



Measurement of Harmonic Power Flows

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Outline

- Harmonics in Voltage and Current
- Harmonic Power Flows in Theory
- Metrological Challenges
- New Approaches
- Measurements

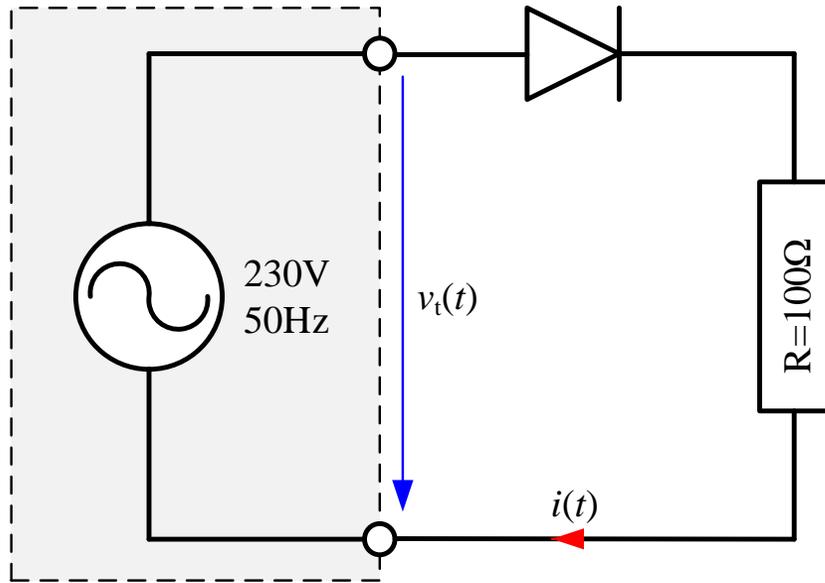
Harmonics in current

- Caused by non-linear current draw

Harmonics in current

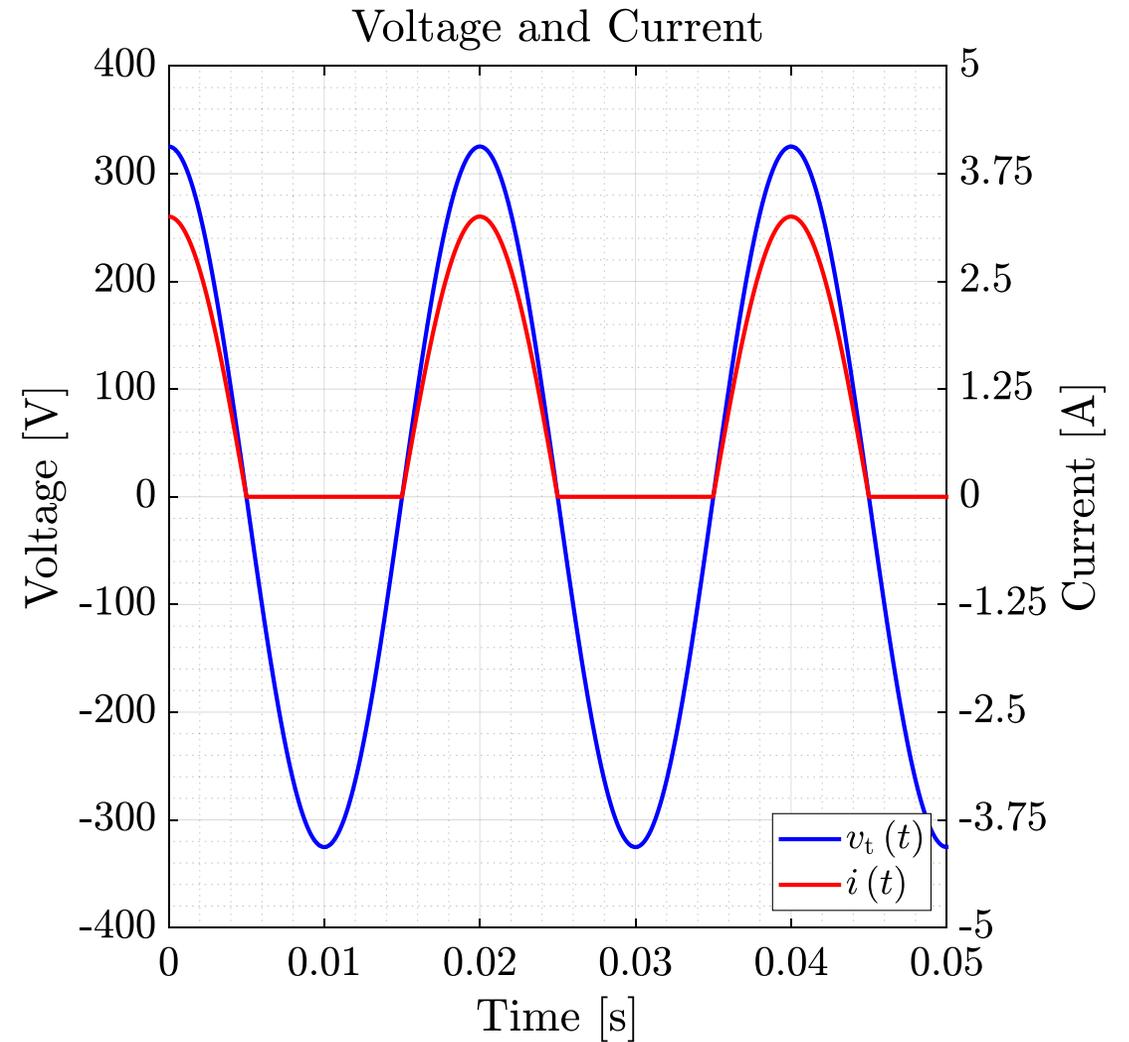
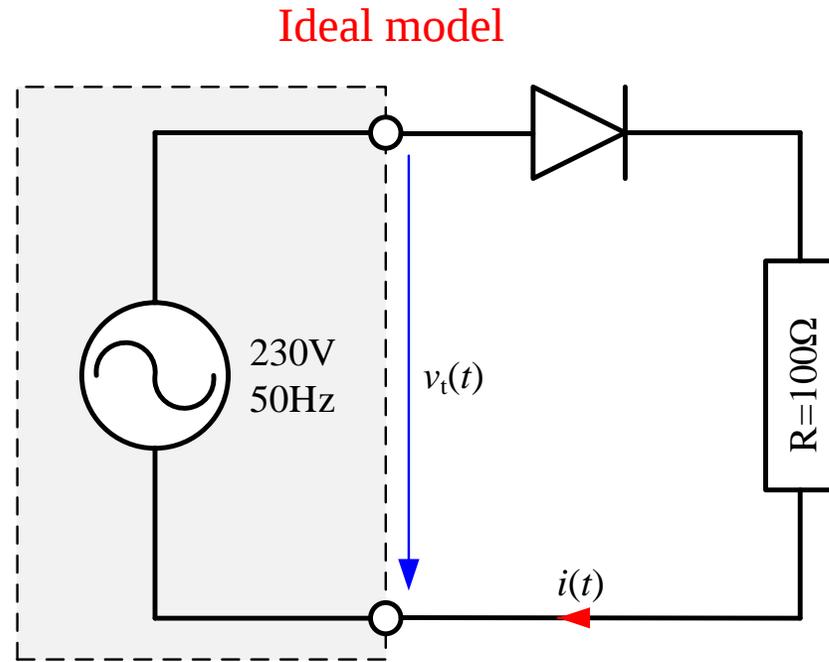
