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ENM061 - Power Electronic Converters 7.5 ECTS, 2017

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Lecture outline

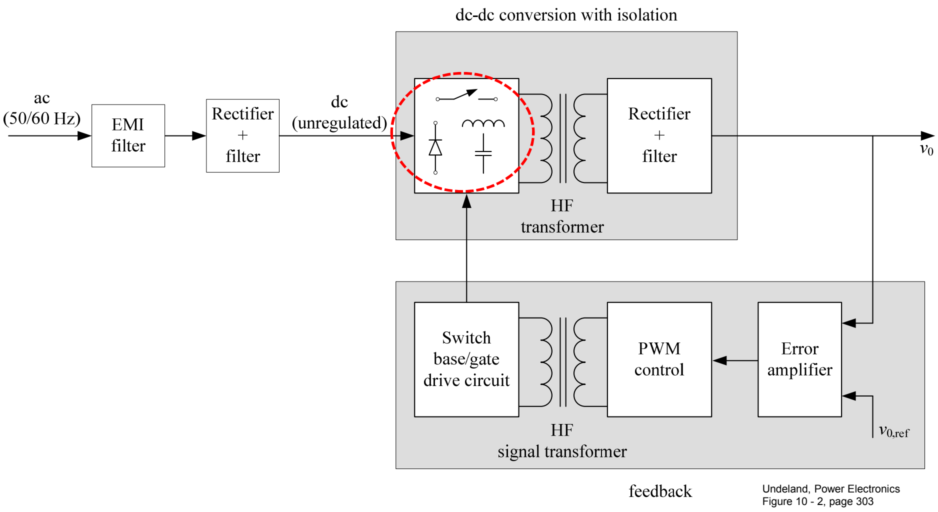
Step-up (Boost) and Buck-Boost DC/DC converters

- The Boost converter
  - ❖ Continuous conduction mode (CCM)
  - ❖ Discontinuous conduction mode (DCM)
  - ❖ Boundary conditions between CCM and DCM
  - ❖ Output voltage ripple
- The Buck-Boost converter
  - ❖ Continuous conduction mode (CCM)
  - ❖ Discontinuous conduction mode (DCM)
  - ❖ Boundary conditions between CCM and DCM
  - ❖ Output voltage ripple
- Brief description of the Tutorial and PSpice 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



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The Step-up DC/DC converter

Assumptions

- All active and passive components are ideal
- We have no losses (input power = output power)
- The source impedance is zero
- Converter is in steady-state condition and the
  - average inductor voltage is zero
  - average capacitor current is zero
- Very large output capacitor => constant output voltage
- Non-ideal behaviors such as losses and voltage ripple are considered after derivations using the ideal assumptions

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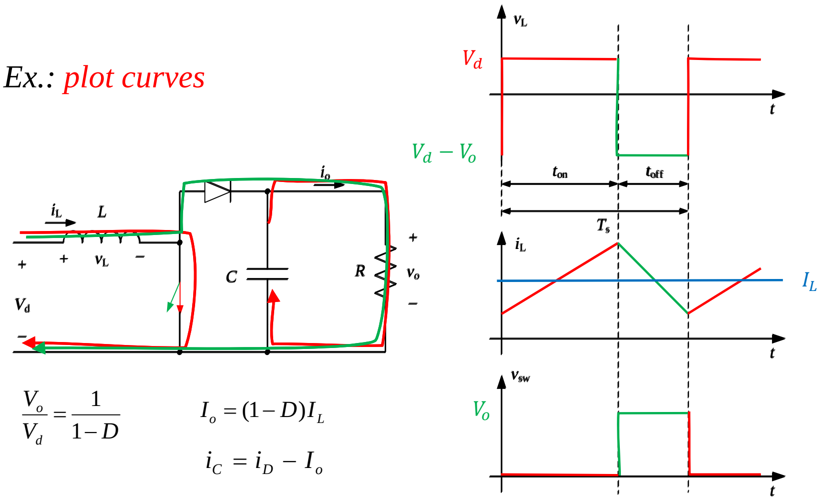
The Boost Converter - CCM

