ENM061 - Power Electronic Converters 7.5 ECTS, 2017

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Lecture outline

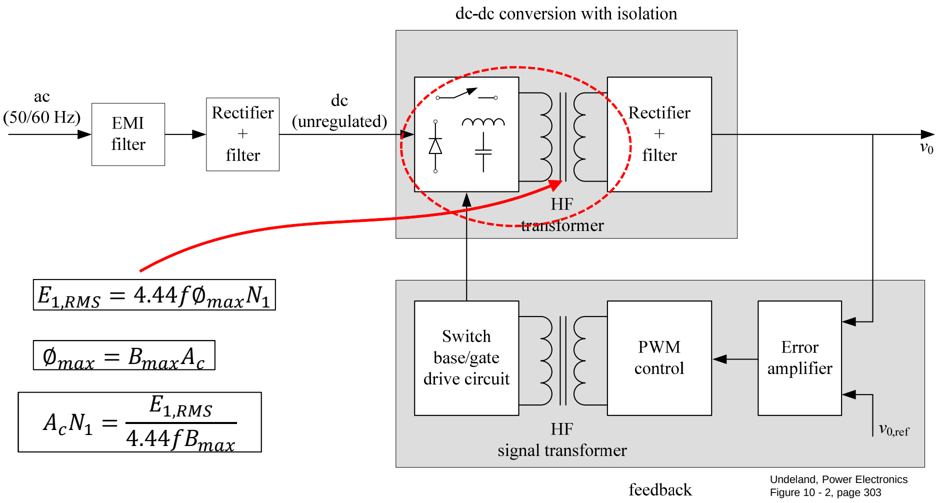
The forward and 2/4-quadrant DC/DC converters

- The forward converter
- Operation quadrants of drives and converters
- The 2-quadrant DC/DC converter
- The 4-quadrant (H-bridge) DC/DC converter
- The H-bridge converter – bipolar vs unipolar switching
- Brief description of the Tutorial 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 half-bridge, the full-bridge and the push-pull 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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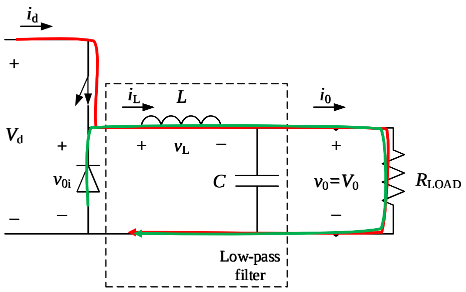
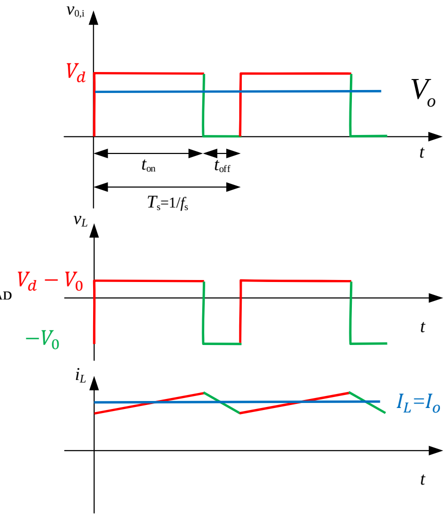
The Buck DC/DC converter in CCM

Ex.: plot waveforms

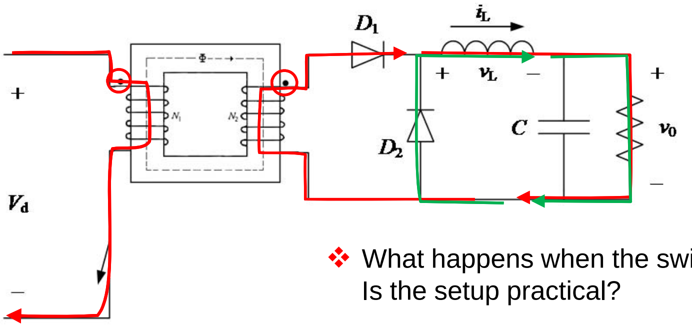




$$\frac{V_o}{V_d} = D$$

The Forward Converter in CCM

- When the switch is on, a current flows into the dot on the primary side and out of the dot on the secondary side via D_1 to the load
- When the switch is off, no current on the primary side and the current freewheels via D_2 to the load.



$$\frac{V_o}{V_d} = ?\frac{N_2}{N_1}D$$

❖ What happens when the switch is off? Is the setup practical?