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Ideal model



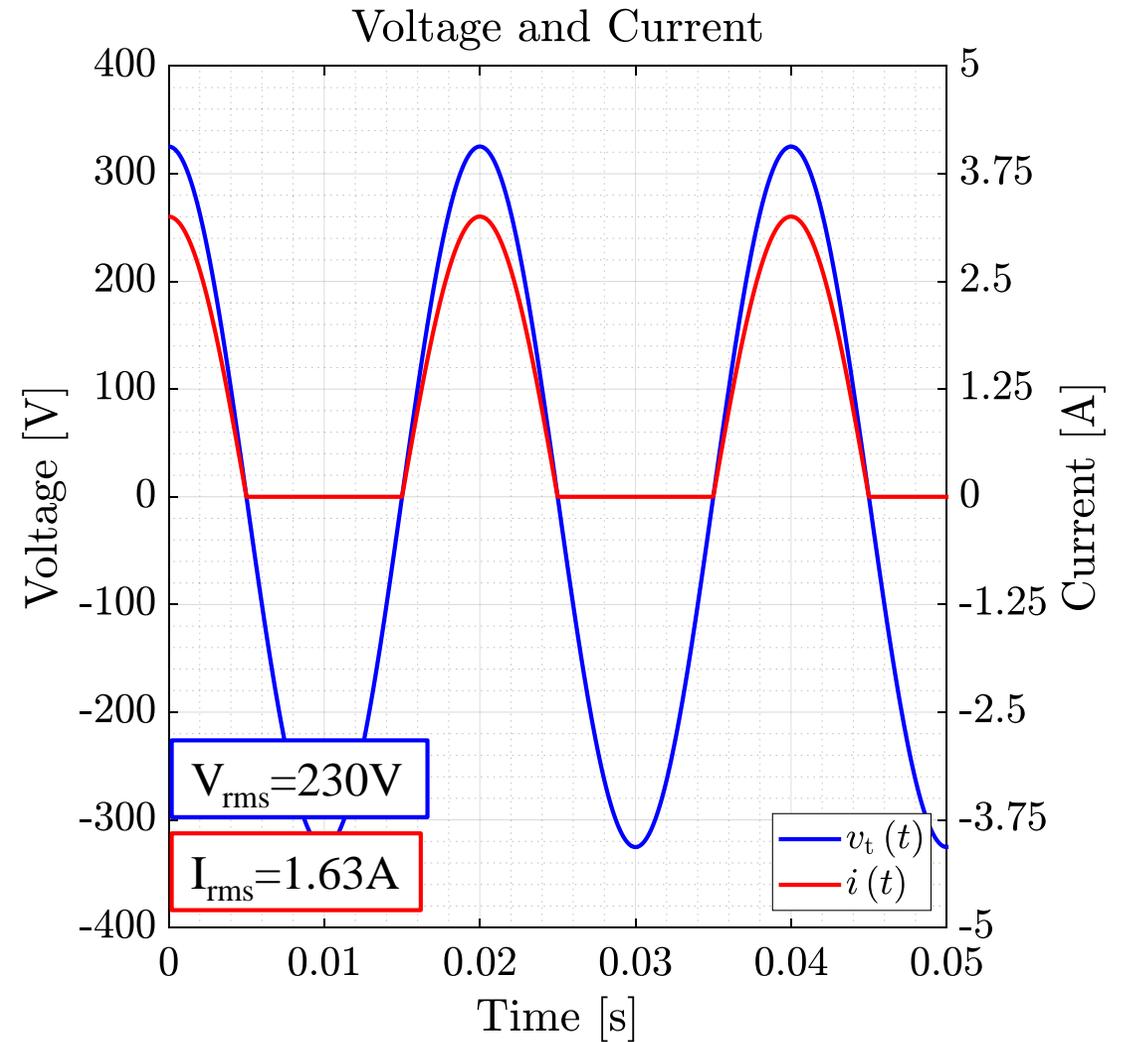
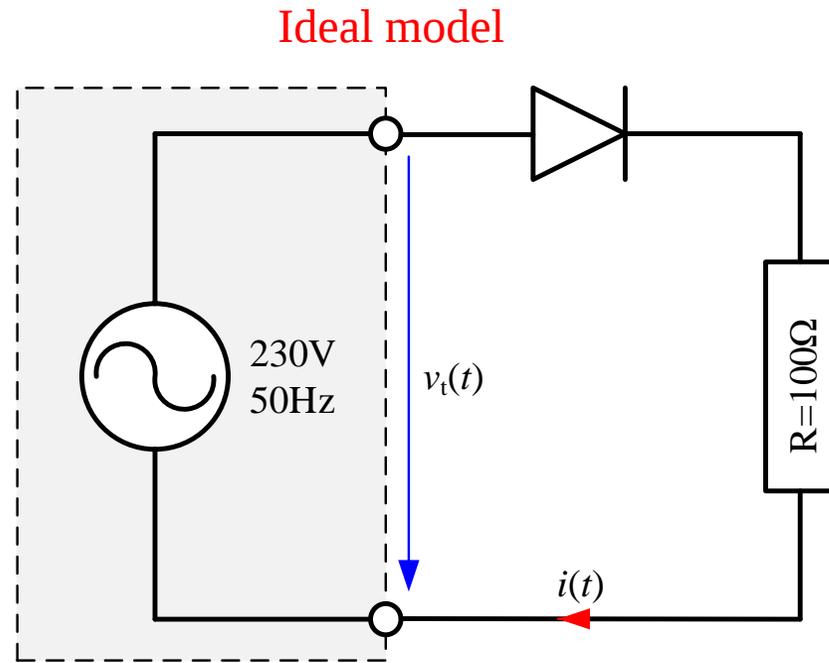
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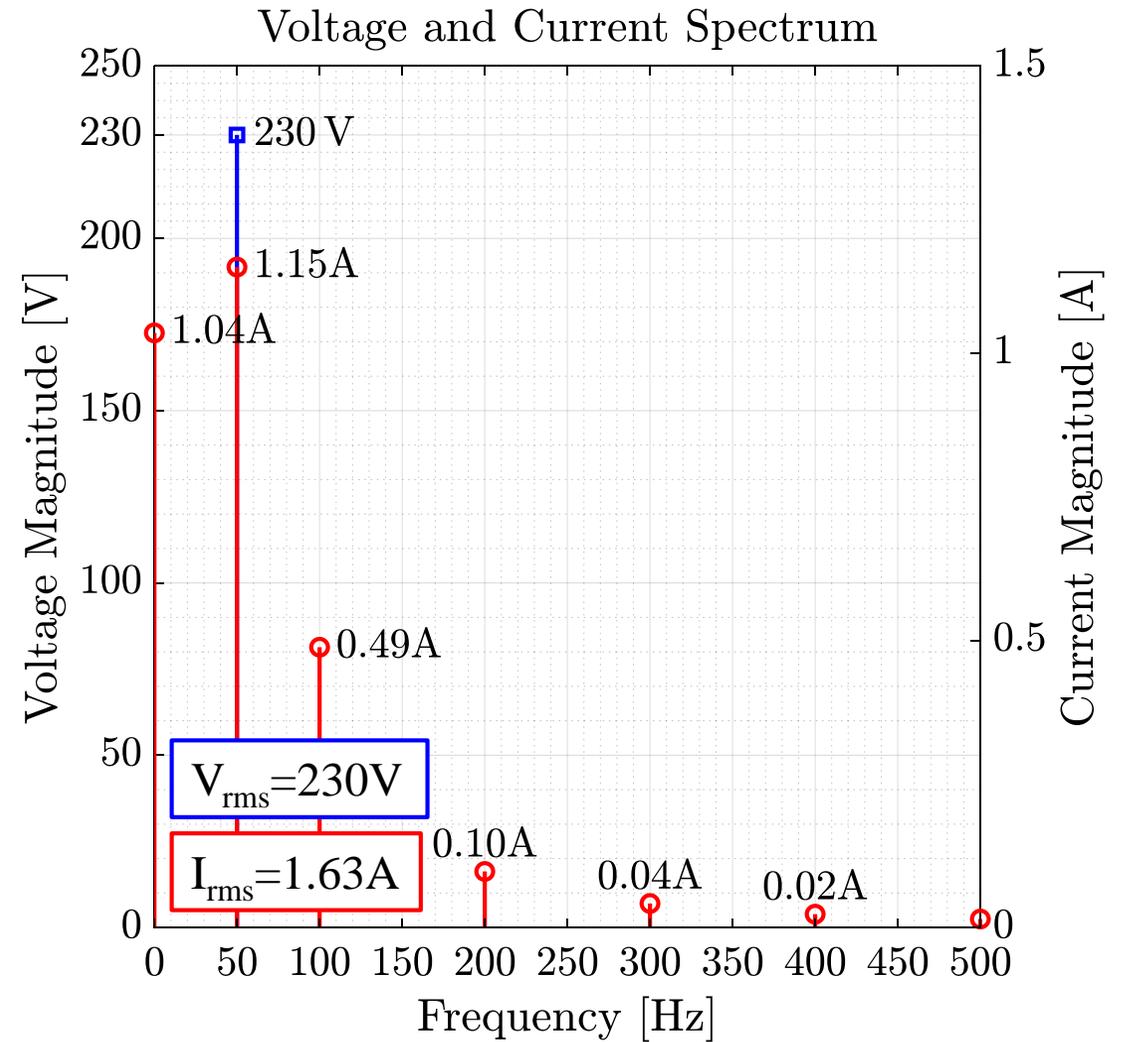