Ex.: plot curves



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

$$I_o = (1-D)I_L$$

$$i_C = i_D - I_o$$

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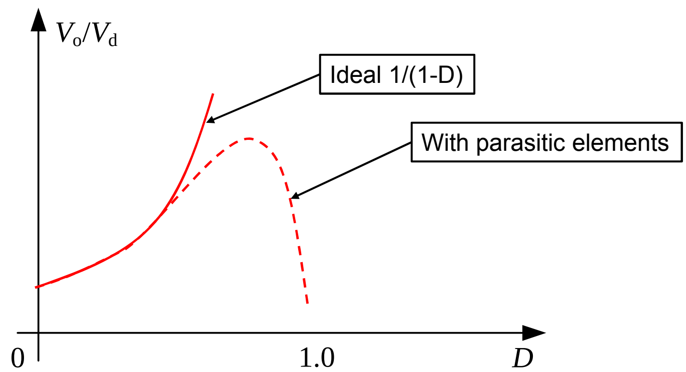
The Boost Converter
Ideal and Actual Duty Ratio



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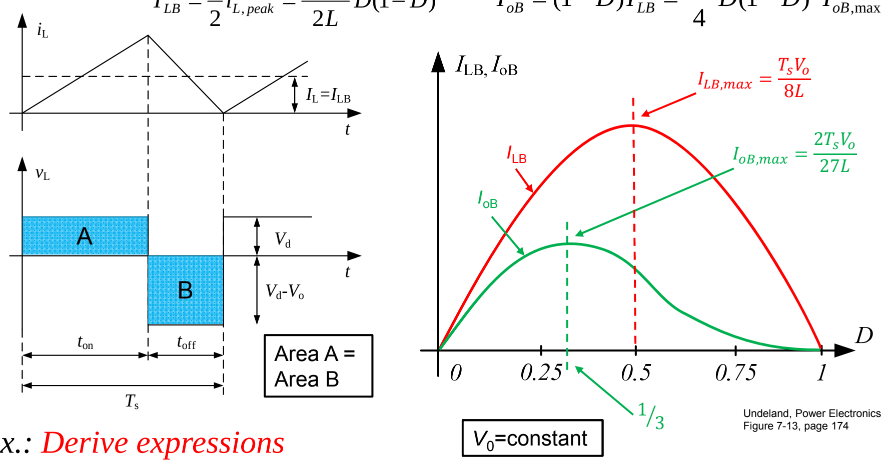
The Boost Converter – Boundary Between CCM and DCM

$$I_{LB} = \frac{1}{2} i_{L,peak} = \frac{T_s V_o}{2L} D(1-D) \qquad I_{oB} = (1-D) I_{LB} = \frac{27}{4} D(1-D)^2 I_{oB,\max}$$



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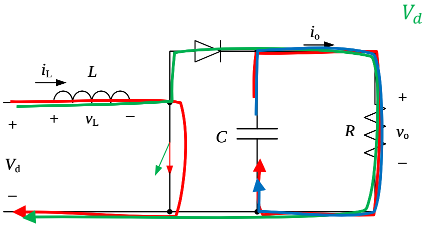
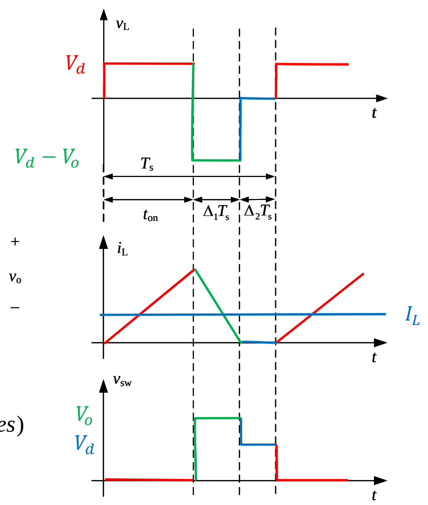
Ex.: Derive expressions

