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ENM061 - Power Electronic Converters 7.5 ECTS, 2017

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Lecture outline

The single-phase thyristor rectifier

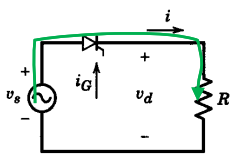
- The operation principle of thyristors
- Single-phase thyristor rectifiers without source inductance
- Single-phase thyristor rectifiers with source inductance and current commutation
- Single-phase thyristor rectifier – the delay angle and inverter mode
- Summary

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.

Simple Thyristor Circuits

- The thyristor can be described as a diode that you can turn on
- The current keeps on flowing until it reaches zero where the thyristor turns off



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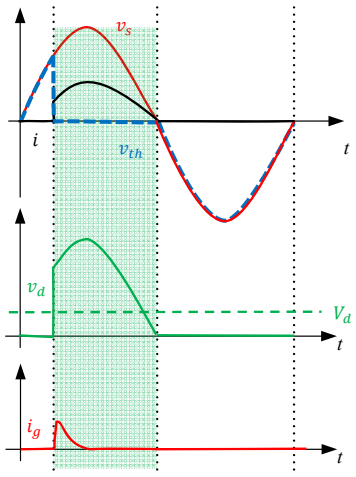
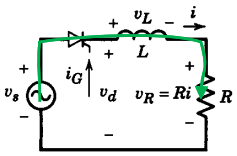


Simple Thyristor Circuits

- If the source inductance is included, the current keeps on flowing even after the source voltage becomes negative



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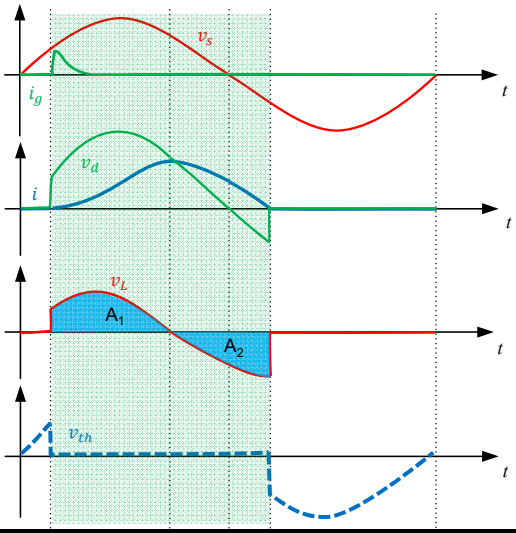
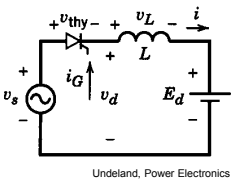
Area A_1 = Area A_2



Simple Thyristor Circuits

- If a DC-source is added in series, the current will start to flow once the source voltage exceeds the DC-level and the thyristor is turned on.



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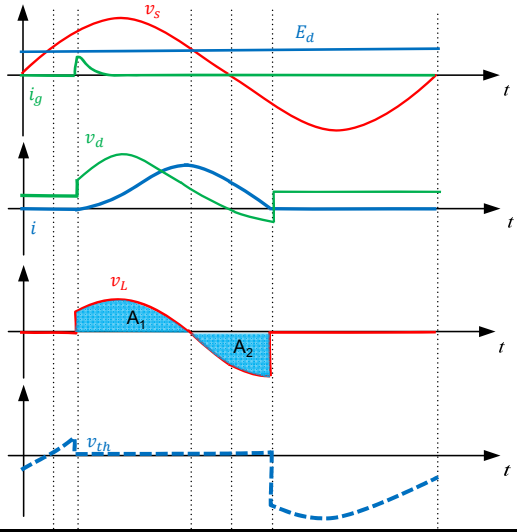
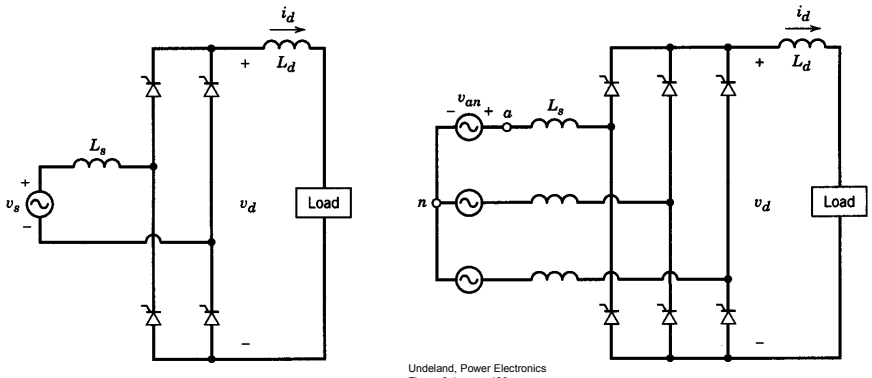
Area A_1 = Area A_2



