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ENM061 - Power Electronic Converters 7.5 ECTS, 2017

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Lecture outline

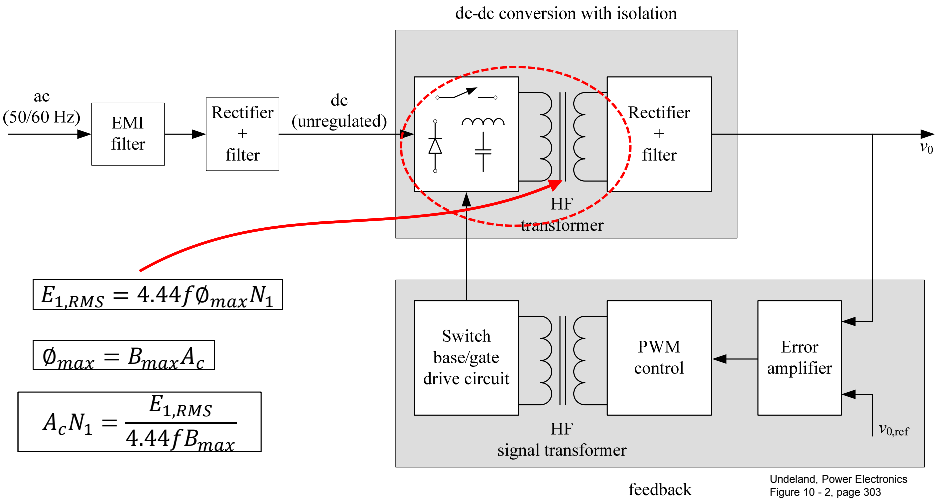
The Full-bridge, half-bridge and Push-Pull DC/DC converters

- The non-isolated full-bridge converter – bipolar vs unipolar switching
- The isolated full-bridge DC/DC converter
- The isolated half-bridge DC/DC converter
- The push-pull DC/DC converter
- How to select a suitable converter topology
  - ❖ Core excitation and isolation
  - ❖ Power rating and efficiency
  - ❖ Switch utilization
- 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



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

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

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

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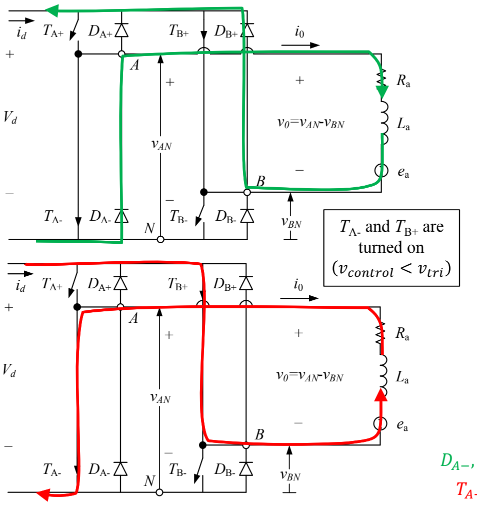
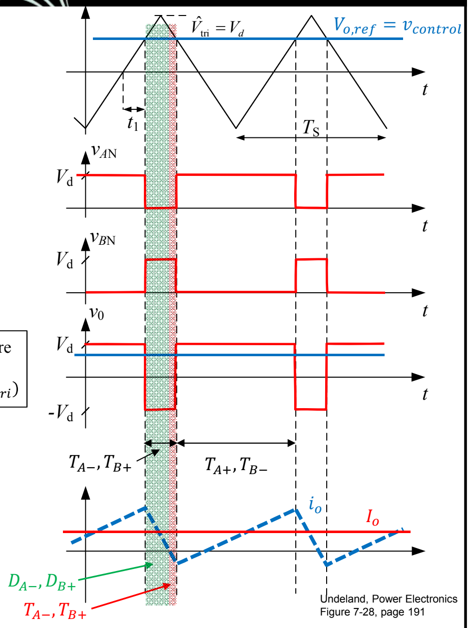
H-Bridge Converter Bipolar Switching 1