The Boost Converter - DCM

Ex.: plot curves





$$\frac{V_o}{V_d} = \frac{\Delta_1 + D}{\Delta_1} \qquad \frac{I_o}{I_L} = \frac{\Delta_1}{\Delta_1 + D} \quad (no\ losses)$$

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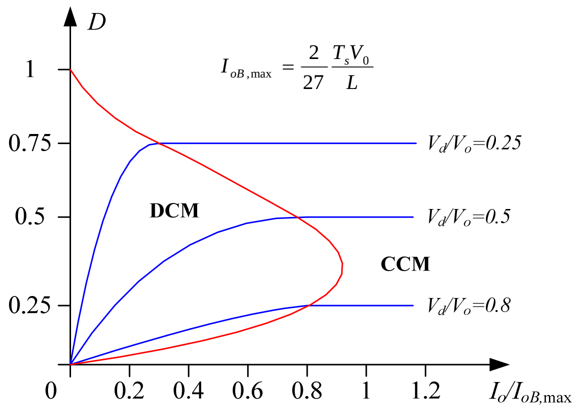
The Boost Converter – Boundary Between CCM/DCM with Constant V_o



- Boundary

$$I_{oB} = \frac{27}{4}D(1-D)^2 I_{oB,max}$$

- CCM

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

- DCM

$$D = \sqrt{\frac{4}{27}\frac{V_o}{V_d}\left(\frac{V_o}{V_d}-1\right)\frac{I_o}{I_{oB,max}}}$$

Ex.: Derive expressions

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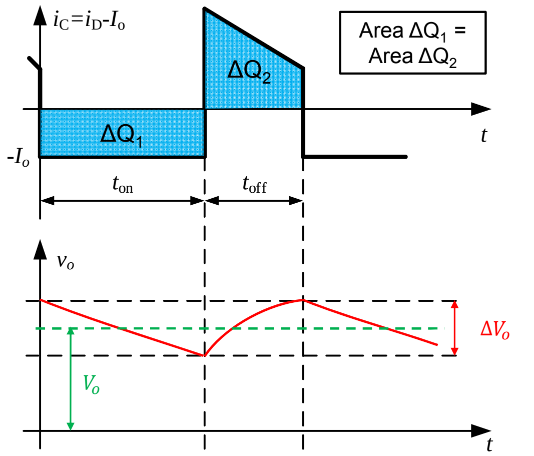
The Boost Converter Output Voltage Ripple



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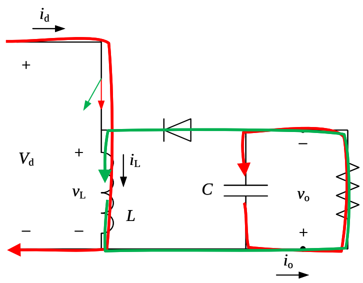
For CCM

$$\Delta V_o = \frac{\Delta Q_1}{C} = \frac{I_o D T_s}{C}$$

$$\Rightarrow \frac{\Delta V_o}{V_o} = \frac{DT_s}{RC} = \frac{DT_s}{\tau_{RC}}$$