Ex.: Show current paths and derive voltage ratio

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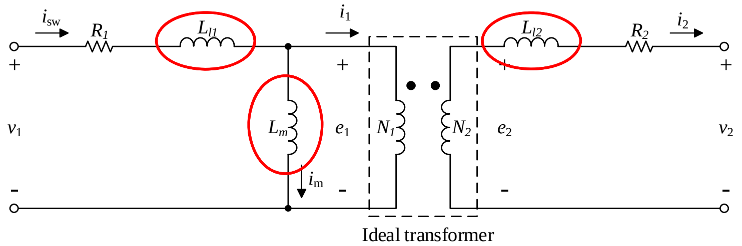
The Transformer Model in the Forward Converter

- We need to consider the non-ideal elements of the transformer



- Desirable to minimize the leakage inductance to reduce unwanted oscillations and therefore the need for snubber circuits – neglected in the ideal converter
- The magnetizing inductance shall be kept as high as possible to reduce the ripple in the magnetizing current (no air-gap in the transformer)
- When the current flows into the dot on the primary side – the current flows out of the dot on the secondary side

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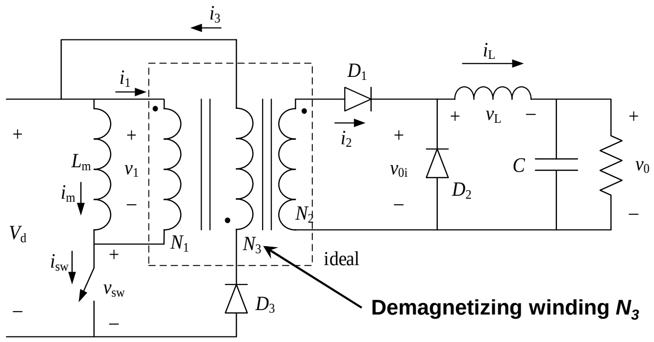
Forward Converter With Demagnetizing Winding

- A third winding is added so that the transformer can demagnetize
- Observe the major difference to the third winding in a flyback converter!



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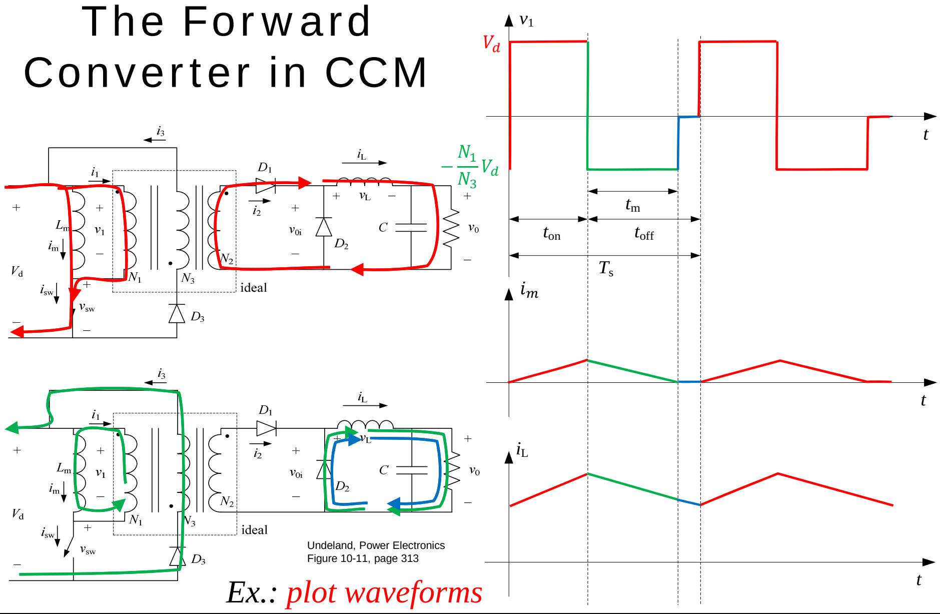
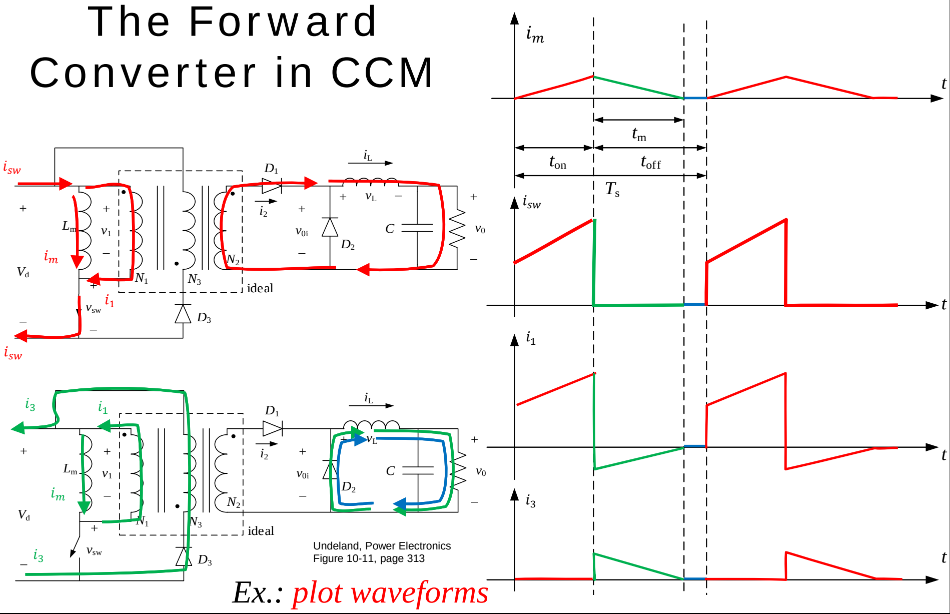
The Forward Converter in CCM