Ex.: current paths





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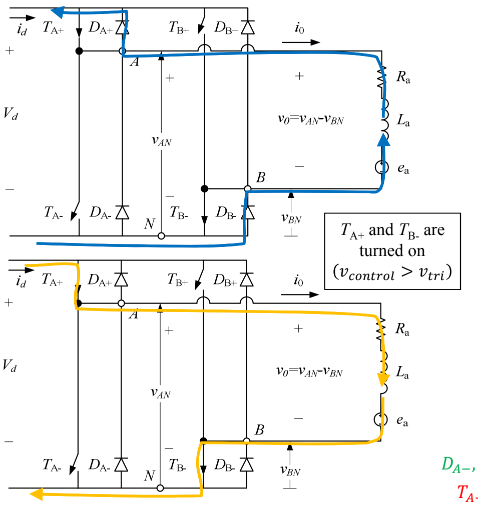
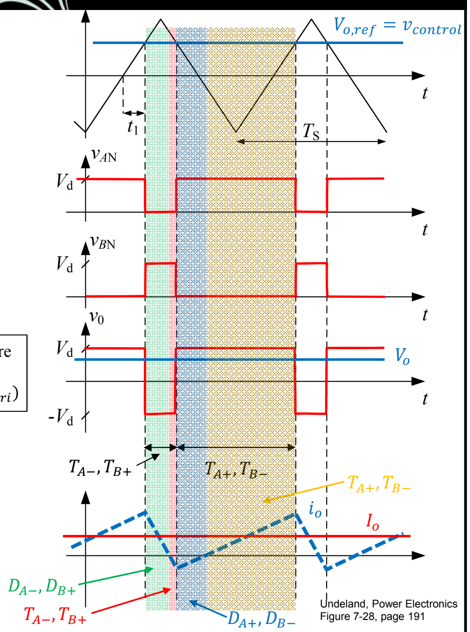
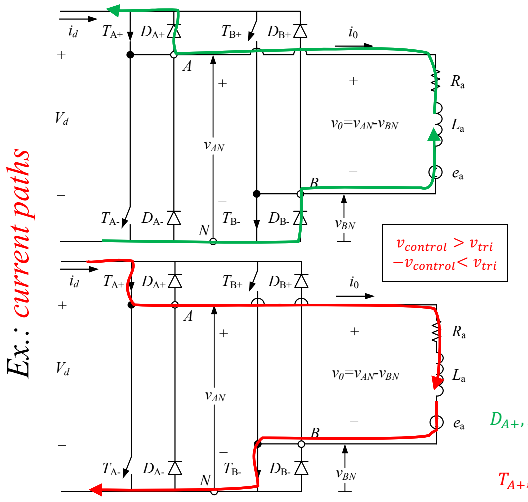
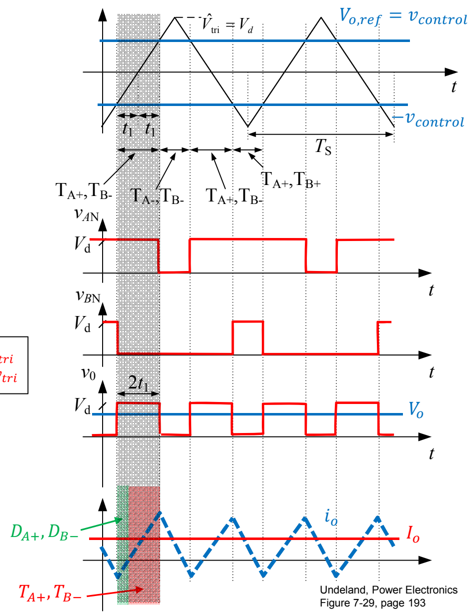
H-Bridge Converter Bipolar Switching 2