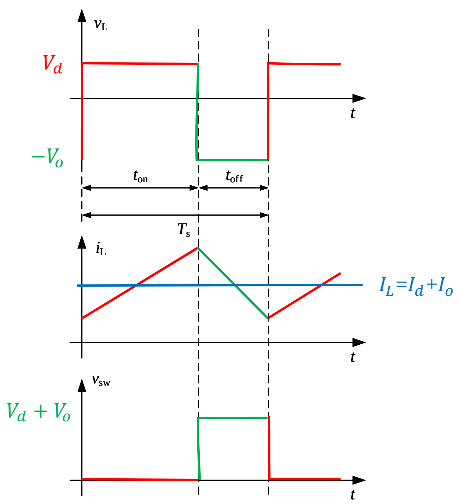
The Buck-Boost Converter - CCM

Ex.: plot curves

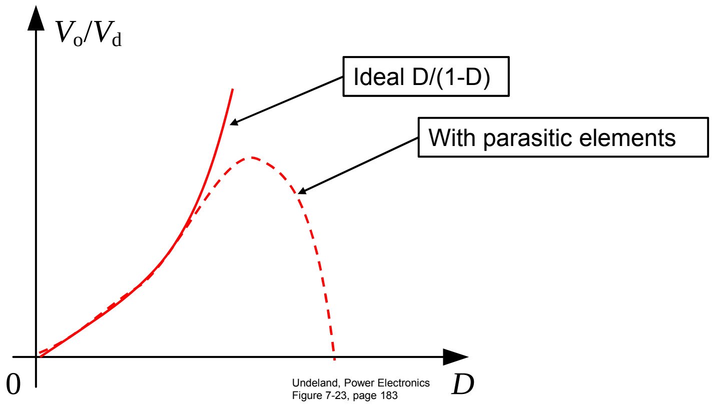


$$\frac{V_o}{V_d} = \frac{D}{1-D} \qquad I_o = (1-D) I_L$$

$$I_d = D I_L$$



The Buck-Boost Converter
Ideal and Actual Duty Ratio



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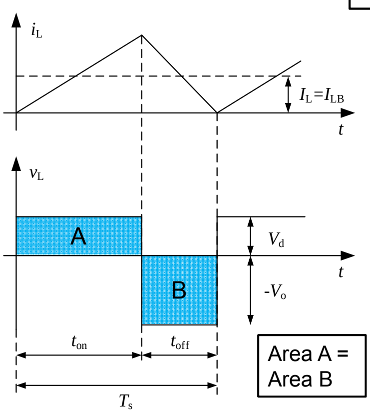
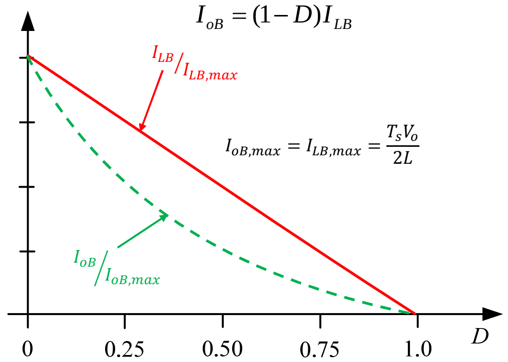
The Buck-Boost Converter
Boundary Between CCM and DCM

V_0=constant

$$I_{LB} = \frac{T_s V_o}{2L}(1-D)$$

$$I_{oB} = (1-D) I_{LB}$$





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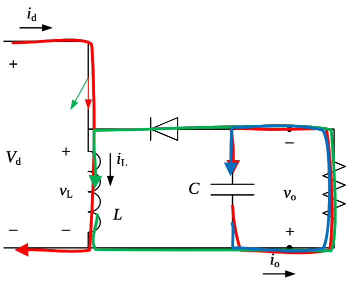
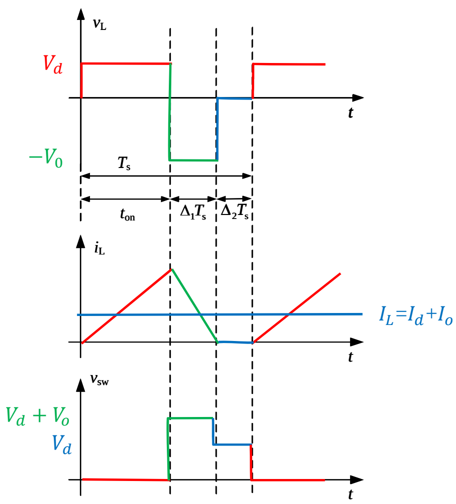
Ex.: Derive expressions

The Buck-Boost Converter - DCM

Ex.: plot curves





$$\frac{V_o}{V_d} = \frac{D}{\Delta_1} \qquad \frac{I_o}{I_d} = \frac{\Delta_1}{D} \ (no\ losses)$$