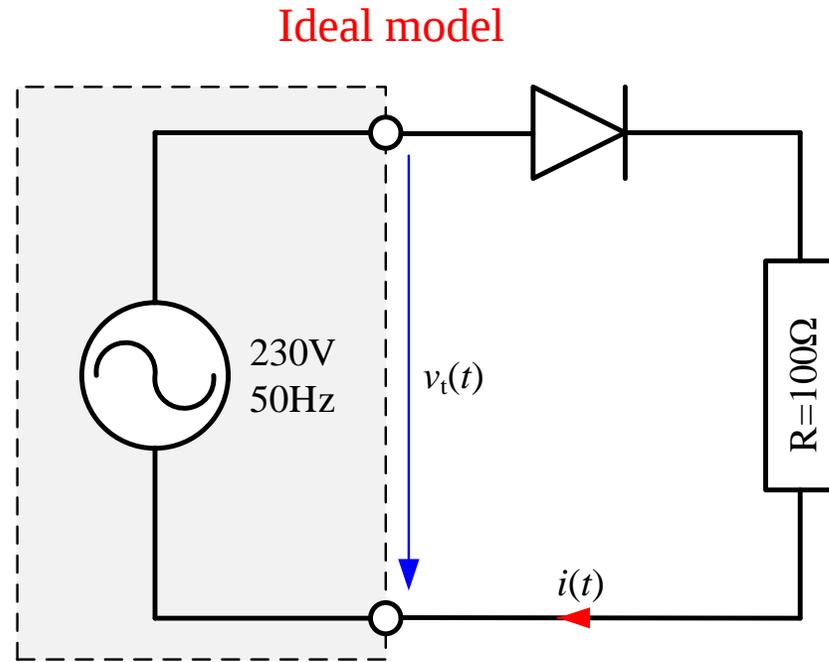
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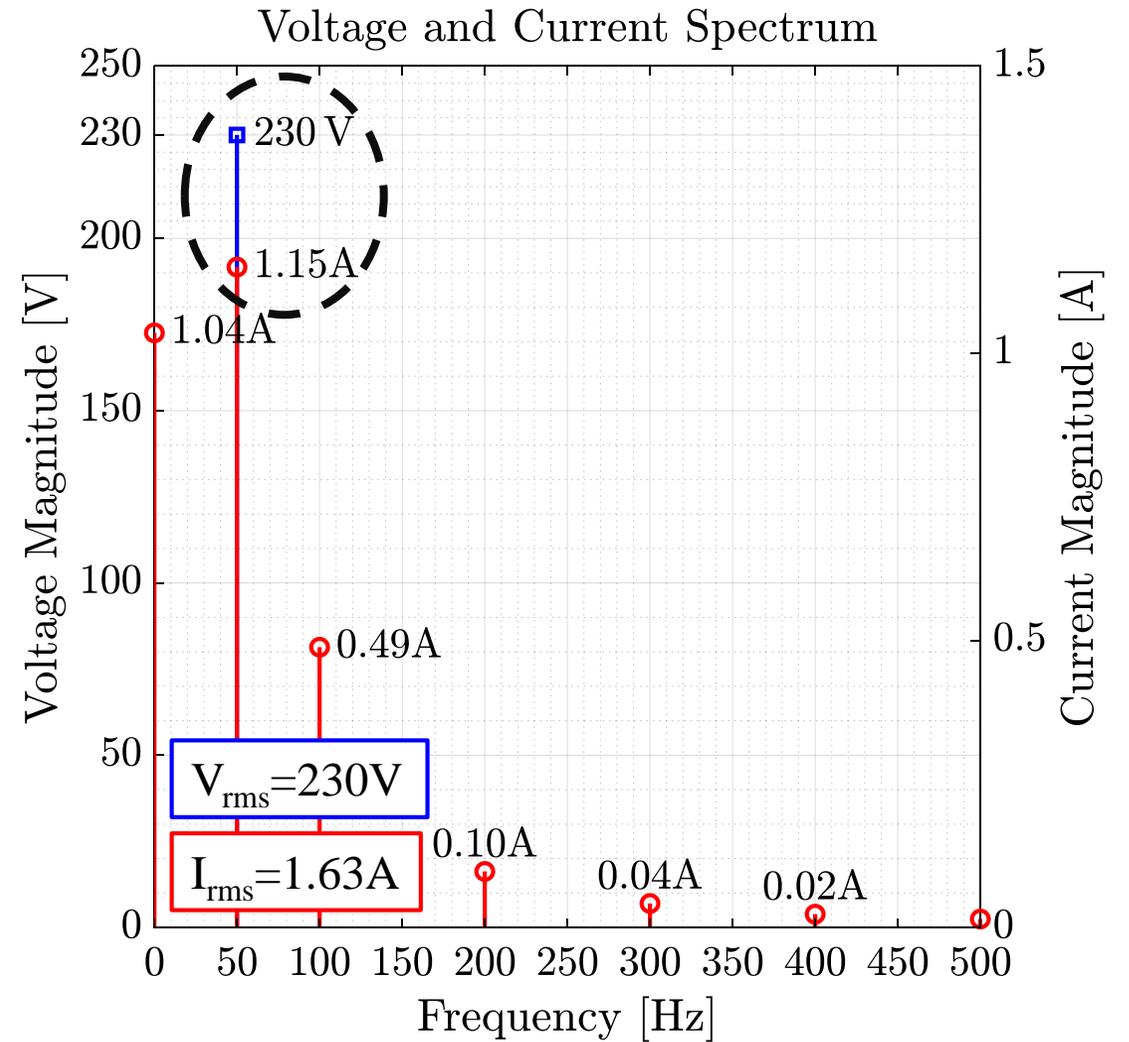
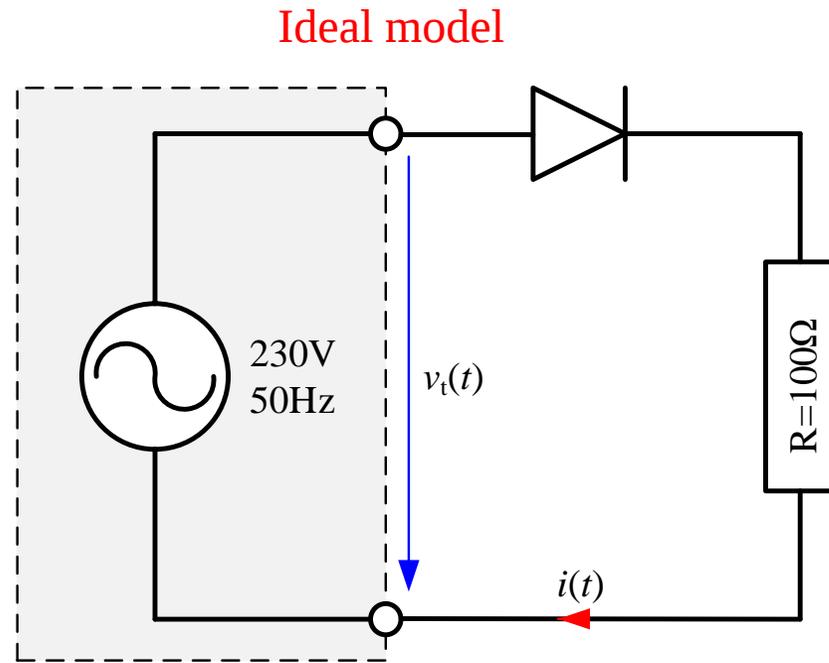