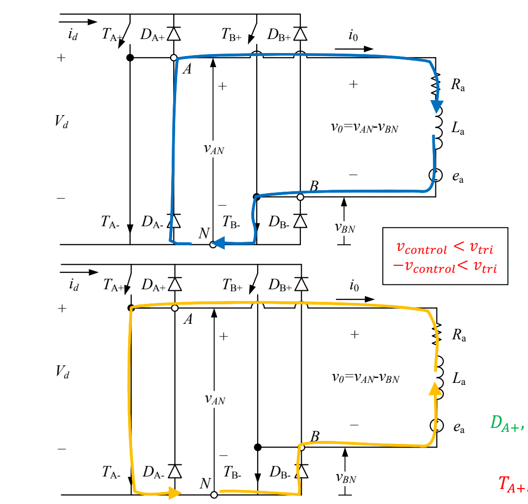


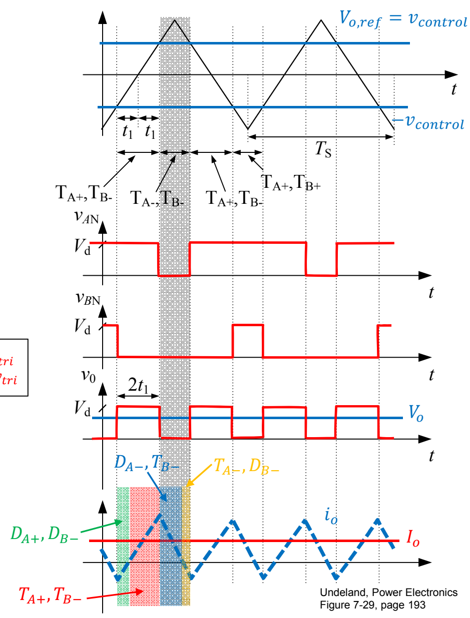
H-Bridge Converter Unipolar Switching 1





H-Bridge Converter Unipolar Switching 2





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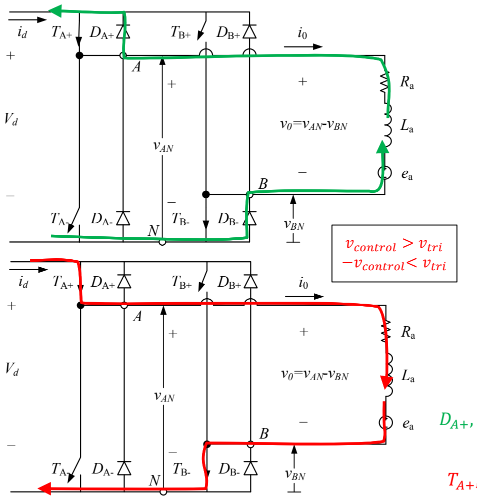
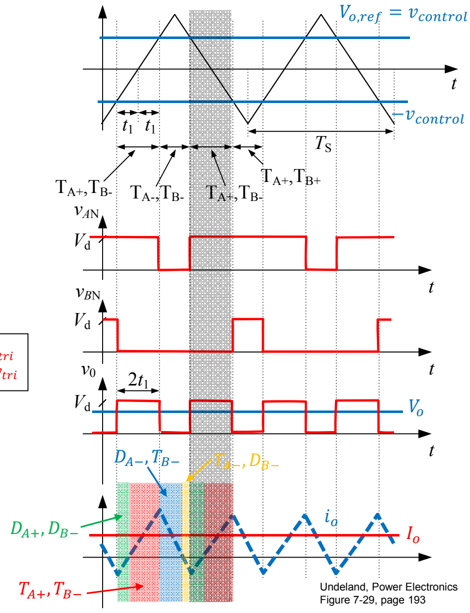
H-Bridge Converter Unipolar Switching 3





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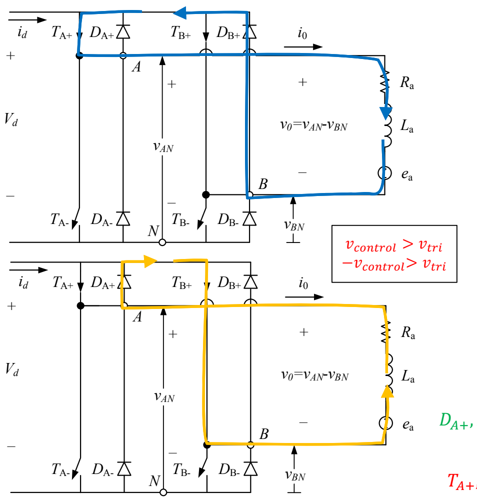
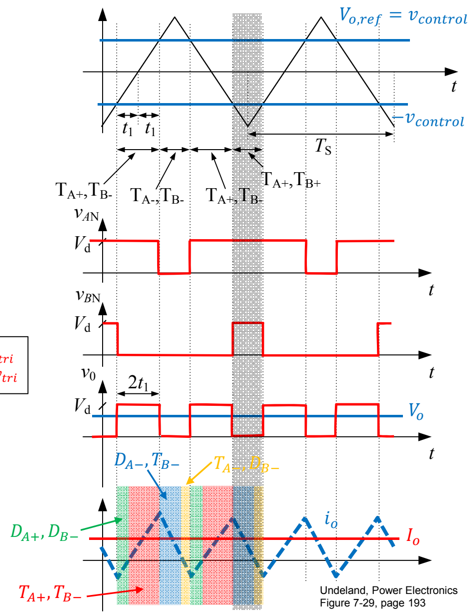
H-Bridge Converter Unipolar Switching 4





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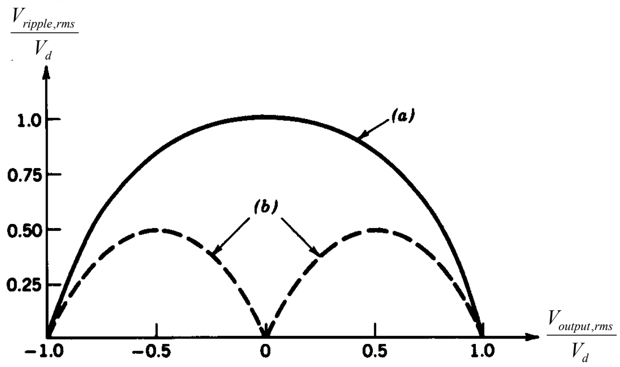
Bipolar vs unipolar switching Output Voltage Comparison



(a) bipolar switching, (b) unipolar switching

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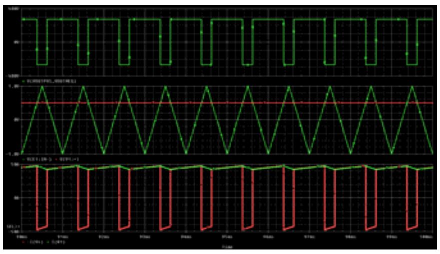
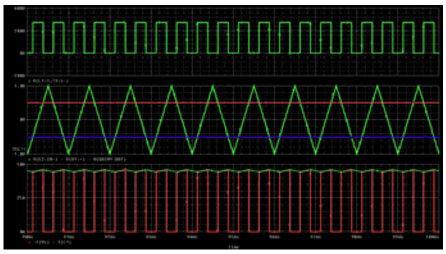
Bipolar vs unipolar switching Output current comparison

- With the same switching frequency, PWM with unipolar switching results in a lower RMS ripple component in the output voltage.