Ex.: plot waveforms

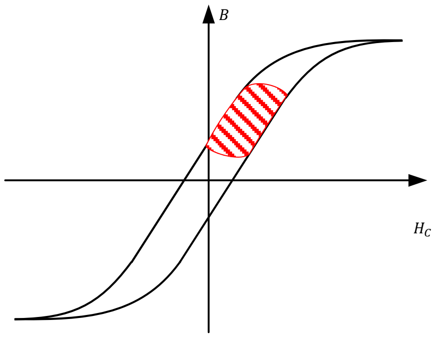
The Forward Converter in CCM



Ex.: plot waveforms

The Forward – Core Excitation

- Uses unidirectional core excitation, the core must be fully demagnetized at every switching cycle.
- Higher magnetizing inductance and no air gap
- The core is made of ferrite due to the high switching frequency.



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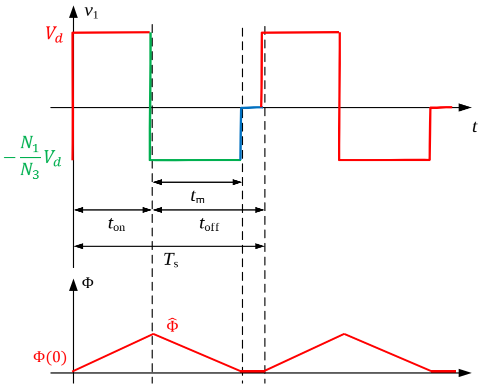


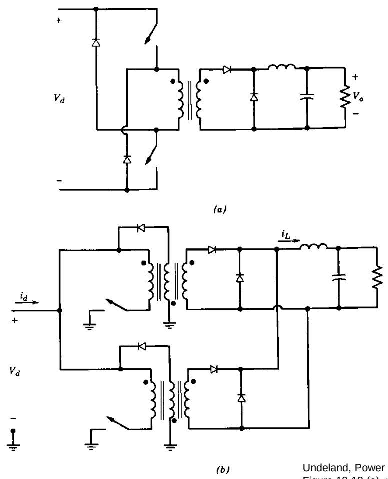
Two-transistor and Parallelled Forward Converters

(a) Increased power level and no demagnetizing winding or snubber due to current path through diodes

Results in increased cost and complexity

(b) Increased power level and reliability (due to redundancy)

Increased effective switching frequency and lower current/voltage ripple



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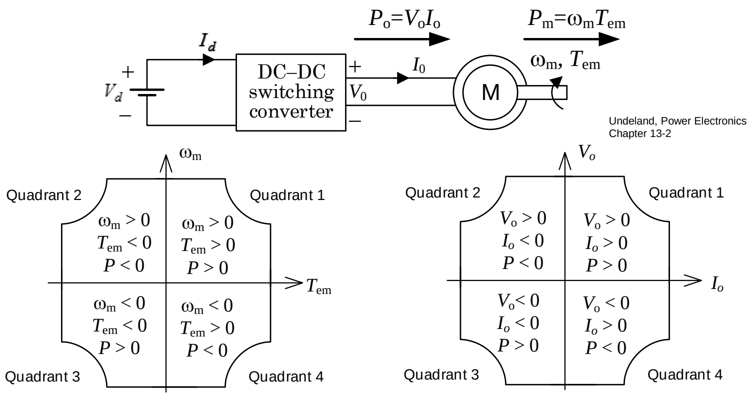
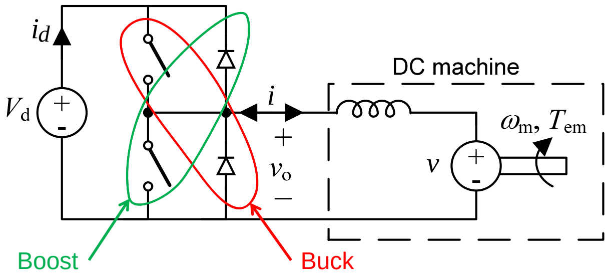
Quadrants of Drives and Converters