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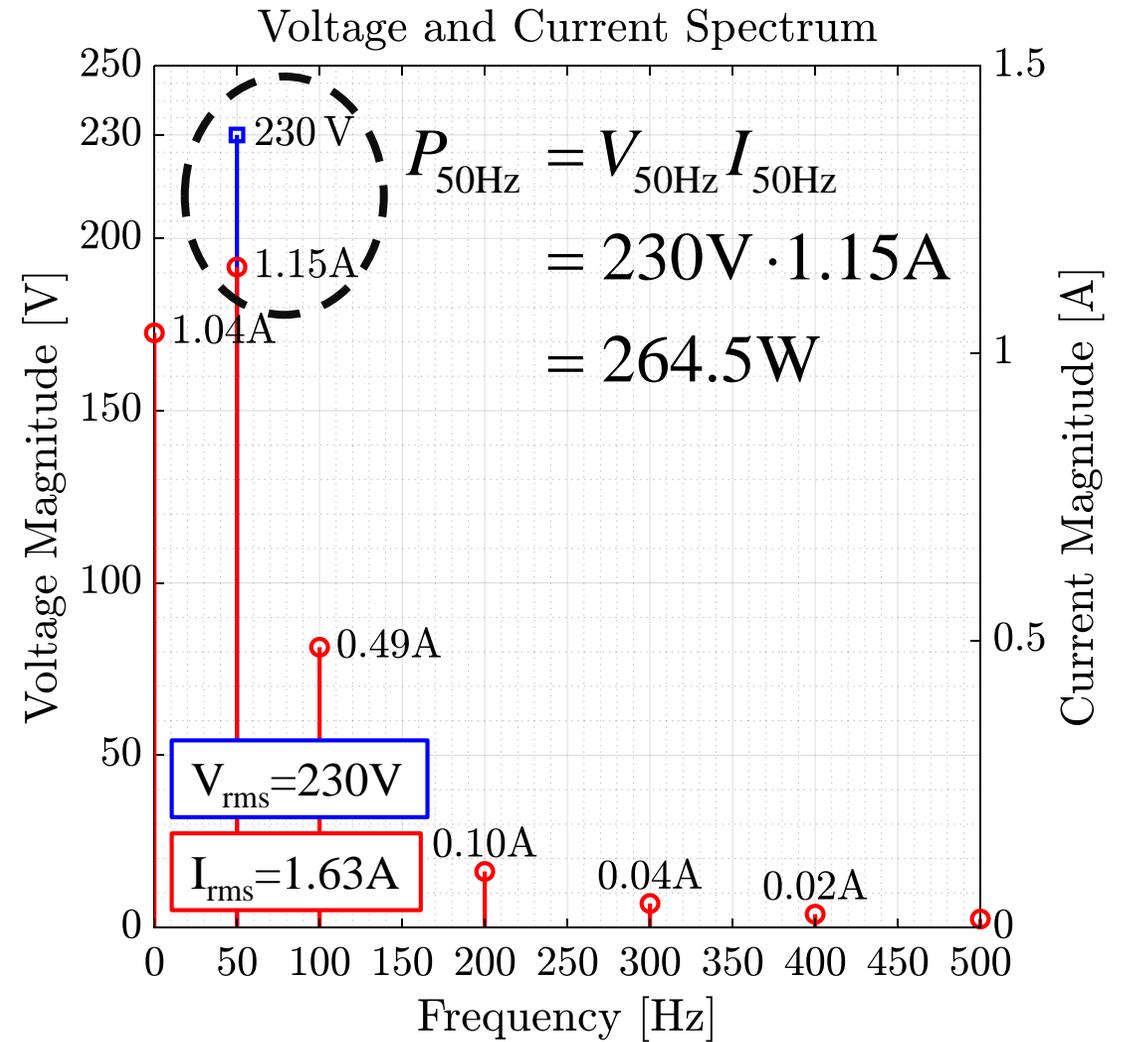
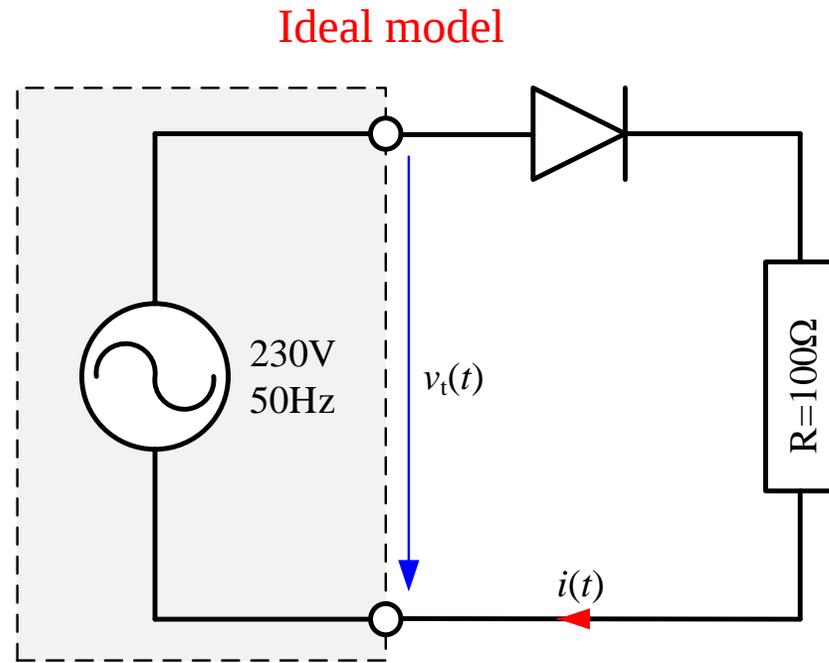
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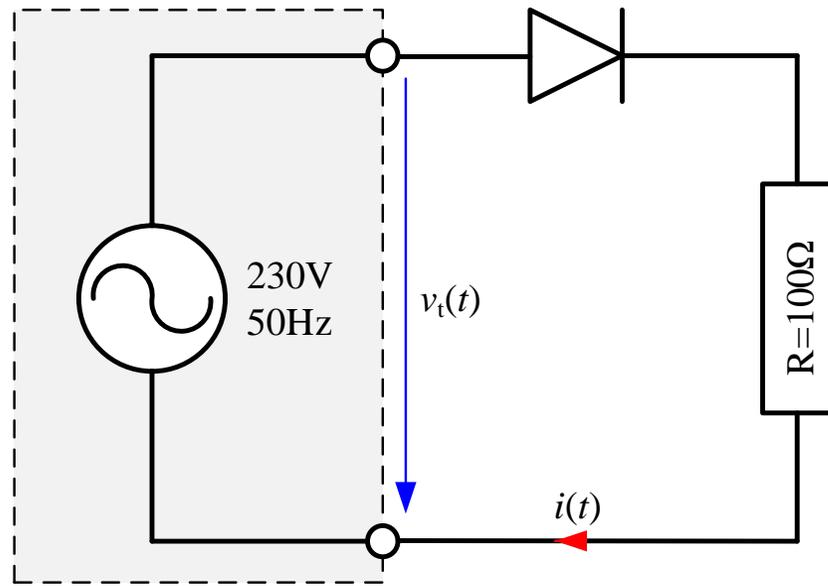
