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ENM061 - Power Electronic Converters 7.5 ECTS, 2017

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Lecture outline

The three-phase diode rectifier

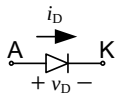
- Prerequisites for today's lecture
- Three-phase diode rectifier with current stiff load
- Impact of source inductance for current commutation
- Three-phase diode rectifier with voltage stiff load
- Practical implementation of a three-phase diode rectifier
- Summary

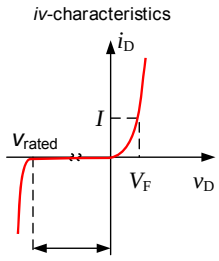
Learning outcomes

- 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





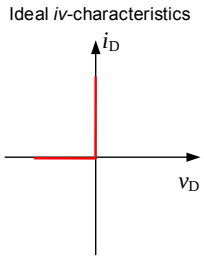


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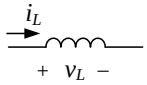
Figure 2-1, page 17

Inductors and Capacitors

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

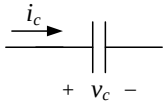
$$i_L = i_L(t_1) + \frac{1}{L}\int v_L dt$$



Average and RMS current and voltage?
Current stiff component

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

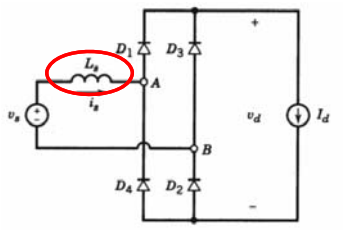
$$v_C = v_C(t_1) + \frac{1}{C}\int i_C dt$$

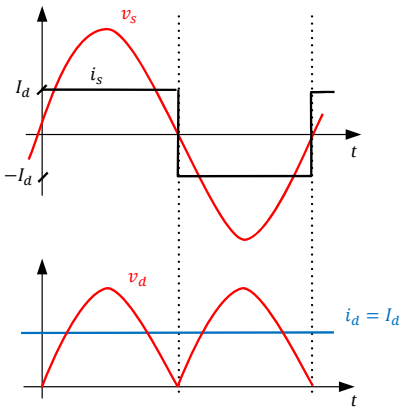


Average and RMS current and voltage?
Voltage stiff component

Single-Phase Diode Rectifier Current-Stiff Load

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

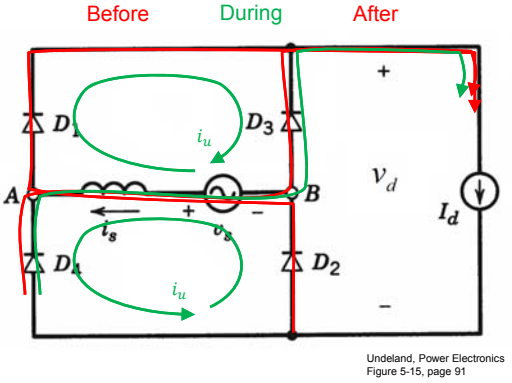




Diode Rectifier with Inductive Load Current Commutation

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

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



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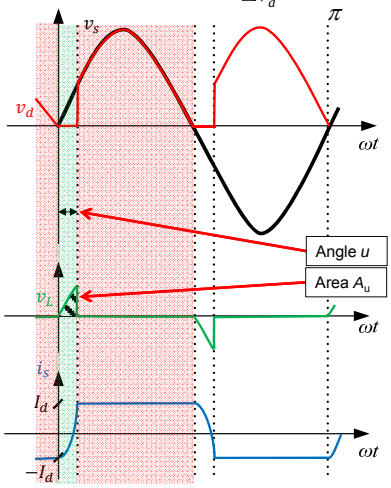
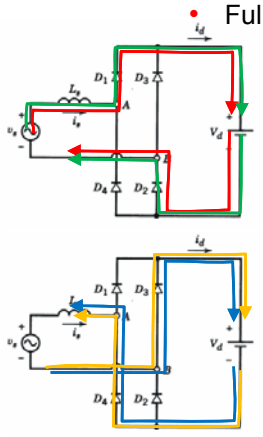