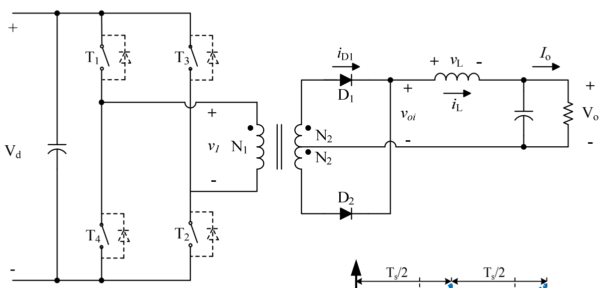




Bipolar: v_c=0.5
V_{out}=135V ($-V_d$ to $+V_d$)
Current ripple: 5.3A (RL load)
Current ripple freq: 1kHz

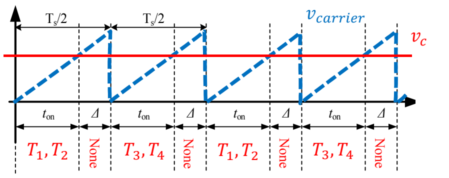
Unipolar: v_c=0.5
V_{out}=135V (0 to $+V_d$)
Current Ripple: 1.6A (RL load)
Current ripple freq: 2kHz

The Isolated Full-Bridge DC/DC Converter – Ideal Waveforms 1



Switching within half - cycle

Derived from buck converter



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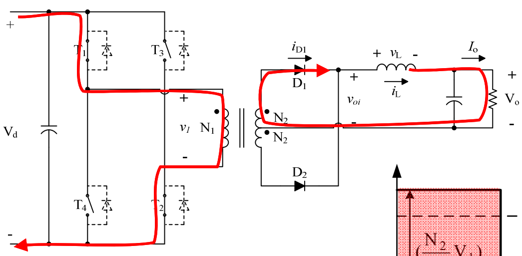
The Isolated Full-Bridge DC/DC Converter – Ideal Waveforms 1



Ex.: current paths and plots

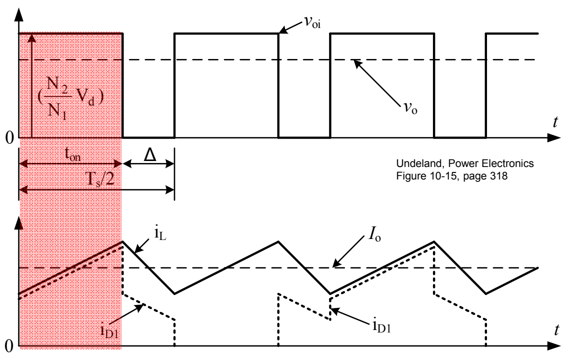
Ex.: $\frac{V_o}{V_d} = ?$

Switching within half - cycle

Derived from buck converter

$$\frac{V_o}{V_d} = 2\frac{N_2}{N_1}D \quad (D \le 0.5)$$

$$D = \frac{t_{on}}{T_s}$$



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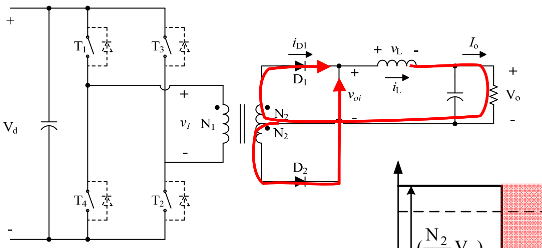
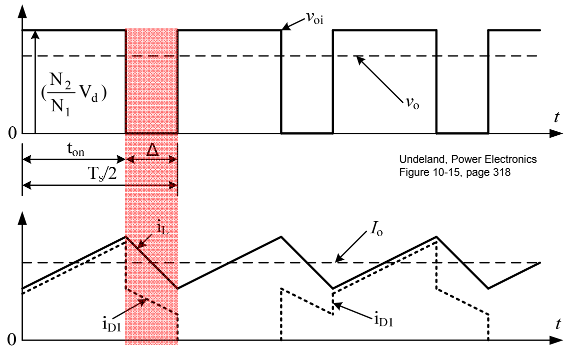
The Isolated Full-Bridge DC/DC Converter – Ideal Waveforms 2



Ex.: current paths and plots



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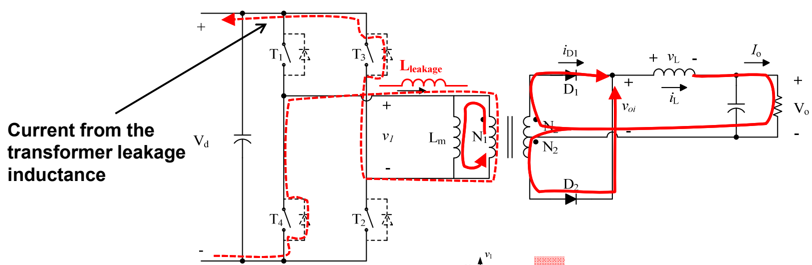
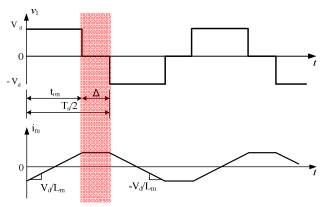
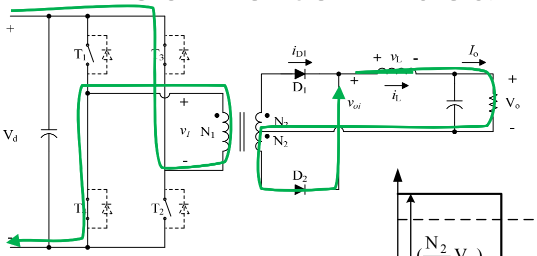
Isolated Full-Bridge DC/DC Converter – Nonideal Waveforms 2