Thyristor Rectifiers
Basic Configurations

- Practical area application of the thyristor – a rectifier in which you can control the output voltage level



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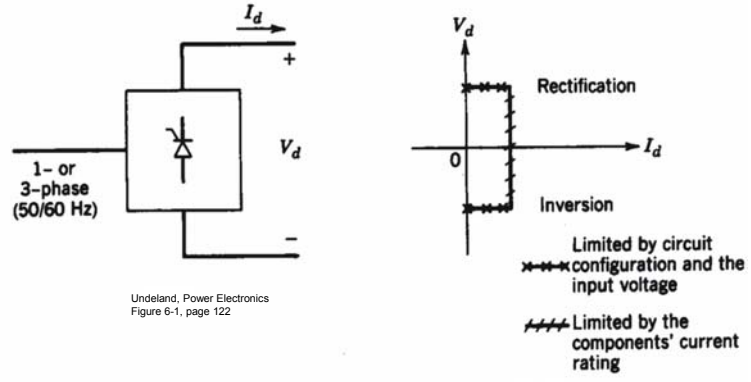
Thyristor Rectifiers
Operating Conditions

- The thyristor rectifier can invert the output voltage



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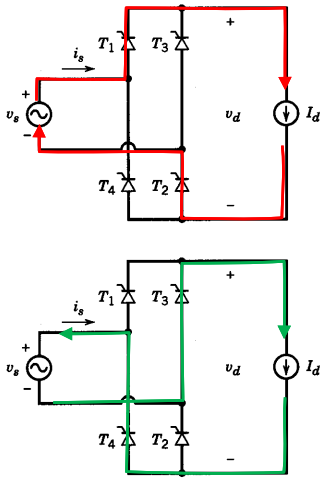
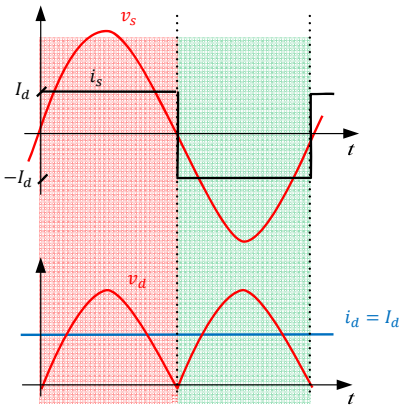
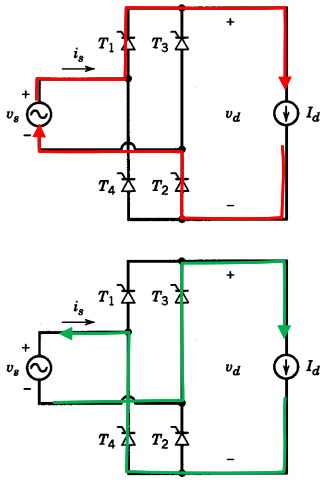
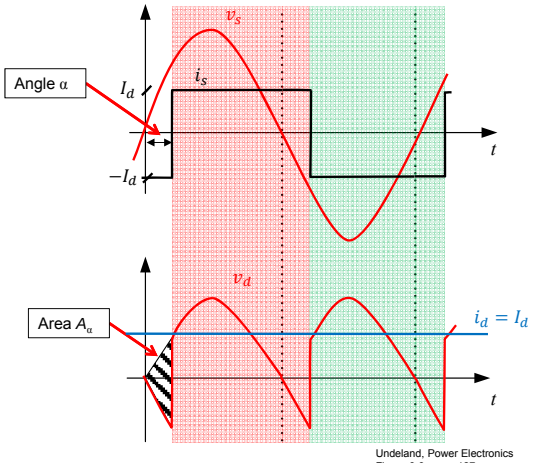
Single-Phase Thyristor with Constant DC-Side Current (α=0°)





Single-Phase Thyristor with Constant DC-Side Current (α=30°)