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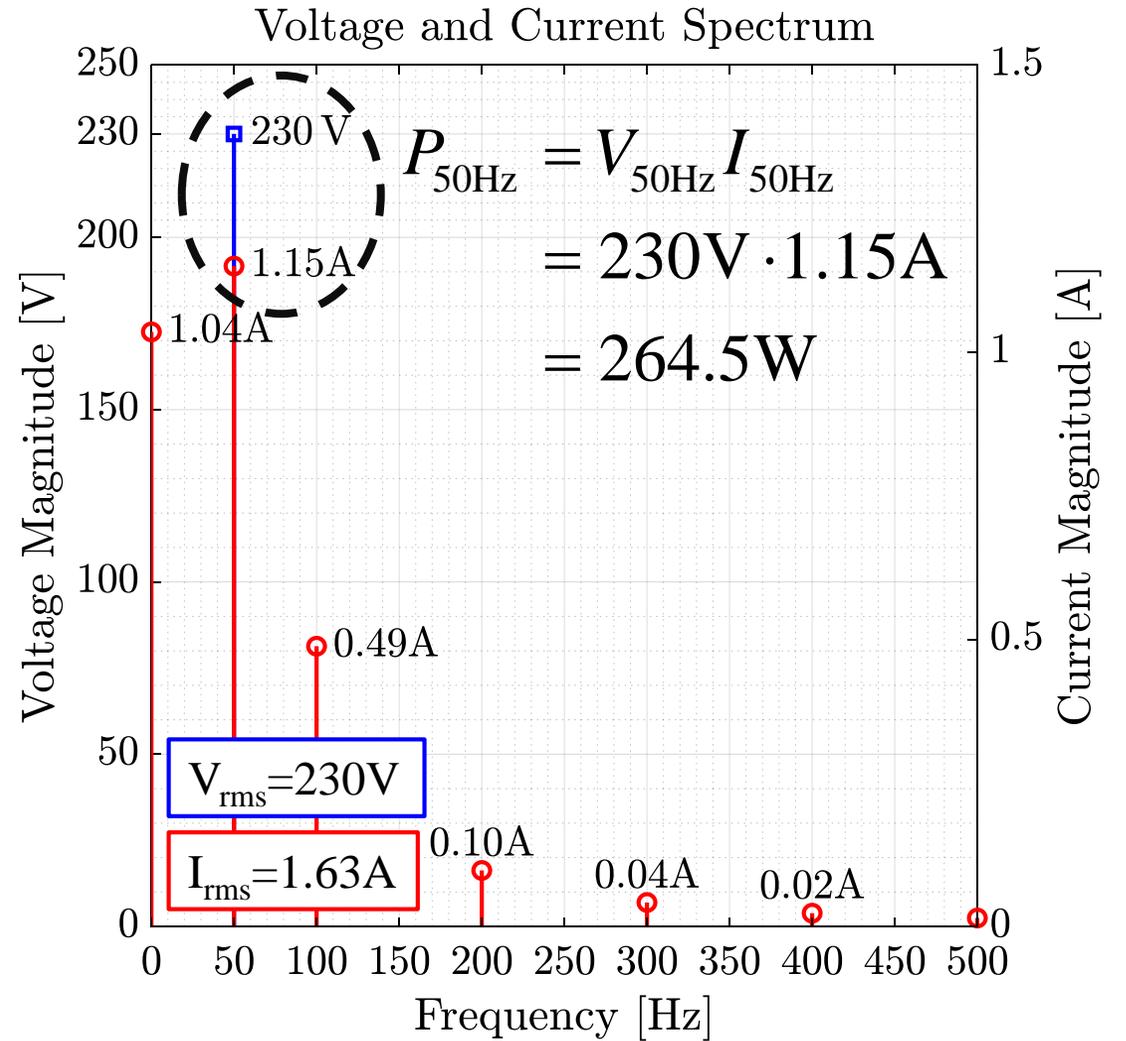
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Ideal model



$$P_{\text{tot}} = \frac{1}{T} \int_t^{t+T} [v_t(\tau) i(\tau)] d\tau = 264.5\text{W}$$



