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ENM061 - Power Electronic Converters 7.5 ECTS, 2017

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Lecture outline

The single-phase diode rectifier

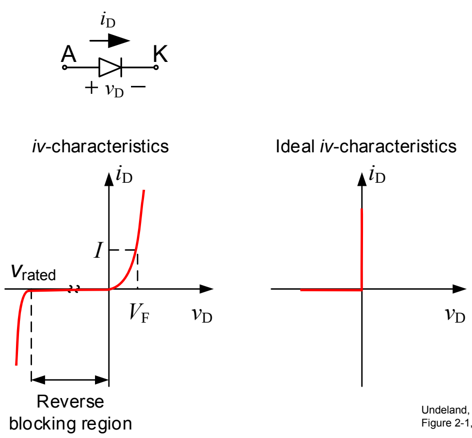
- Prerequisites for today's lecture
- The concept of rectification
- The effect of inductance on diode currents
- Single-phase diode rectifier with resistive and inductive load
- Single-phase diode rectifier with source inductance
- Single-phase diode rectifier with voltage and current stiff loads
- Practical single-phase diode rectifiers
- Impact of non-linear rectifier loads and the power factor corrector (PFC)
- 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.

The Diode

- On and off states controlled by the power circuit



Undeland, Power Electronics
Figure 2-1, page 17

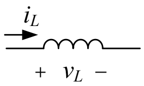
Inductors and Capacitors

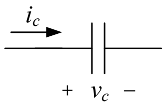
$$v_L = L\frac{di_L}{dt}$$

$$i_C = C\frac{dv_C}{dt}$$

$$i_L = i_L(t_1) + \frac{1}{L}\int v_L dt$$

$$v_C = v_C(t_1) + \frac{1}{C}\int i_C dt$$





Average and RMS current and voltage?
Current stiff component

Average and RMS current and voltage?
Voltage stiff component

The Concept of Rectification
Diode Rectifier Block Diagram

- Generates uncontrolled DC voltage for low or high power application

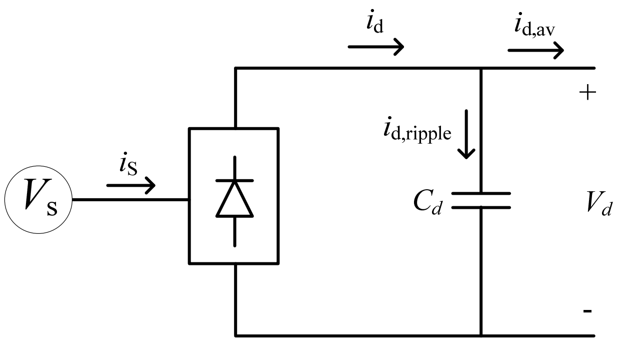


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Figure 5-1, page 79

The Effect of Inductance on Diode Currents – Resistive Load

- A diode in series prevents the current flow in one direction when the source voltage becomes negative

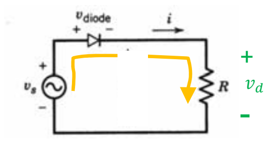

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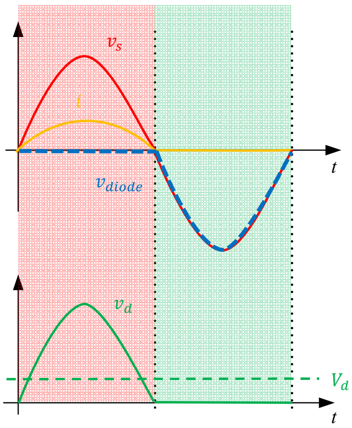
Figure 5-2, page 80



Ex: plot i, v_d and v_{diode}

The Effect of Inductance on Diode Currents – Inductive Load

- An inductor in series keeps the current flowing in the same direction for some tiime – even when the source voltage becomes negative