Diode Rectifier With DC-Side Voltage

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



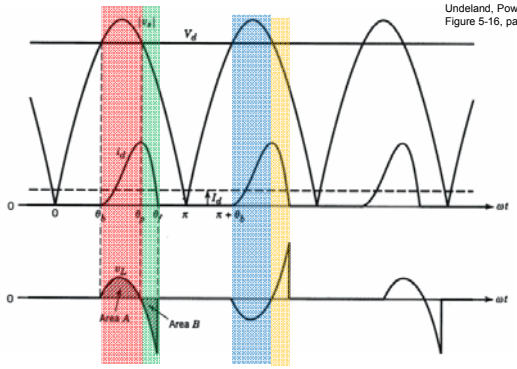


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Figure 5-16, page 92

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

Three-phase Rectifier

- If all 3-phase AC-voltages are available – use a 3-phase rectifier which provides less harmonics and higher PF than a 1-phase.

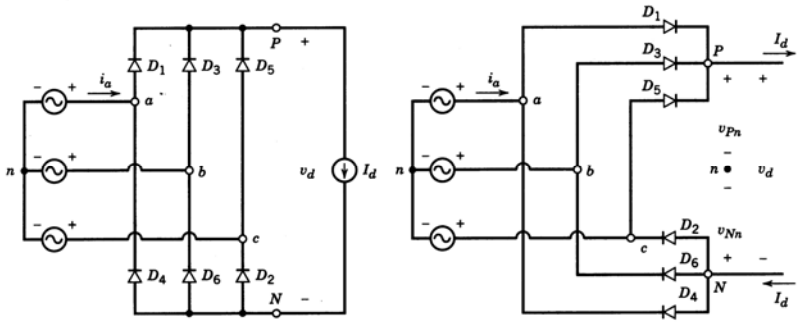

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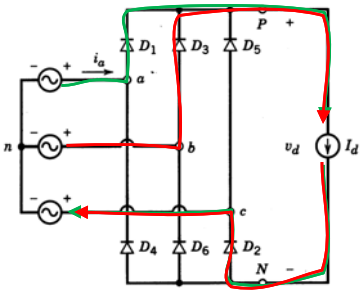
Figure 5-31, page103

Waveforms in a Three-phase Rectifier with Inductive Load (Positive)