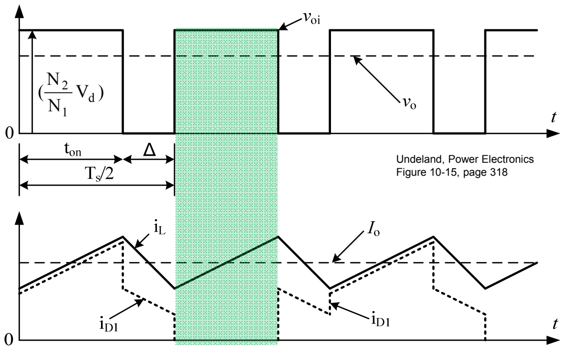
Ex.: current paths



The Isolated Full-Bridge DC/DC Converter - ideal Waveforms 3



Ex.: *current paths and plots*



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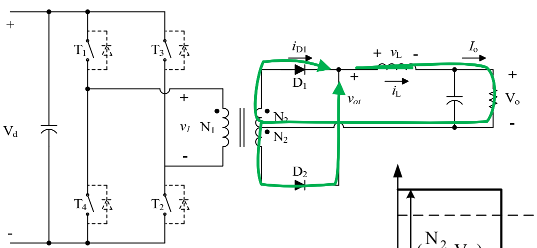
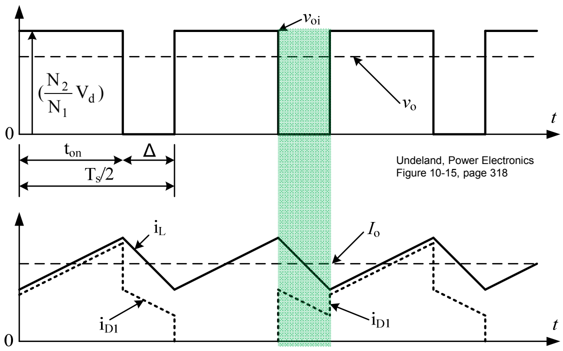
The Isolated Full-Bridge DC/DC Converter – Ideal Waveforms 4



Ex.: *current paths and plots*



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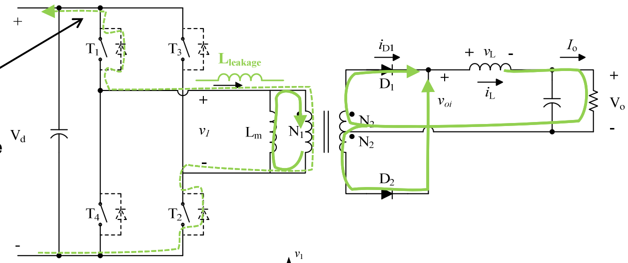
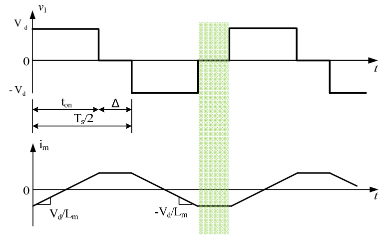
Isolated Full-Bridge DC/DC Converter – Nonideal Waveforms 4

Current from the transformer leakage inductance

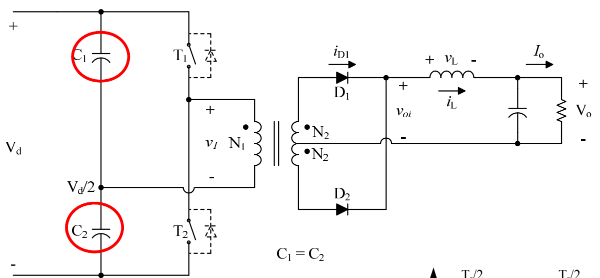




Ex.: current paths

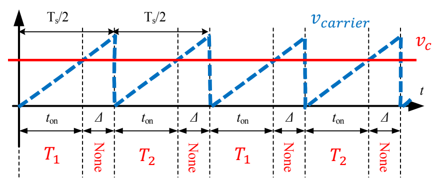
The Half-Bridge Converter

- The two switches from the full-bridge are replaced with two capacitors



Switching within half-cycle

Derived from buck converter



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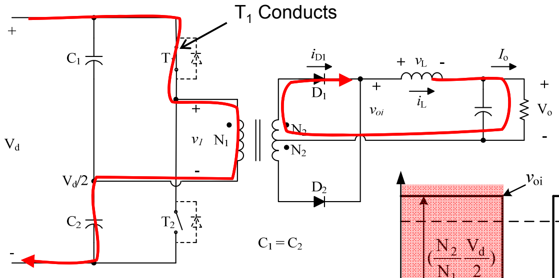
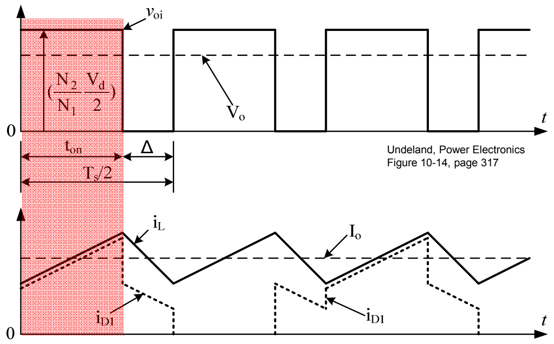
Half-Bridge Converter – Waveforms 1