Area A_1 = Area A_2

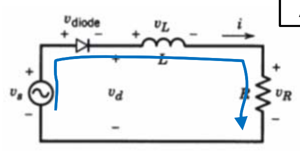


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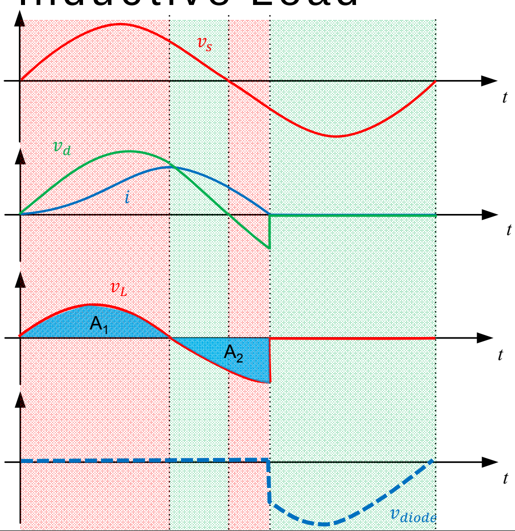
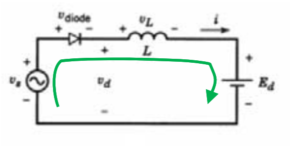
Figure 5-3, page 81



Ex: plot i, v_L , v_d , v_R and v_{diode}

The Effect of Inductance on Diode Currents – Inductive Load and EMF

- An inductor in series keeps the current flowing in the same direction – even when the source voltage becomes negative



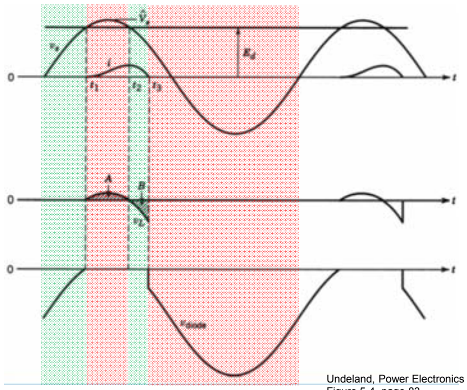


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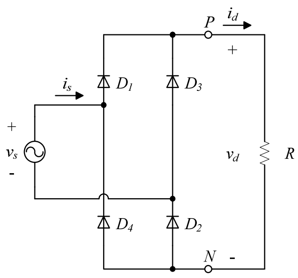
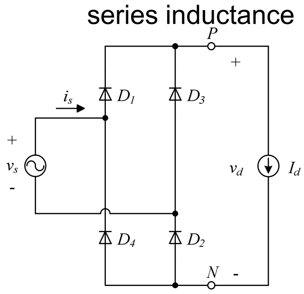
Figure 5-4, page 83

Single-phase Diode Rectifier

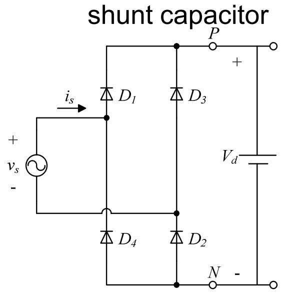
- Resistive Load



- Current stiff load series inductance



- Voltage stiff load shunt capacitor



Diode Rectifier with Resistive Load

- The voltage over the resistor is a full-wave rectified sinusoidal wave

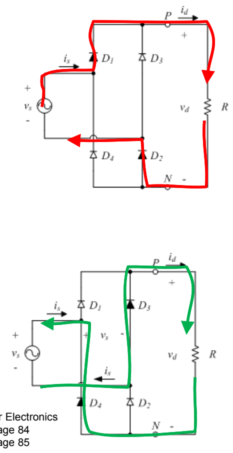


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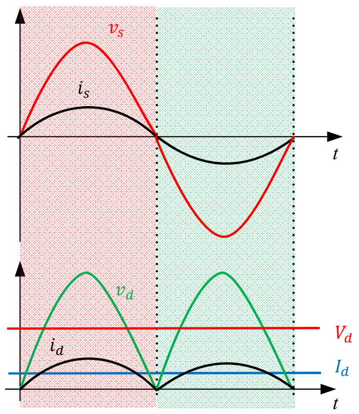
Figure 5-6 (a), page 84
Figure 5-8 (a), page 85



Ex: plot i_s, i_d and v_d

Diode Rectifier with Inductive Load

- The output current is a constant DC-current (assume large L)
- With no source inductance, the source current is square-wave shaped

Ex: plot i_s and v_d

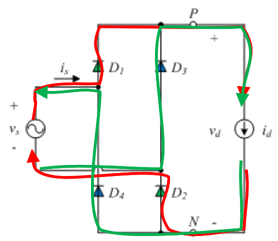


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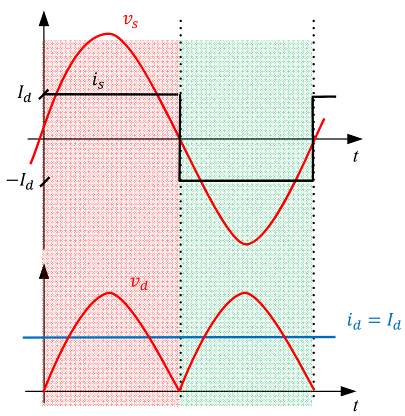
Figure 5-6 (b), page 84
Figure 5-8 (b), page 85