EX: show current paths



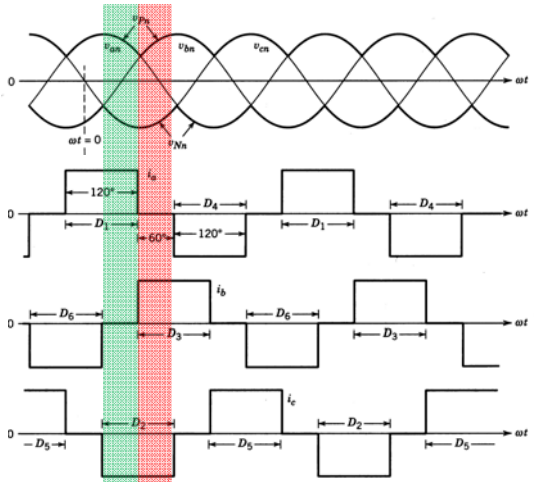


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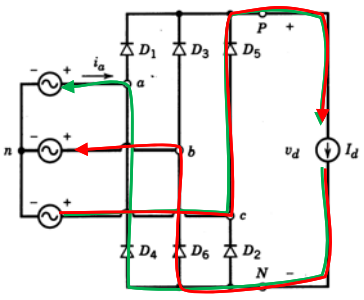
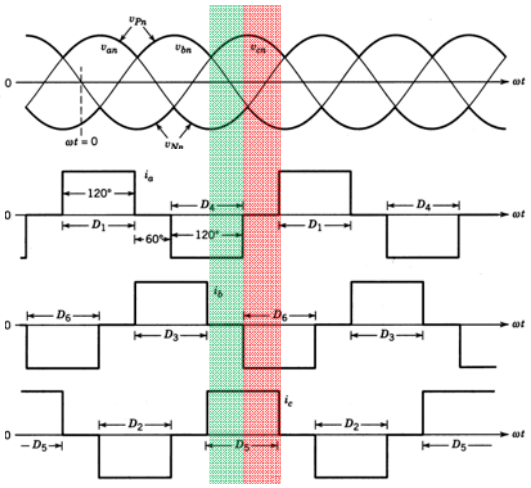
Figure 5-32, page104

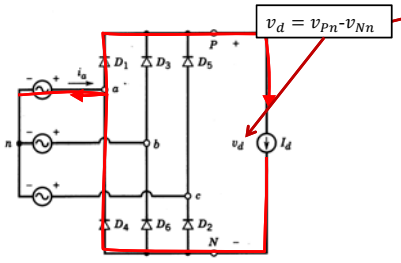
Waveforms in a Three-phase Rectifier with Inductive Load (Negative)

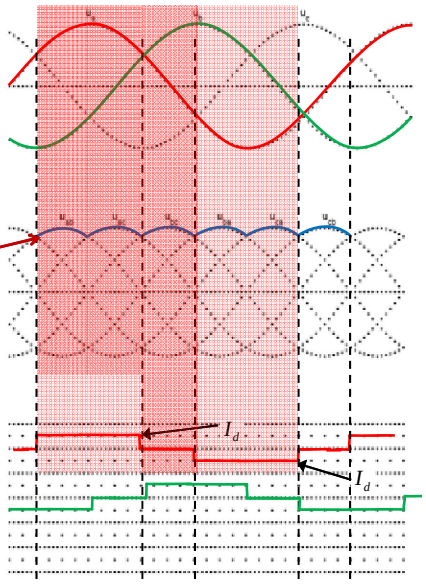
EX: show current paths





Waveforms in a 3-phase Rectifier with Inductive Load The Dot-paper



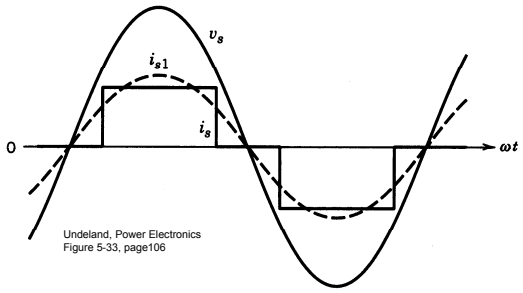


- Each small dot: 5°
- Each large dot: 15°

EX: estimate v_d and i_a

Three-phase Rectifier Inductive Load and Input Line Current

- Quasi-square wave shaped source current – all odd harmonics that are multiples of 3 are canceled out



