309

$$\frac{V_o}{V_d} = \frac{N_2}{N_1}\frac{D}{1-D}$$

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

Ex.: Derive expressions

The Flyback – Waveforms in DCM

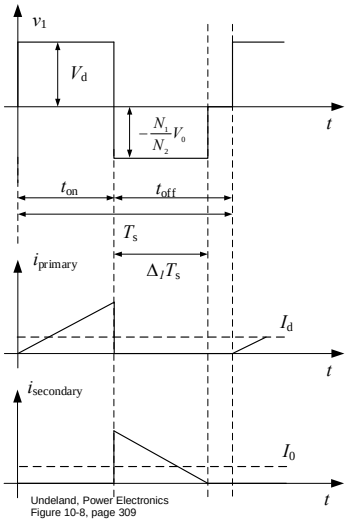

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Figure 10-8, page 309

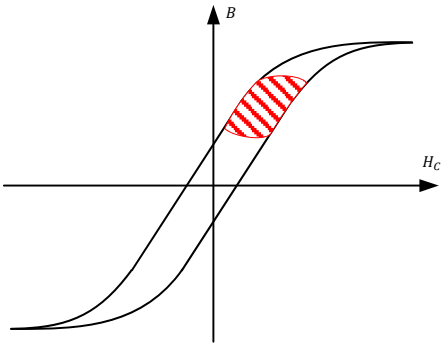
$$\frac{V_o}{V_d} = D\sqrt{\frac{RT_s}{2L_m}}$$

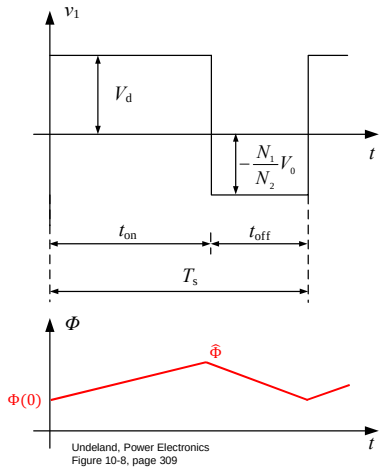
$$\frac{\Delta V_o}{V_o} = ?$$

Ex.: Derive expressions

The Flyback – Core Excitation

- Uses unidirectional core excitation
- An airgap is introduced as to avoid saturation of the core.
- The core is made of ferrite due to the high switching frequency.





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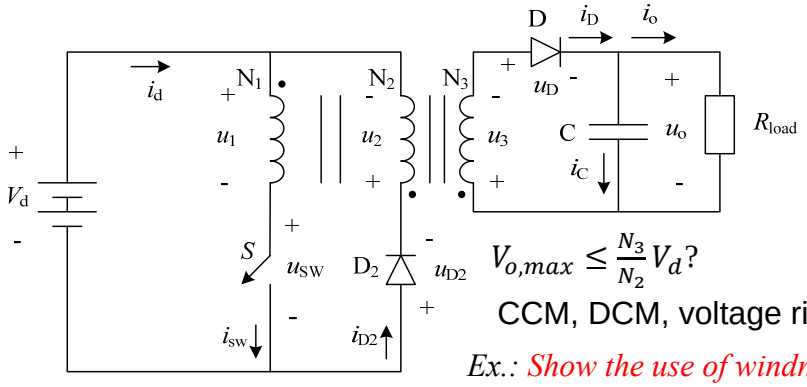
The Flyback – Load Voltage Limiting

- To avoid that the load voltage becomes very high at low load conditions, a third winding can be implemented that feeds energy back to the source



$V_{o,max} \leq \frac{N_3}{N_2} V_d$?

CCM, DCM, voltage ripple?

Ex.: Show the use of windng N_2

Two-transistor and Parallelled Flyback Converters

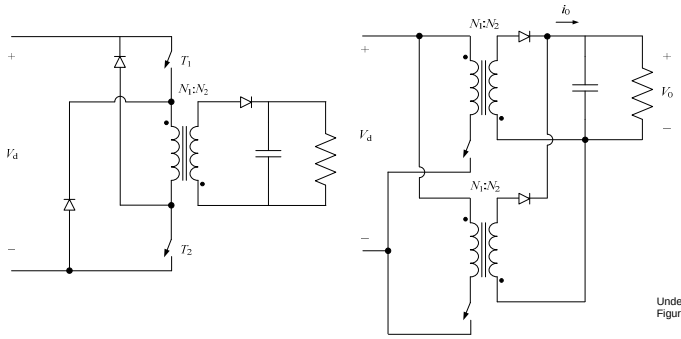


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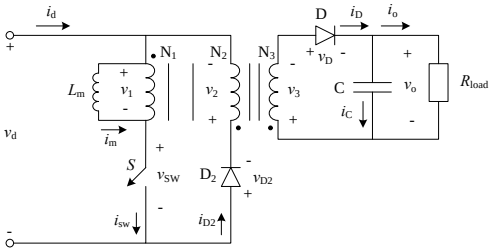
Figure 10 - 9, page 311

+L Increased power level and no snubber due to current path through diodes

+R Increased power level and reliability (due to redundancy), increased effective switching frequency and lower current/voltage ripple

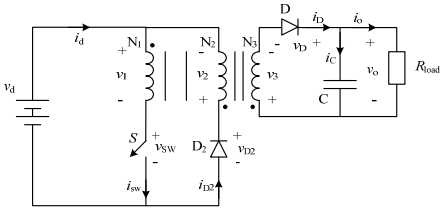
- L&R Increased cost and complexity

Tutorial 5



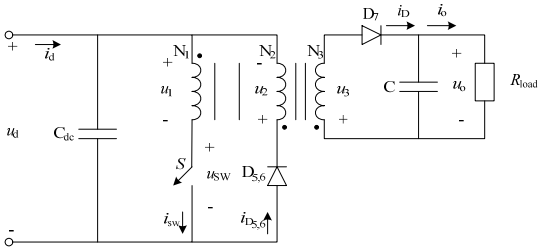
- Derivation of flyback from buck-boost converter
- For DCM, find voltage ration V_o/V_d using R_{load}, f_{sw}, L_m and D
- Waveforms during a no-load operation with $D = 0.3$
- Explan how N_2 and D_2 can limit the maximum duty ratio
- When is the flyback operation changing from CCM to DCM

PSpice 3



- For CCM and without N_2, plot waveforms and find V_o, average and peak-to-peak ripple in the magnetizing current
- Output to input voltage ratio for CCM and DCM and investigate the impact of R_{load} on the voltage ratio
- Maximum output voltage and the purpose of N_2
- Purpose of a snubber circuit on the switch

Laboratory 2



- Find L_m by calculation and measurement, purpose of N_2
- Output to input voltage ratio for CCM and DCM
- Waveforms and impact of switching frequency on the mode of operation
- Waveforms for a no load operation
- Impact of a snubber circuit and a fast or slow diode ($D_{5,6}$)

Summary

- What is the use of electrical isolation in power electronic converters?
- How do you decide if a flyback converter is operating in CCM or DCM operation?
- What is the purpose of the third winding in a flyback converter transformer and when will it be operational?
- Does the transformer in a flyback require an airgap and why?
- Learning outcome:
  - Analysis of a flyback DC/DC converter in CCM and DCM operation.