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Diode Rectifier with Inductive Load Input Current

- The source current has a high harmonic content

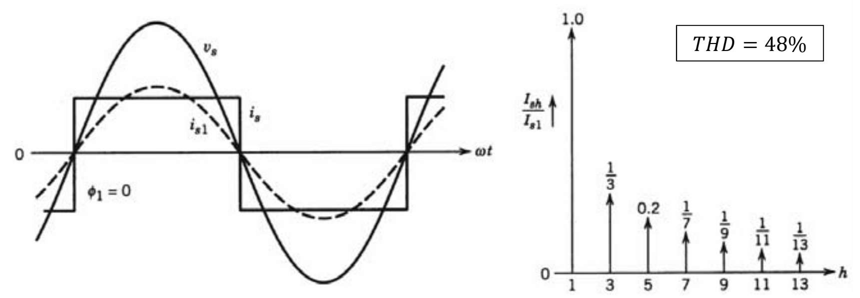

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Figure 5-9, page 86

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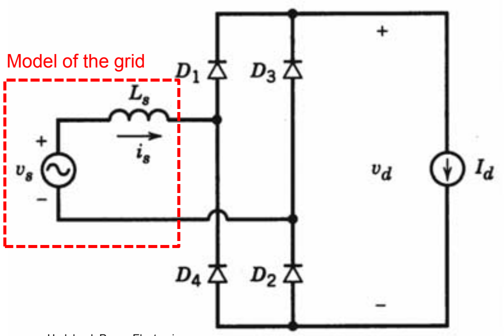
Diode Rectifier with Inductive Load and AC-side inductance

- The source inductance in the grid will influence the operation of the rectifier – the commutation will not be instantaneous



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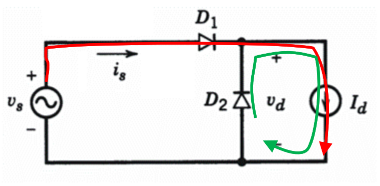
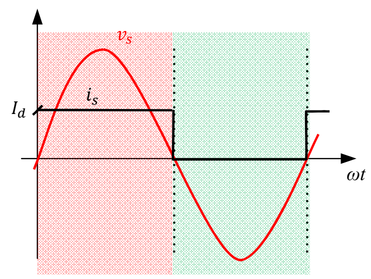
Diode Rectifier with Inductive Load
Current Commutation

- Half-rectification with one current path without source inductance (L_s=0)





Ex: *show current paths for one cycle*

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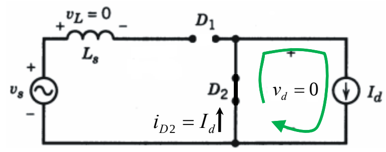
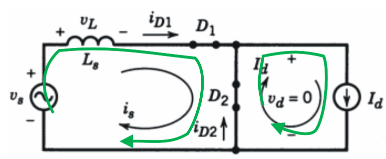
Ex: *what happens during current commutation between D_1 to D_2*

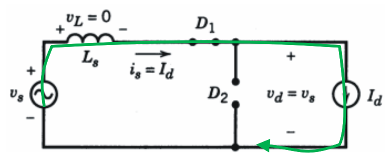
Diode Rectifier with Inductive Load
Current Commutation



Before, $\omega t < 0$



During, $0 \le \omega t \le u$



After, $\omega t > u$

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Figure 5-12, page 88

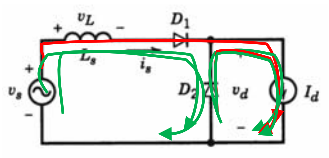
Diode Rectifier with Inductive Load
Current Commutation

- Half-rectification with one current path and with source inductance ($L_s \neq 0$)