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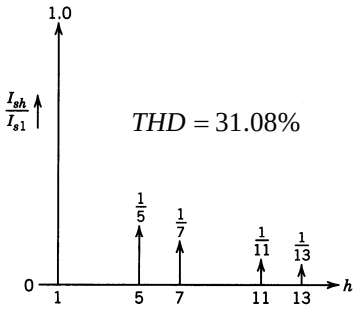
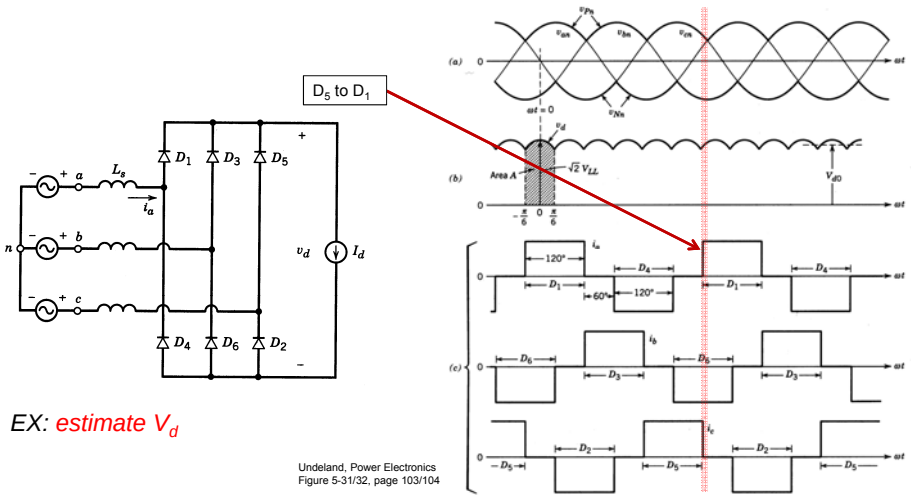


Three-phase Rectifier with Inductive Load – Impact of Source Inductance



EX: estimate V_d

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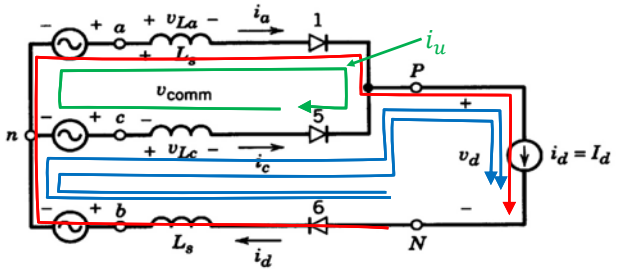
Three-phase Rectifier with Inductive Load – Current Commutation

Before: $i_c = I_d$

During: $\begin{cases} i_a = i_u \\ i_c = I_d - i_u \end{cases}$

After: $i_a = I_d$



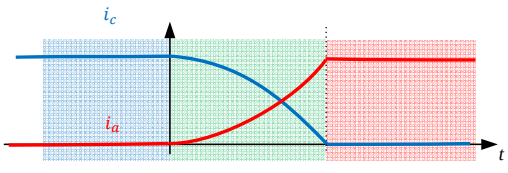


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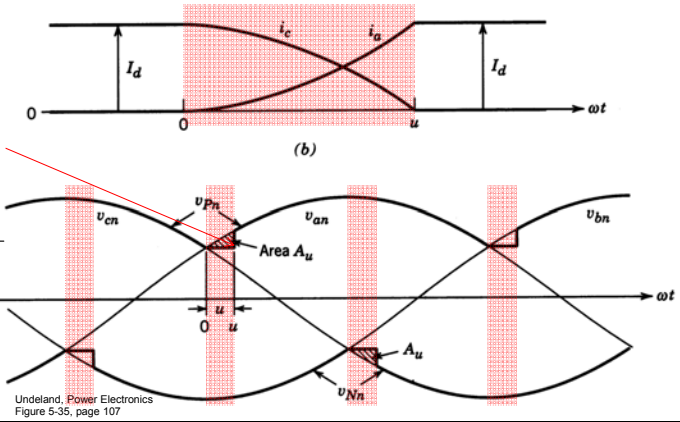
Figure 5-35, page 107

Three-phase Rectifier with Inductive Load – Current Commutation

- The output voltage is reduced with an area A_u during the commutation
  EX: estimate voltage reduction and the commutation angle