- A DC-machine can act as a generator while braking which means that the power flows from the machine to the converter



The 2-Quadrant Converter

- The output voltage is always positive (v_o>0)
- The current (i) can flow in both directions



- Note that an anti-parallel diode is needed for the current to be able to flow back to the source if an unidirectional component is used (e.g. an IGBT)

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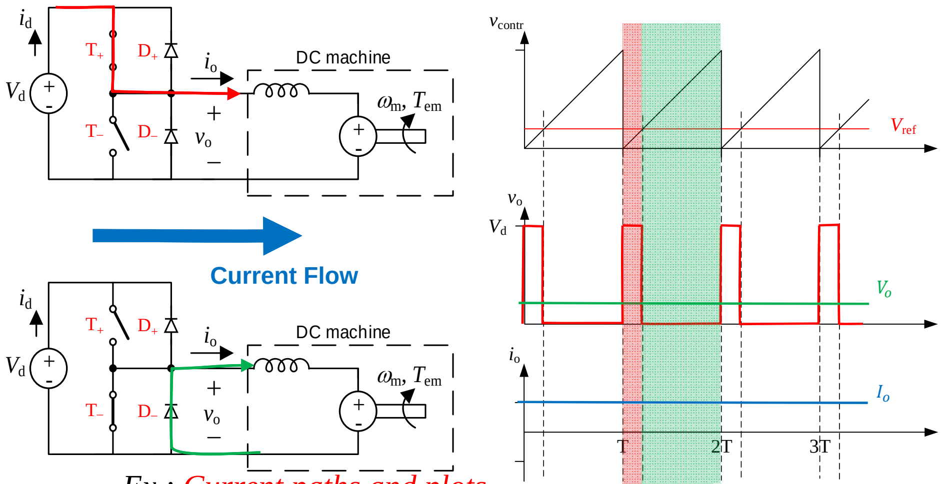
2-Quadrant Converter – PWM and Motor (Buck) Operation



Ex.: Current paths and plots

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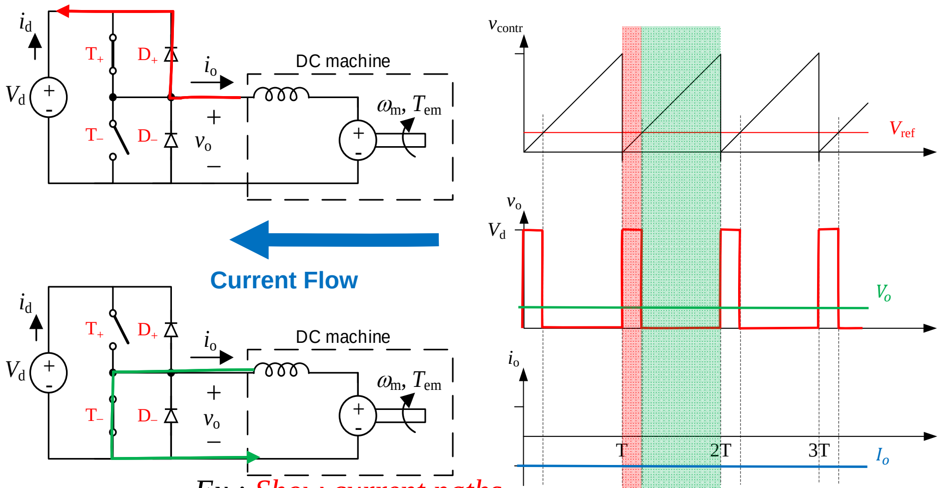
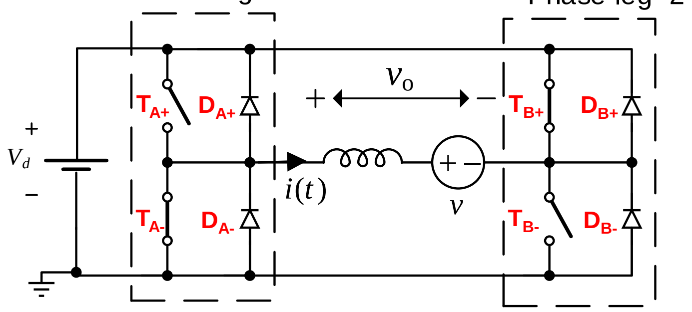
2-Quadrant Converter – PWM and Generator (Boost) Operation