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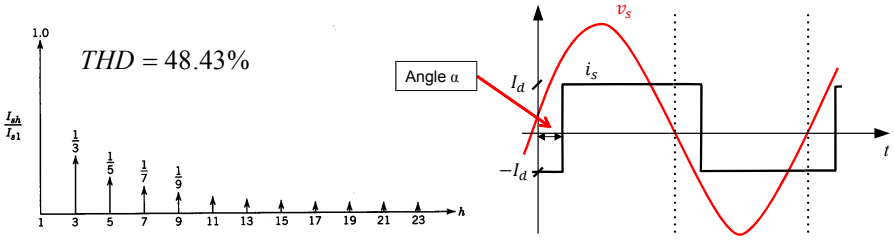
Single-Phase Thyristor Rectifier Input Line Current Harmonics

- The source current (i_s) is square-wave shaped and consists of odd harmonics



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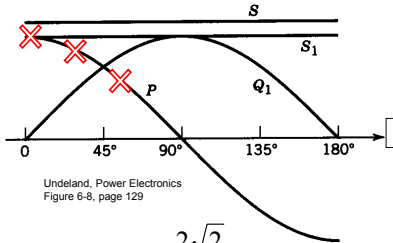
Single-Phase Thyristor Rectifier Input Line Current Harmonics

- As the delay angle increases, the phase shift of the fundamental frequency component in the source current ($i_{s(1)}$) also increases. This reduces the active power transfer.



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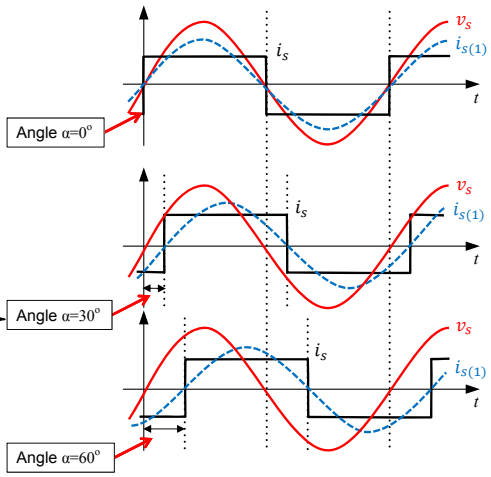
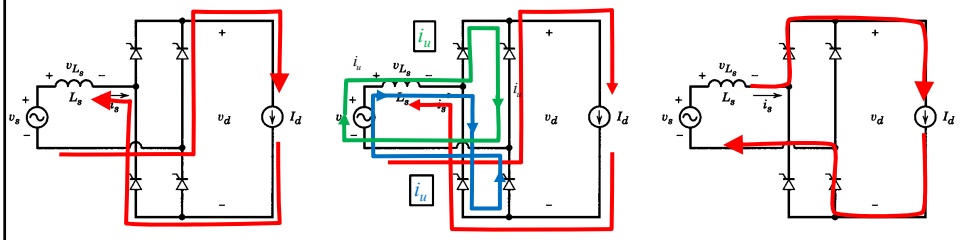
$$DPF = \cos(\alpha),\ PF = \frac{2\sqrt{2}}{\pi}\cos(\alpha)$$



Single-Phase Thyristor Rectifier AC-Side Inductance

Before: $(\omega t < \alpha)$ During: $(\alpha \le \omega t \le \alpha + u)$ After: $(\omega t > \alpha + u)$



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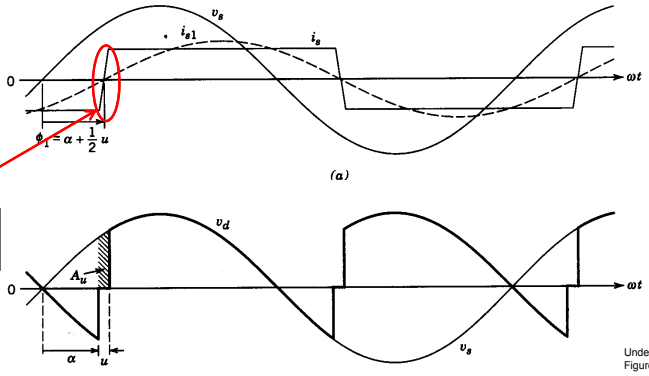
Single-Phase Thyristor Rectifier AC-Side Inductance

- The commutation of the input current takes a certain time known as the commutation angle (u)
- The output voltage reduced due to the commutaion



Idealized commutaion!