Ex: plot i_s, v_L and v_d

Ex: calculate the voltage reduction

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



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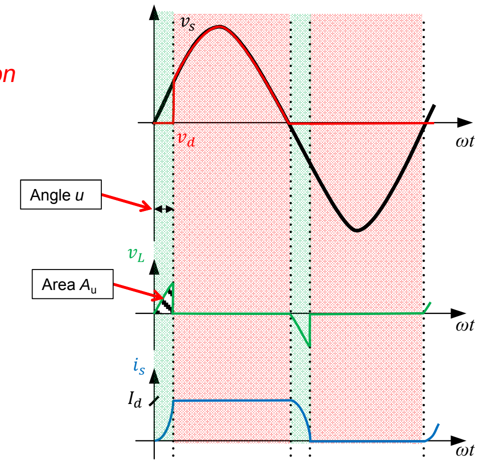

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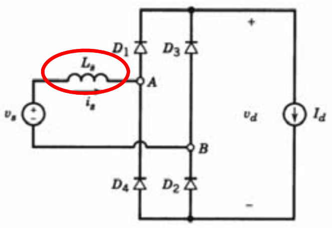
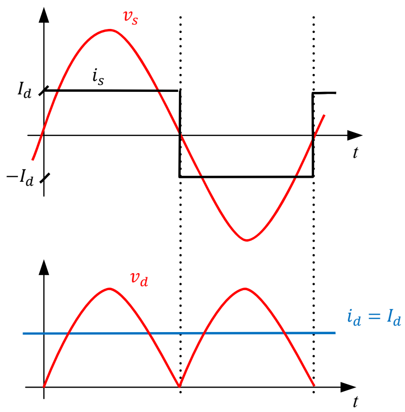
Diode Rectifier with Inductive Load

- Full-rectification without source inductance (L_s=0)





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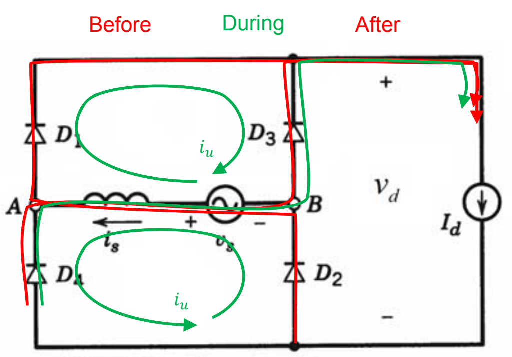
Diode Rectifier with Inductive Load Current Commutation

- Full rectifier (slightly redrawn) with source inductance (L_s≠0)



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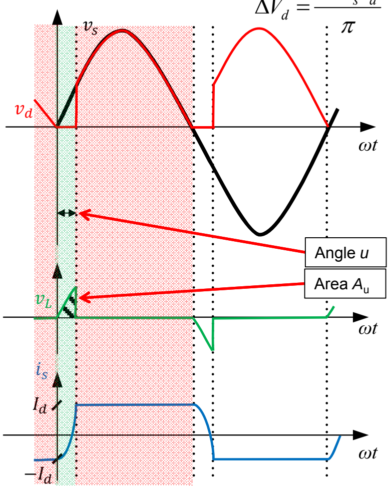
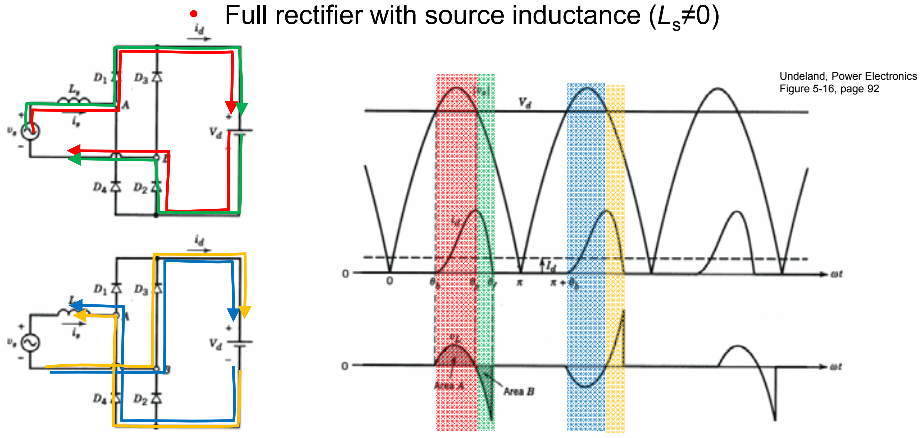
$$\Delta V_d = \frac{2\omega L_s I_d}{\pi}$$