Ex.: Show current paths

The 4-quadrant (H-Bridge) Converter

- The output voltage (v_o) can be both positive and negative
- Current ($i(t)$) can flow in both directions



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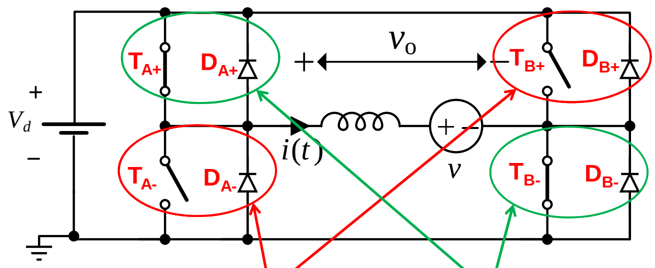
The H-Bridge Converter Bipolar Switching

- Bipolar Switching – The switches are operated in pairs – T_{B+} and T_{A-}
- Bipolar Switching – The switches are operated in pairs – T_{A+} and T_{B-}



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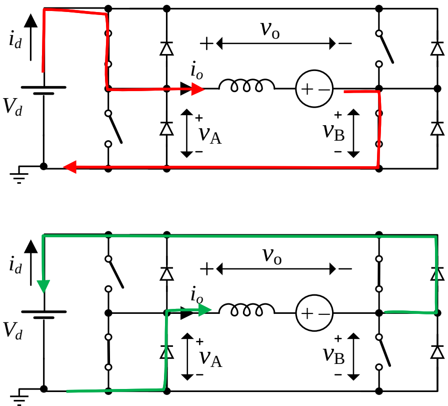
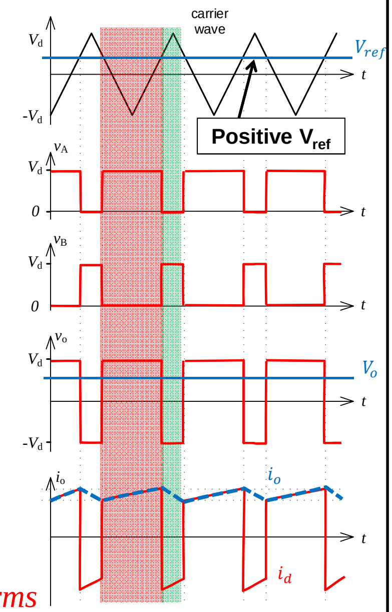
H-Bridge Converter Bipolar Switching, $V_{ref}>0$





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Ex.: current paths and waveforms

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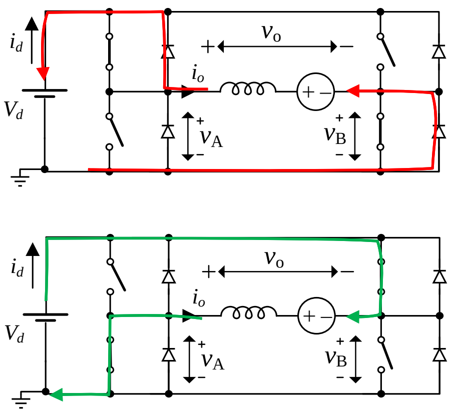
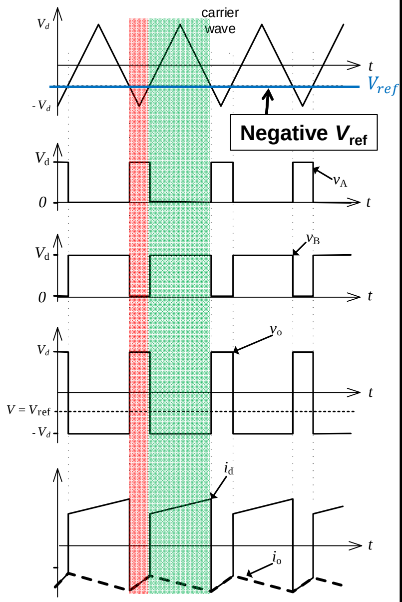
H-Bridge Converter Bipolar Switching, $V_{ref}<0$