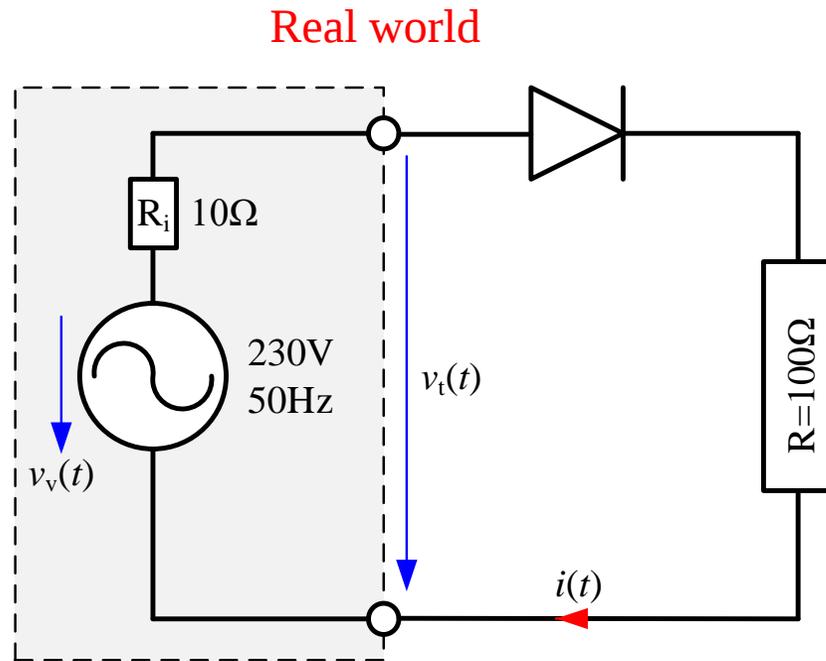
Harmonics in voltage

Harmonics in voltage

- Caused by internal impedance of power source

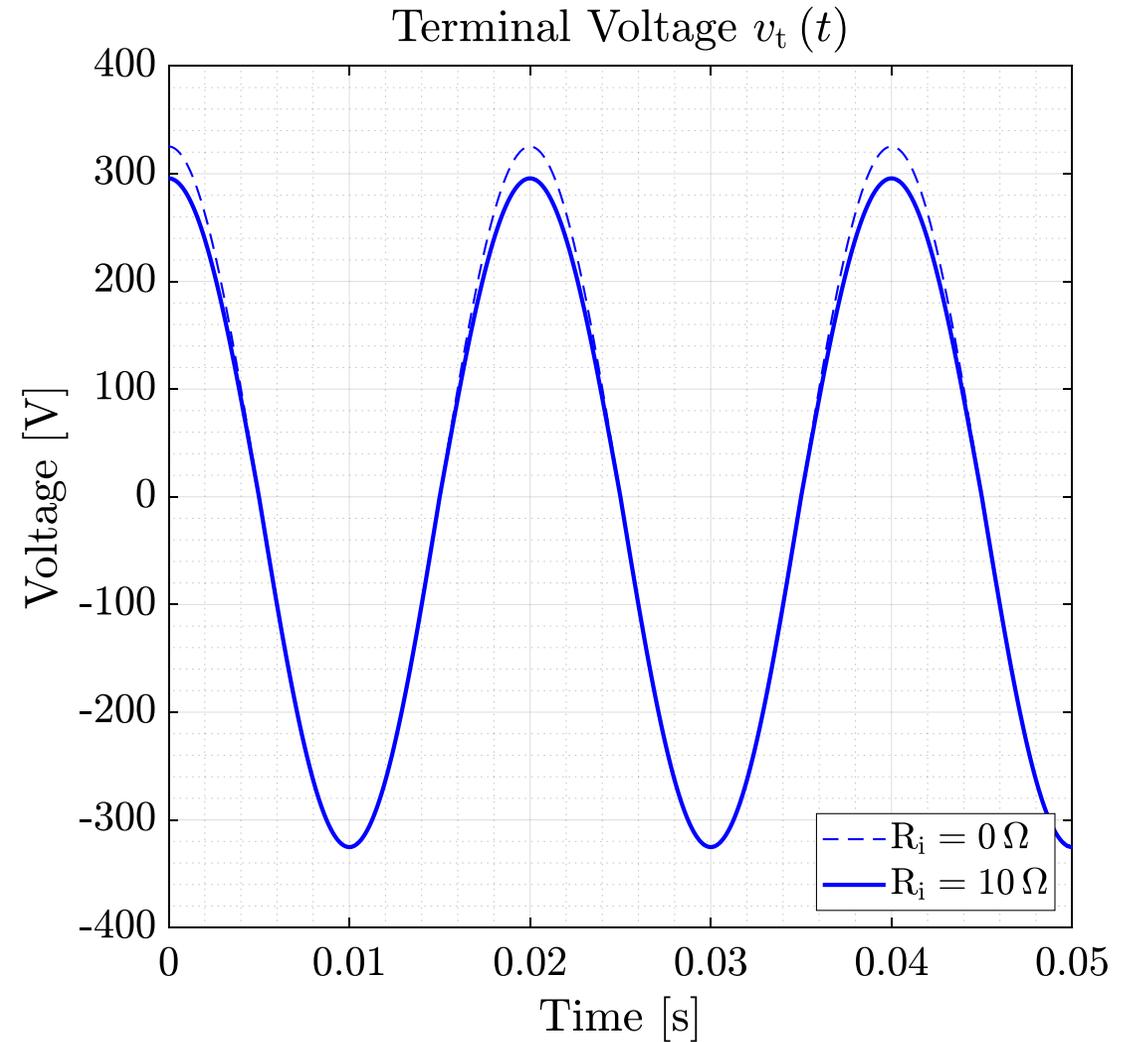