Ex.: current paths and plots

Ex.: $\frac{V_o}{V_d} = ?$



Switching within half-cycle

Derived from buck converter

$$\frac{V_o}{V_d} = \frac{N_2}{N_1} D \quad (D \le 0.5)$$

$$D = \frac{t_{on}}{T_s}$$

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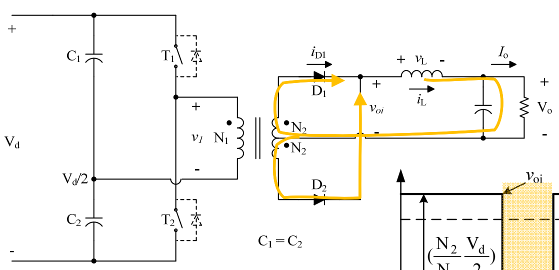
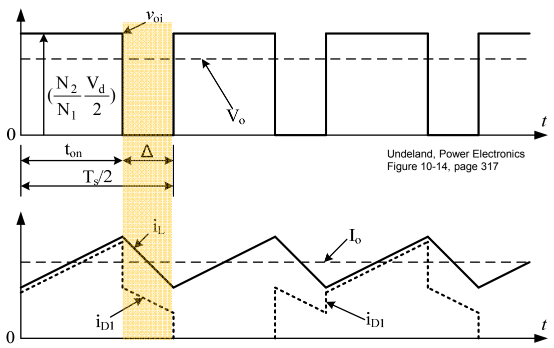
Half-Bridge Converter – Waveforms 2



Ex.: current paths and plots

T_1 and T_2 are turned off



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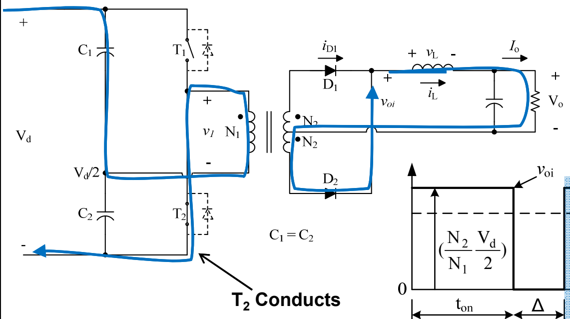
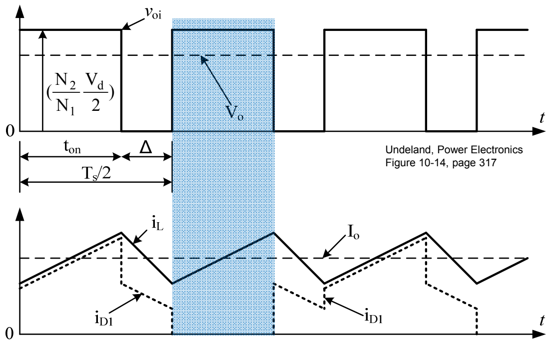
Half-Bridge Converter – Waveforms 3

Ex.: current paths and plots





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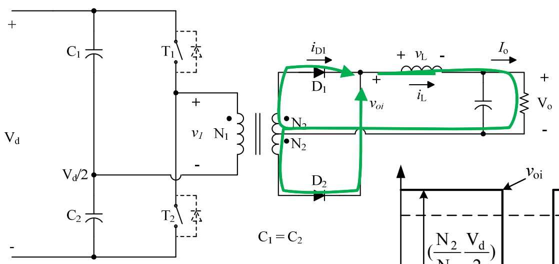
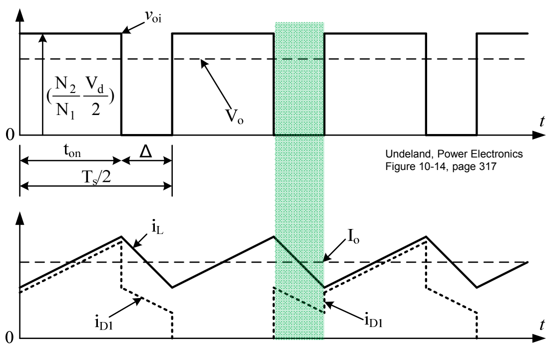
Half-Bridge Converter – Waveforms 4

Ex.: current paths and plots



T_1 and T_2 are turned off



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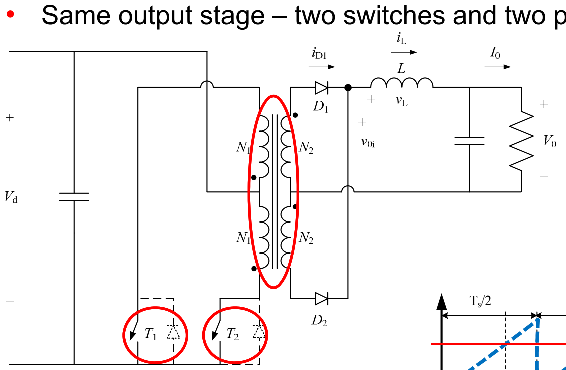
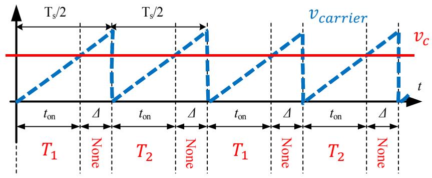
The Push-Pull Converter