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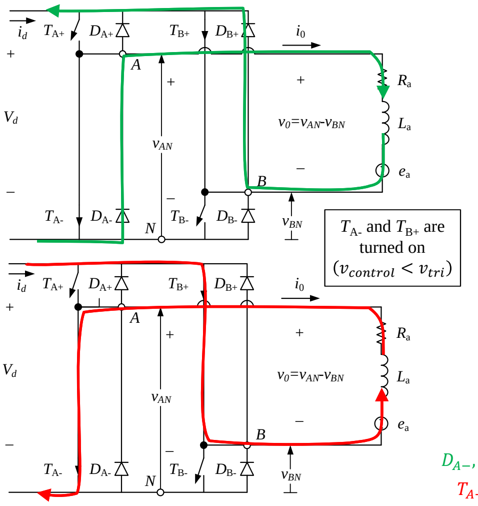
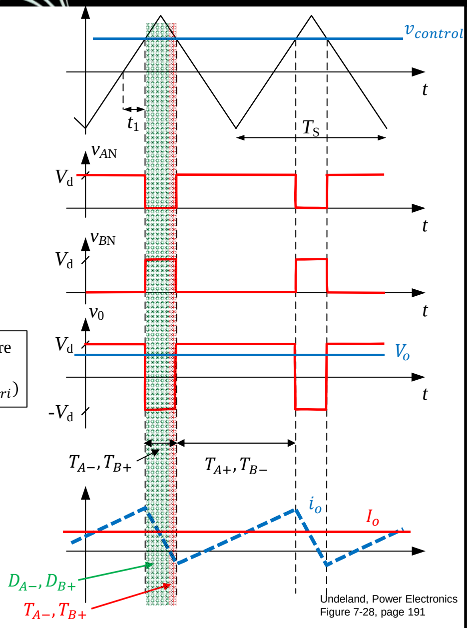
Ex.: current paths

H-Bridge Converter Bipolar Switching 1

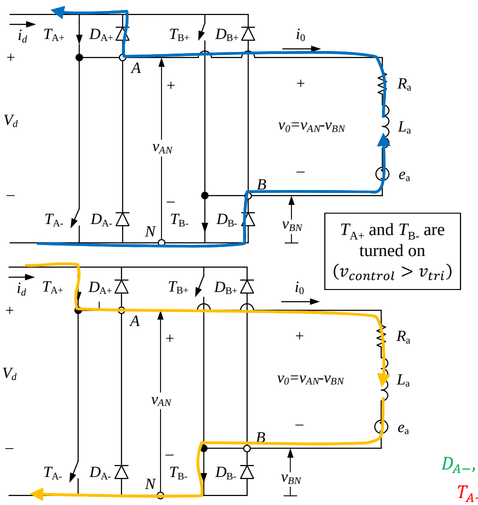
Ex.: current paths and plots

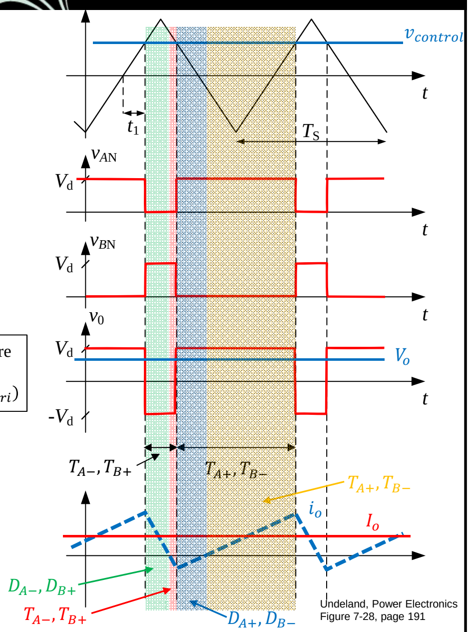




H-Bridge Converter Bipolar Switching 2

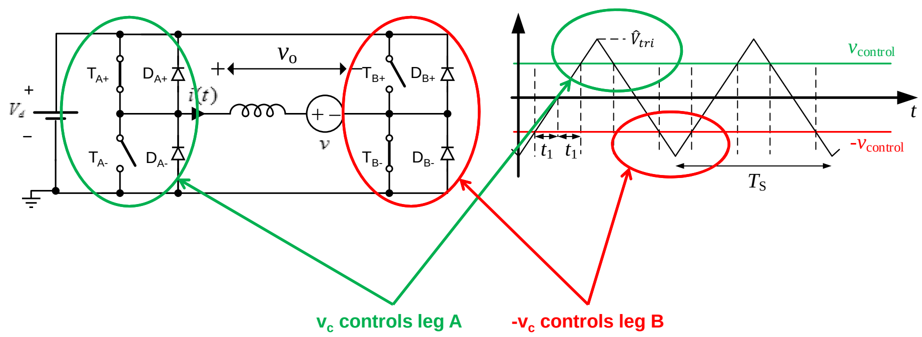
Ex.: current paths





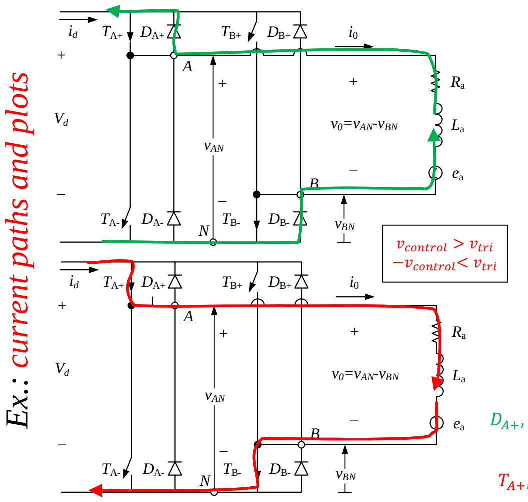
The H-Bridge Converter Unipolar Switching