$$v_{Pn} = \frac{v_{an} + v_{cn}}{2}$$

$$\Delta V_d = \frac{3\omega L_s I_d}{\pi}$$



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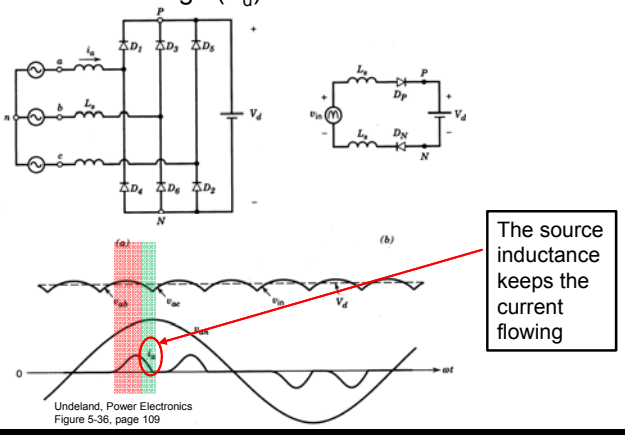
Three-phase Rectifier with Voltage Stiff DC-side

- The source current will only flow when the output voltage (line to line voltage) exceeds the DC-voltage (V_d)



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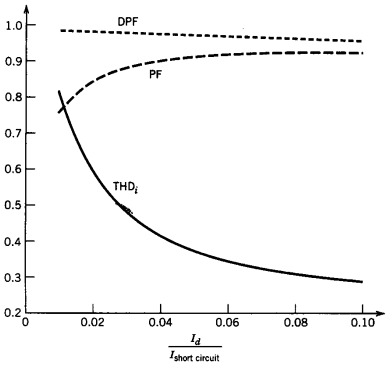
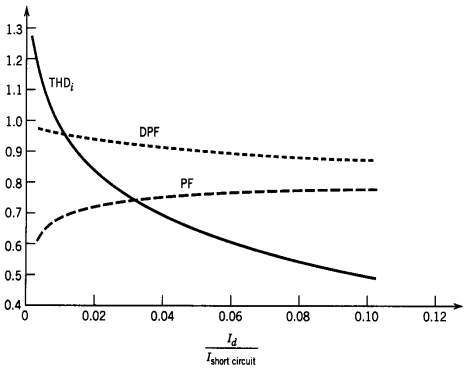
Diode Rectifier With DC-Side Voltage THD, PF and DPF

Three phase



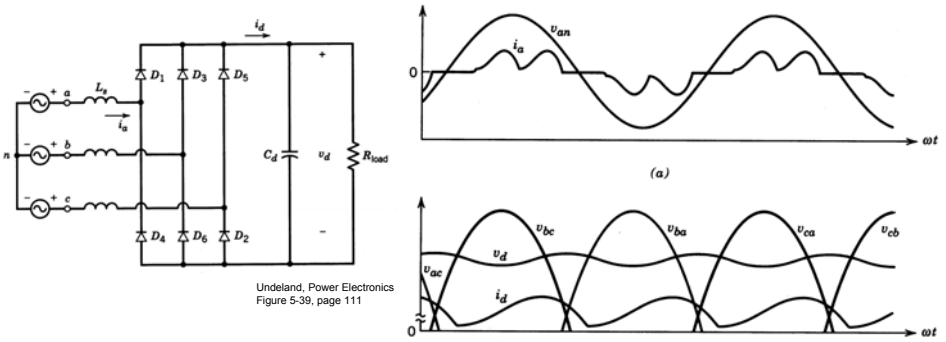
Single phase



- Very high THD at low currents but with lower THD and higher PF for the three-phase case than the single-phase case

Three-phase Rectifier Practical Implementation

- A large DC-link capacitor represents the constant voltage load
- Even a small source inductance will result in a continuously flowing (i_d)
  => A simulation software necessary to analyze the circuit



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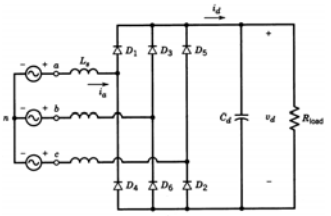
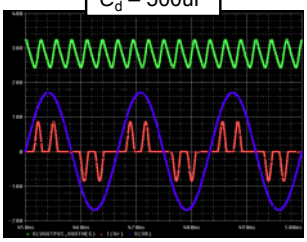
Three-phase Rectifier Practical Implementation

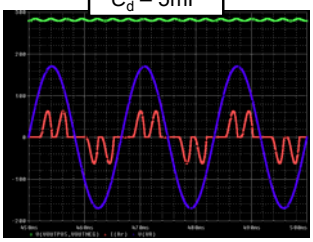
- The value of the DC-link capacitor will determine the output voltage ripple.