$$\Delta V_d = \frac{2\omega L_s I_d}{\pi}$$

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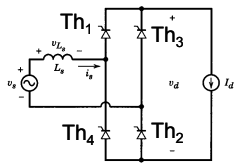
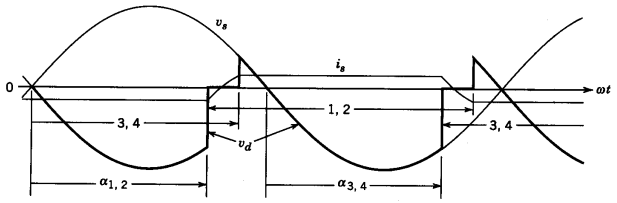
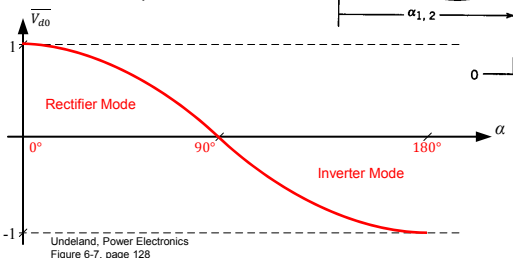
Delay Angle in the Thyristor Rectifier

- The variation of V_d as a function of α shows that the average output voltage becomes negative when α>90°







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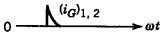

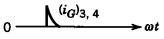

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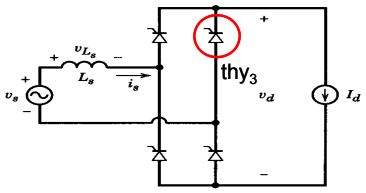
$$V_d = \frac{2\sqrt{2}V_s \cos(\alpha)}{\pi}$$

Thyristor inverter mode
Importance of extinction angle γ



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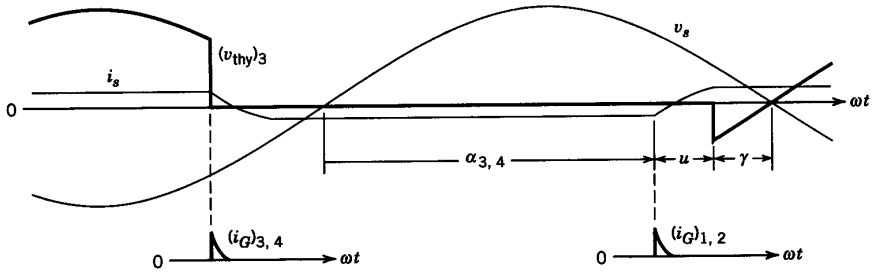
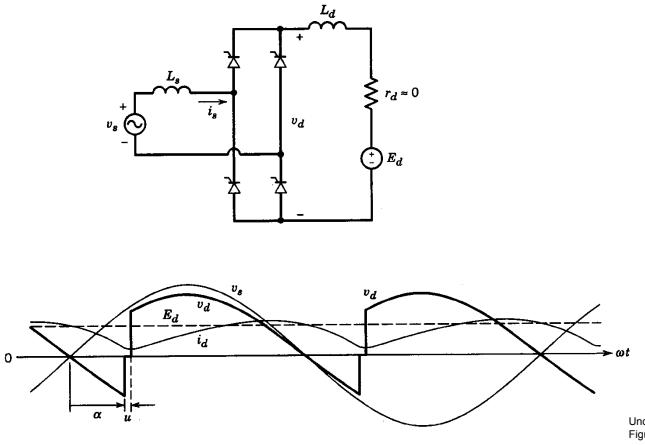


Practical thyrisitor converter



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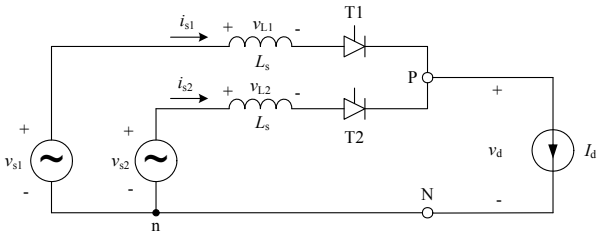
- Discontinous mode: it can occur in a dc-drive at light loads

Tutorial 11



For two delay angles of 45° and 135° and with L_s = 5 mH, v_{s1} and v_{s2} have 120 V RMS and phase shifted by 180° at 60 Hz, and I_d = 10 A,

- Plot the waveforms of v_{s1}, i_{s1} and v_d
- Calculate the average output voltage V_d and the commutation interval u

Summary

- The operation principle of thyristors
- Single-phase thyristor rectifiers without source inductance
- Single-phase thyristor rectifiers with source inductance and current commutation
- Thyristor converters in inverter mode of operation
- Learning outcome:
  - Operation of a single-phase thyristor rectifier operating with a current-stiff DC-side and the impact of line impedance for current commutation.