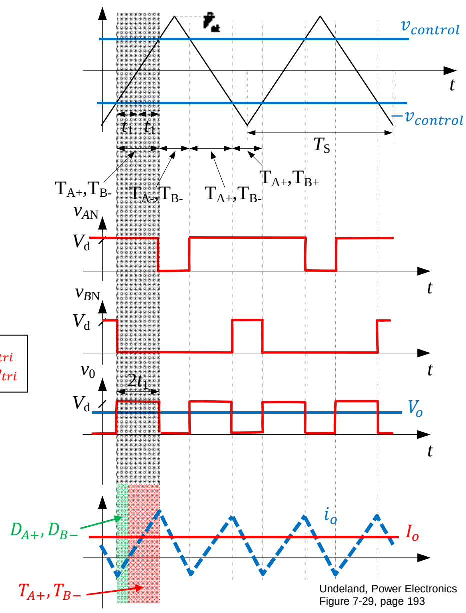
- Unipolar Switching – The switches are controlled by two different control voltages ($v_{control}$ for T_{A+} and T_{A-} and $-v_{control}$ for T_{B+} and T_{B-})



H-Bridge Converter Unipolar Switching 1

Ex.: current paths and plots





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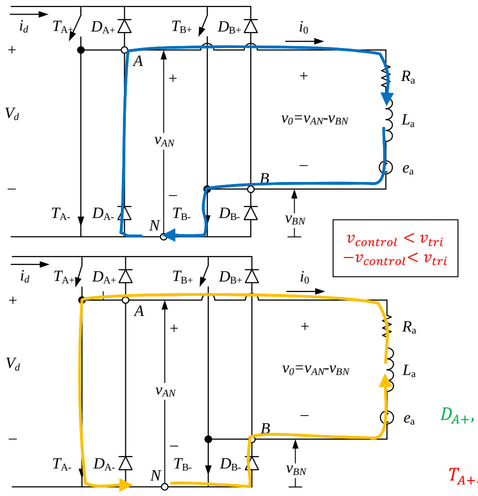
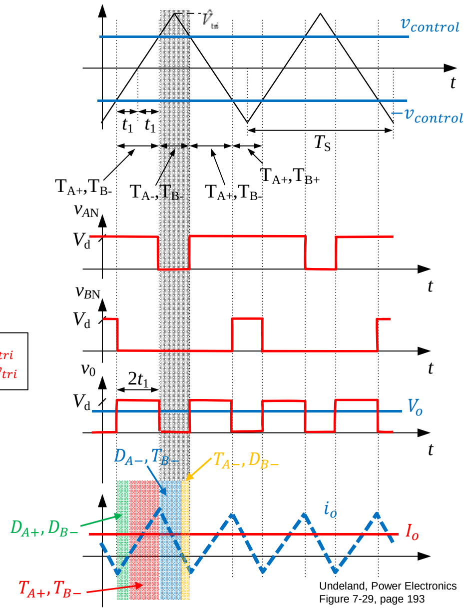
H-Bridge Converter Unipolar Switching 2

Ex.: current paths





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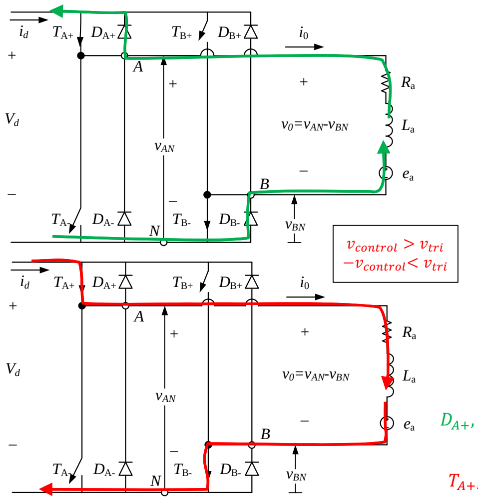
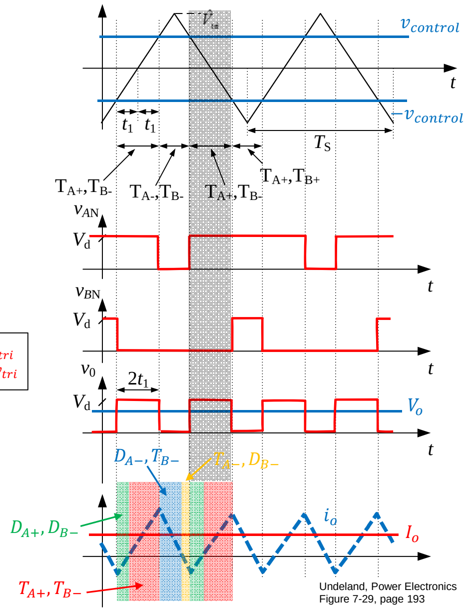
H-Bridge Converter Unipolar Switching 3