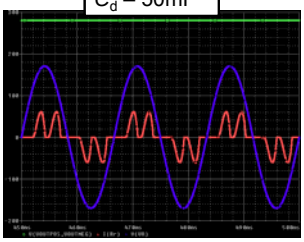
C_d – 500uF



C_d – 5mF

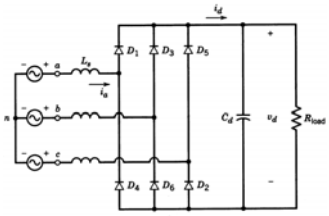


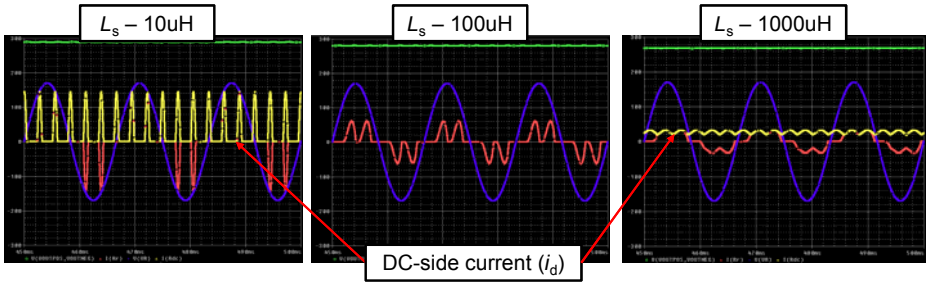
C_d – 50mF



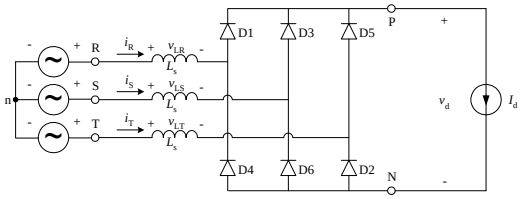
Three-phase Rectifier Practical Implementation

- The value of the source inductance will determine the shape of the source current.



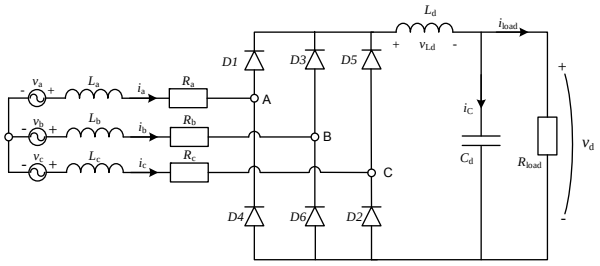


Tutorial 10



- With L_s = 0, calculate the average and RMS diode current in terms of I_d
- With L_s = 0, calculate the average output voltage if the input voltage is symmetrical with a line to line RMS value of 200 V.
- For L_s = 2 mH, V_{LL} = 208 V @60Hz and I_d = 10 A, calculate (derive expression) for the commutation angle
- Estimate the output power reduction (input power factor) due to the input inductance

PSpice 6



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

- Plot current and voltage waveforms
- Calculate the total power loss in the diodes
- Impact of source inductance on commutation and output voltage for the two types of loads

Summary

- Three-phase diode rectifier with current stiff load
- Impact of source inductance on current commutation
- Three-phase diode rectifier with voltage stiff load
- Practical implementation of a three-phase diode rectifier
- Comparison with single-phase diode rectifier
- Learning outcome:
  - Operation of a 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.