- Same output stage – two switches and two primary windings

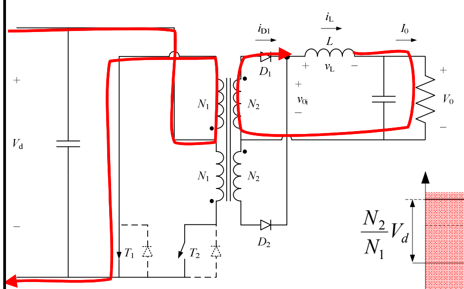




Switching within half-cycle

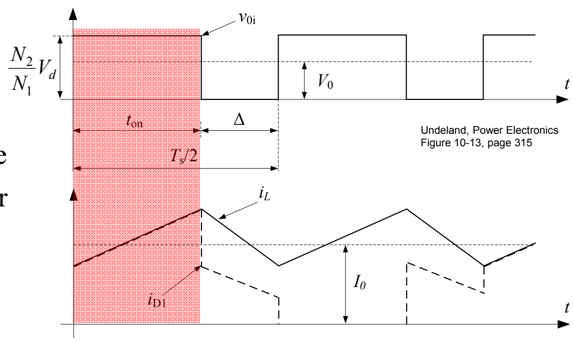
Derived from buck converter

Push-Pull Converter – Waveforms 1



Ex.: *current paths and plots*

Ex.: $\frac{V_o}{V_d} = ?$



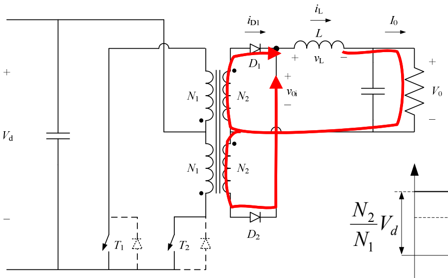
Switching within half-cycle

Derived from buck converter

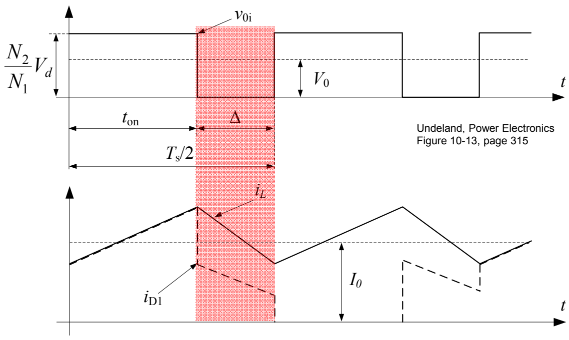
$$\frac{V_o}{V_d} = 2\frac{N_2}{N_1}D \quad (D \le 0.5)$$

$$D = \frac{t_{on}}{T_s}$$

Push-Pull Converter – Waveforms 2



Ex.: *current paths and plots*



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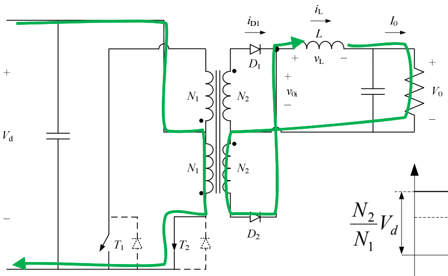
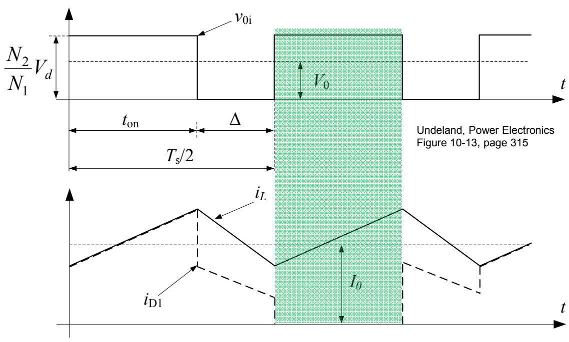
Push-Pull Converter – Waveforms 3



Ex.: *current paths and plots*



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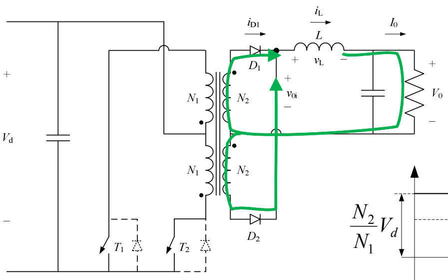
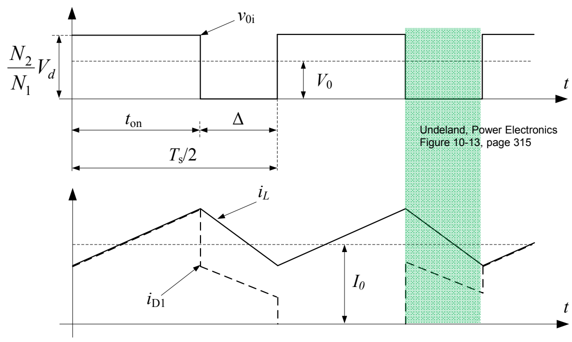
Push-Pull Converter – Waveforms 4