Ex: plot i_s, v_L and v_d

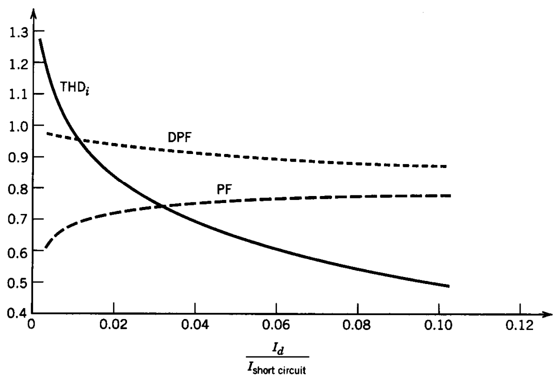
Diode Rectifier With DC-Side Voltage

- Full rectifier with source inductance ($L_s \neq 0$)



- No current commutation since the current is zero when the polarity changes!

Diode Rectifier With DC-Side Voltage THD, PF and DPF



$$I_{\text{short circuit}} = \frac{V_s}{\omega L_s}$$

- Very high THD at low currents

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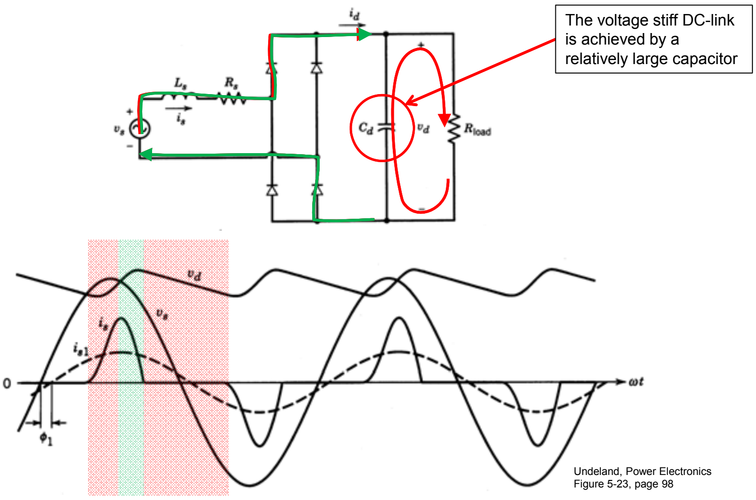
Diode Rectifier – Practical Implementation and Power Factor



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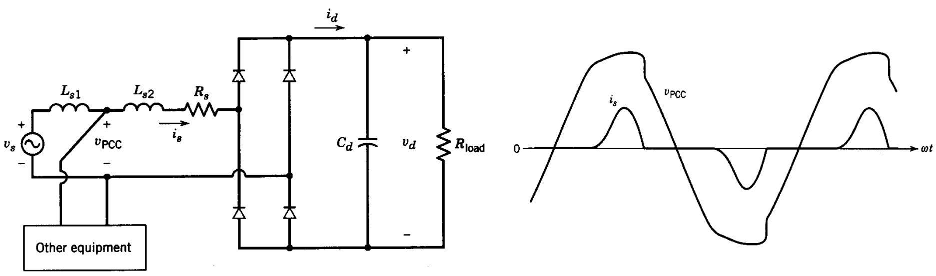
Impact of Diode Rectifier loads Distorted voltage for other loads



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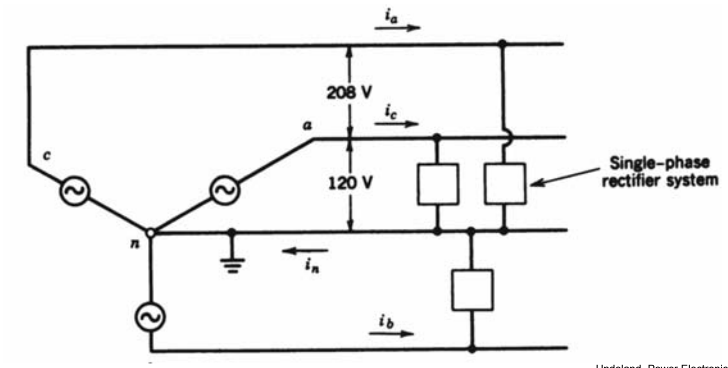
Impact of Diode Rectifier loads High current in the neutral conductor

- A typical application of a 3-phase utility source with several 1-phase loads connected on each phase