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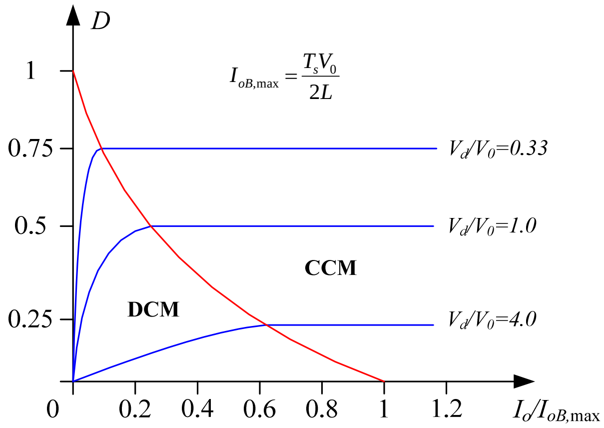
The Buck-Boost Converter – Boundary Between CCM/DCM with Constant V_o



- Boundary

$$I_{oB} = (1-D)^2 I_{oB,max}$$

- CCM

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

- DCM

$$D = \frac{V_o}{V_d}\sqrt{\frac{I_o}{I_{oB,max}}}$$

Ex.: Derive expressions

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The Buck-Boost Converter Output Voltage Ripple

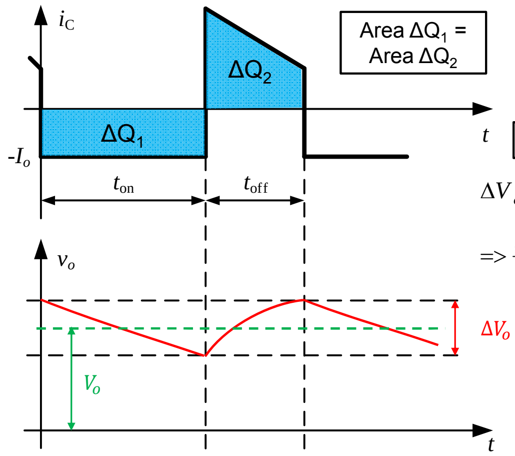

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Figure 7-24, page 184

For CCM

$$\Delta V_o = \frac{\Delta Q_1}{C} = \frac{I_o D T_s}{C}$$

$$\Rightarrow \frac{\Delta V_o}{V_o} = \frac{D T_s}{RC} = \frac{D T_s}{\tau_{RC}}$$

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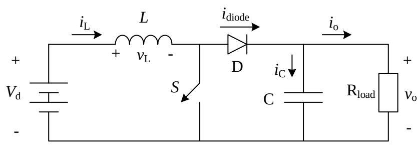
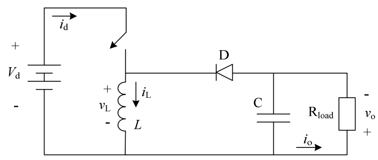
Tutorial 4 and 5





V_0=24v (constant), V_d = 8 - 16v, $P_o > 5$ W, C=470 uF and f_{sw} = 20 kHz

- L_{min} for CCM mode of operation in the entire operating range

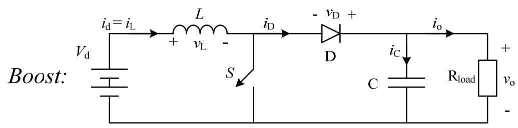
V_0=24 v, V_d = 12 v, I_o = 0.5A, L = 150 uH, C = 470 uF and f_{sw} = 20 kHz

- Voltage ripple (First CCM or DCM?)

V_0=15v (Buck-Boost converter above), V_d = 12v, I_o = 2.5A, L, C and f_{sw} given:

- Voltage ripple (First CCM or DCM?)

PSpice 2



- Waveforms, CCM or DCM, average and ripple output voltage
- FFT of the output voltage
- Impact of L, C, R_{load}, and R_{ESR}
- Impact of increasing D with parasitic components

Summary

- Describe the components of boost and buck-boost converters
- Describe how to identify the modes of operation of boost and buck-boost converters in CCM, DCM and Boundary conditions
- Show how to calculate the voltage ripple in the two converters
- Learning outcome:
  - Analysis of boost and buck-boost DC/DC converters in CCM and DCM operation.