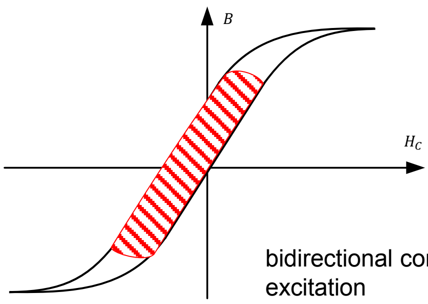


Ex.: current paths and plots

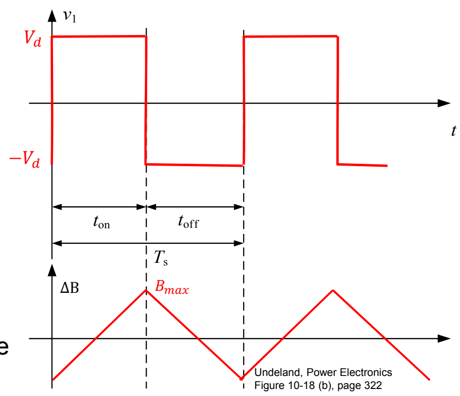


Isolated DC/DC Converters transformer core excitation

- Unidirectional, $\Delta B = B_{max}$ (Flyback, forward) vs bidirectional, $\Delta B = 2B_{max}$ (Push-pull, HB, FB). **ΔB prioratized for smaller core size or low core loss!!!**
- Usually no air gap for higher mutual inductance but in flyback is necessary for energy storage
- The core is chosen based on the switching frequency and excitation type



bidirectional core excitation



Isolated DC/DC Converters
Power rating and efficiency

Converter Topology	Typical max output power
Flyback	200W
Forward	300W
Two transistor forward / flyback	400W
Push-pull	500W
Half-Bridge	1000W
Full-Bridge	>1000W

Table 1. Converter output power range.

© Philips

Topology	Max. Power (Watts)	Typical Efficiency (%)
Flyback	30	75
1 Transistor Forward	150	80
2 Transistor Forward	200	83
Push Pull	350	80
Full Bridge	500	85

Table 1: Comparison of various switching regulator topologies.

Topology	Maximum Drain Voltage	Average Drain Current
Flyback	1.5Vin(max)	751.5Pout/ Vin(max)
1 Transistor Forward	2.5 to 3.0 Vin(max)	1.3Pout/ Vin(max)0
2 Transistor Forward	Vin(max)	1.2Pout/ Vin(max)
Push Pull	352.5 to 3.0 Vin(max)0	0.65Pout/ Vin(max)
Full Bridge	Vin(max)	0.60Pout/ Vin(max)

Table 2: Power MOSFET voltage and current ratings versus power supply topology.

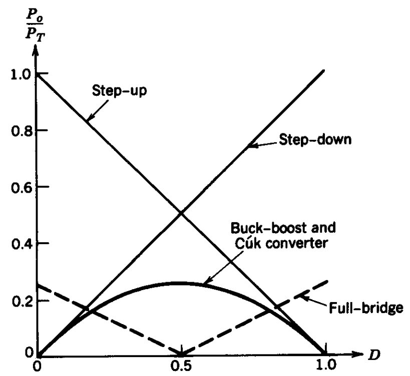
© Fairchild

TABLE 4: SMPS TOPOLOGY SELECTION GUIDELINES

Input voltage	Output power	Preferred Topology
Universal input (90-264) VAC	Po < 150 watt, Load current < 10A	Flyback, Forward
Universal input (90-264) VAC	Po < 150 watt, Load current > 10A	Forward
Universal input (90-264) VAC	150 watt < Po > 350	Two-Switch Forward, Half-Bridge, Push-Pull
Universal input (90-264) VAC	Po < 500 watt	Half-Bridge, Push-Pull
Vin > 350 VDC	Po < 750 watt	Half-Bridge
Vin < 200 VDC	Po < 500 watt	Push-Pull
Vin > 350 VDC	500 < Po > 1000 watt	Full-Bridge
Vin > 350 VDC	Po > 1000 watt	ZVT Full-Bridge
Vin > 350 VDC	Po > 2000 watt	More than one ZVT full-bridge in parallel, interleaved with more than one ZVT full-bridge

© Microchip

non-isolated DC/DC converters
Switch utilization



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- Use step-up or Step-down if possible for a switch utilization point of view
- Use buck-boost if higher or lower output voltage than the input is required
- Use full-bride, If 4-quadrant operation or DC/AC conversion is required
- Other factors can be power rating, cost and efficiency

Summary

- Show current paths for a non-isolated H-bridge converter with bipolar and unipolar switching.
- Explain the operating principle of isolated full-bridge DC/DC converter with and without a non-ideal transformer.
- Explain the operating principle of isolated half-bridge DC/DC converter.
- Explain the operating principle a push-pull converter.
- Compare the different DC/DC converters in terms of power rating, efficiency, isolation and core excitation.
- Learning outcome:
  - Analysis of operation of isolated full-bridge, half-bride and the push-pull converters.