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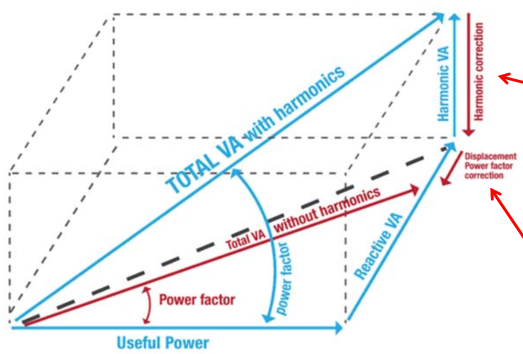
Diode Rectifier – Practical Implementation and Power Factor

- For non-sinusoidal quantities, DPF and PF will differ depending on the harmonic content.
- DPF only takes the angle between the fundamental components into consideration
- PF accounts for the angle between the fundamental components as well as the ratio between the fundamental current component and the total RMS-current (including harmonics)



A large distortion in the current waveform will result in a low PF. By reducing the harmonic content in the current, the PF will also be improved.

$$PF = \frac{I_{S(1)}}{I_S}\cos(\varphi_1) = \frac{DPF}{\sqrt{1+THD_i^2}}$$

Reduction of the displacement power factor (traditional VAr compensation).

$$DPF = \cos(\varphi_1)$$

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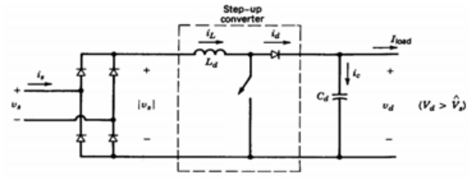
Power Factor Correction (PFC) Unit

- Active (switched) unit that makes the input current more sinusoidal



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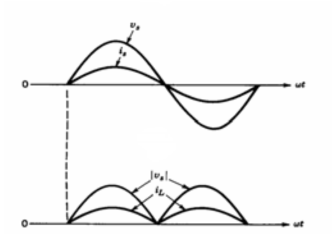

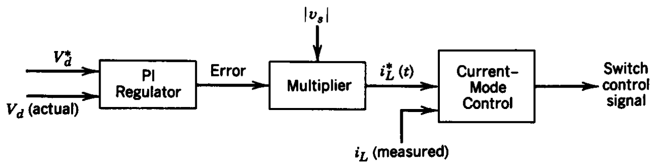

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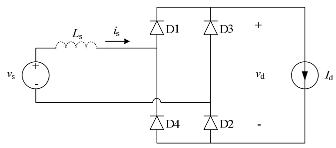
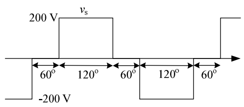
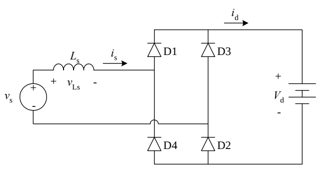
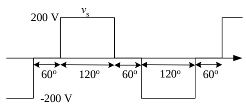
Tutorial 10





- With L_s = 0 and I_d = *10 A*, calculate the average power supplied to the load if the input voltage is sinusoidal with RMS value of 120 V, frequency 60 Hz.
- With L_s = 0 and I_d = *10 A*, calculate the average power supplied to the load if the input voltage is the pulsed waveform above with frequency of 60 Hz.
- *For* L_s = 10 mH and $_d$ = *160 V*, plot i_d and i_s waveforms





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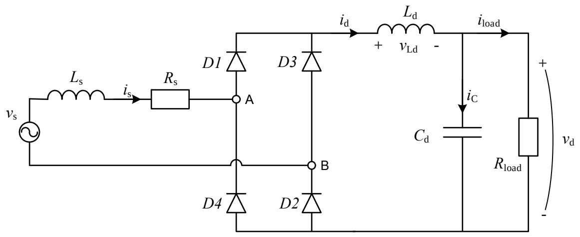
PSpice 6



L_d and C_d decides if the load is of voltage or curretn stiff type

- Plot current and voltage waveforms
- Input PF, DPF, THD and output voltage ripple
- Impact of source inductance on commutation angle and output voltage for the two types of loads

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Summary

- Single-phase diode rectifier with resistive and inductive loads
- Single-phase diode rectifier with a voltage and current stiff loads
- Half- vs full-wave rectification
- Current commutation
- Impact of non-linear rectifier loads on THD, DPF and PF
- The concept of active PFCs
- Learning outcome:
  - Operation of single-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.