Ex.: current paths





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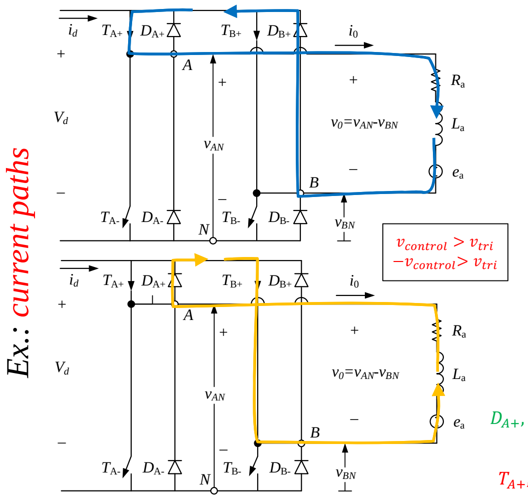
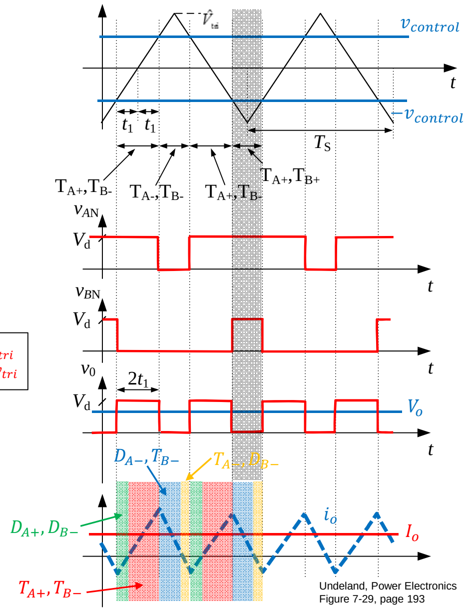
H-Bridge Converter Unipolar Switching 4

Ex.: current paths





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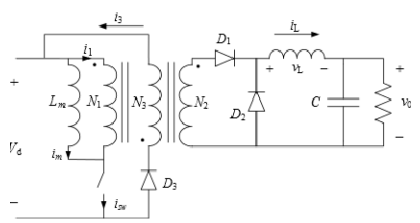
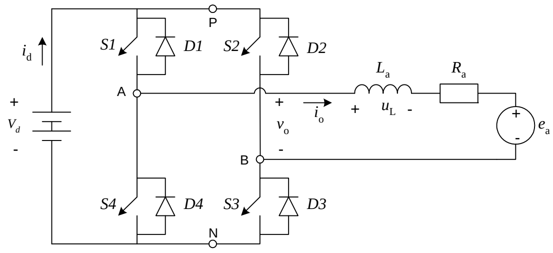
Tutorial 6



$N_1 : N_3 : N_2 = 1 : 1 : 1$
$V_d = 50V$
$D = 0.4V$ $L_m = 22\mu H$
$C = 470\mu F$ $f = 200kHz$
$R_{load} = 1\Omega$ $L_{out} = 7.5\mu H$

- Input-output voltage ratio
- Plot current waveforms through the diodes and the switch
- Power circulating to magnetize the transformer
- Calculate the maximum duty cycle allowed
- $N_1 = N_2 = 10$, N_3 and D to obtain $V_o = 30V$

Tutorial 6



- $v_{control} = 0.5\hat{V}_{tri}$, calculate V_o, I_d in terms of V_d and I_o (assume $i_o = I_o$)
- Using Fourier analysis, calculate the switching-frequency harmonics in v_o and i_d

Summary

- Compare the operating principle of the back and the forward converter.
- How is the third winding in the flyback and forward converters compare?
- Demonstrate the operating principles of the 2/4-quadrant (H-bridge) converters using current paths and output voltage.
- Show various current paths in the 4-quadrant (H-Bridge) converter with bipolar and unipolar switching strategy .
- Learning outcome:
  - ❖ Analysis of the operation of the forward, half-bridge and full-bridge converters.