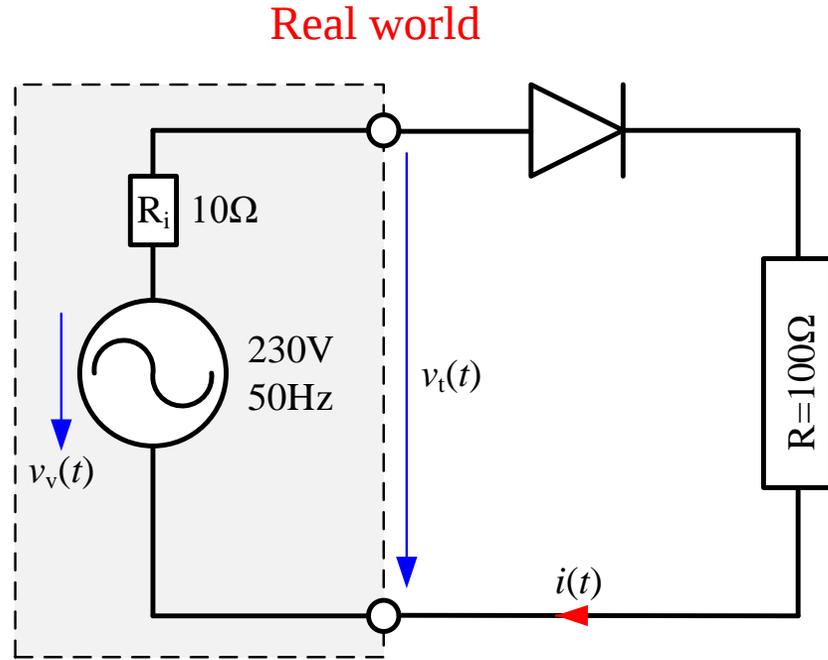
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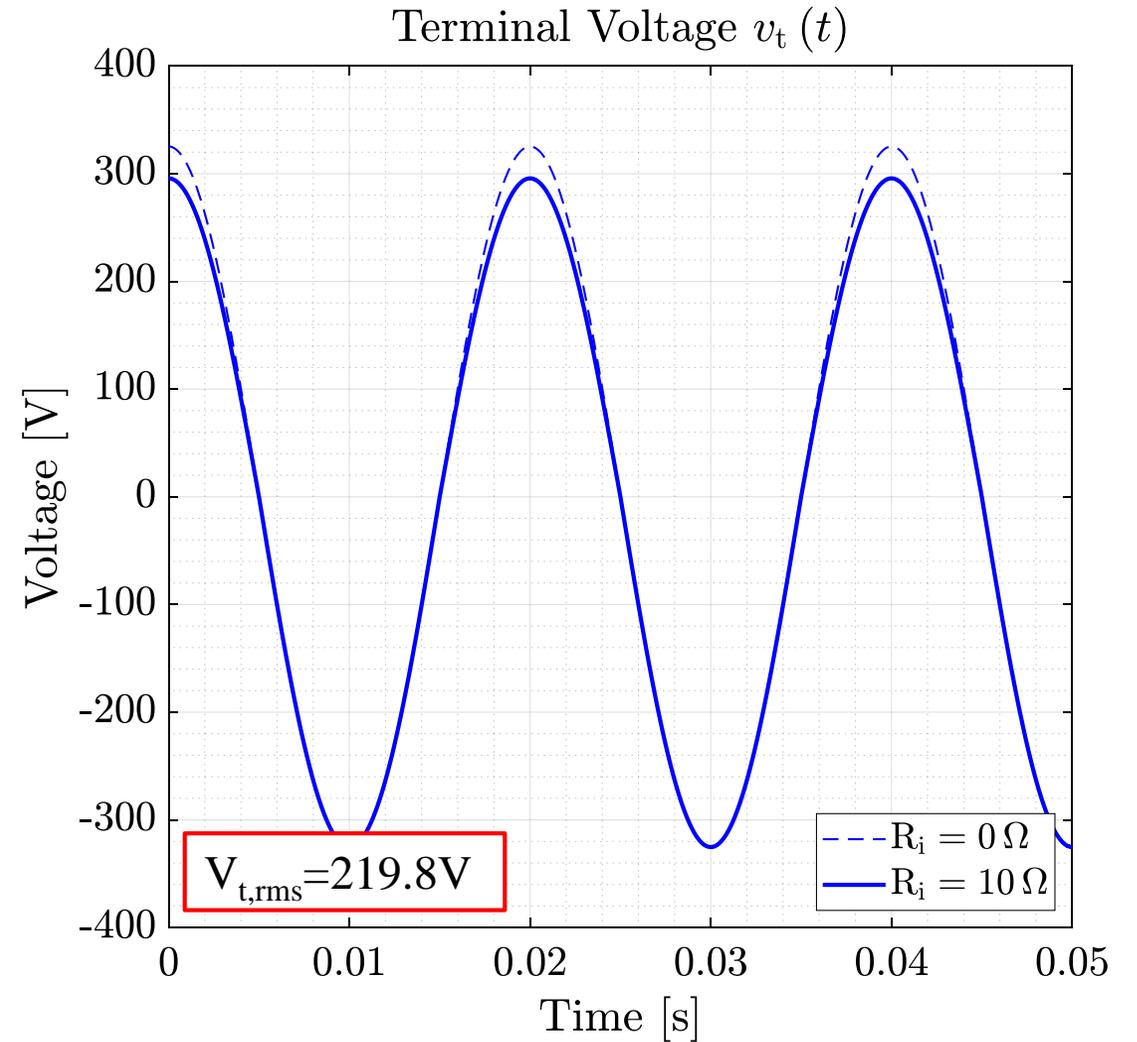
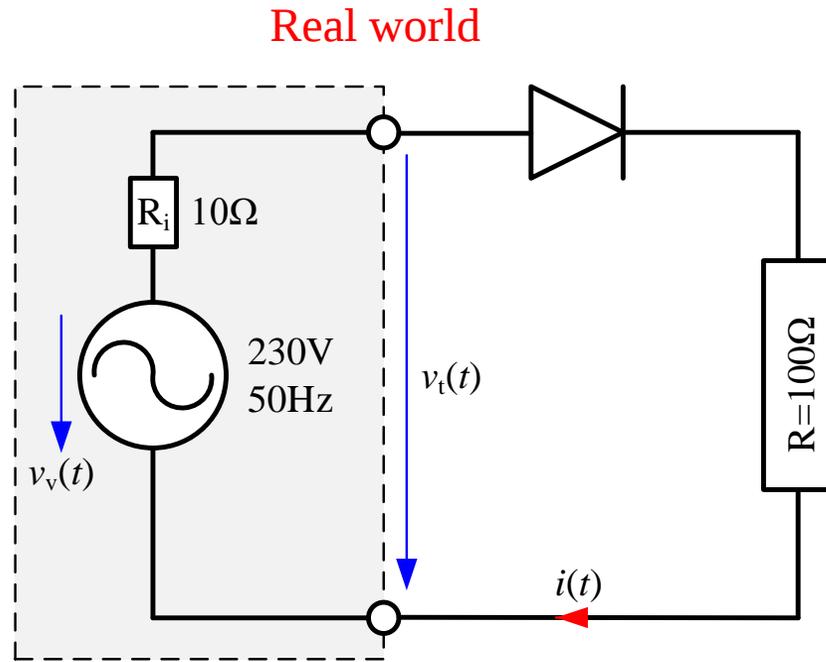
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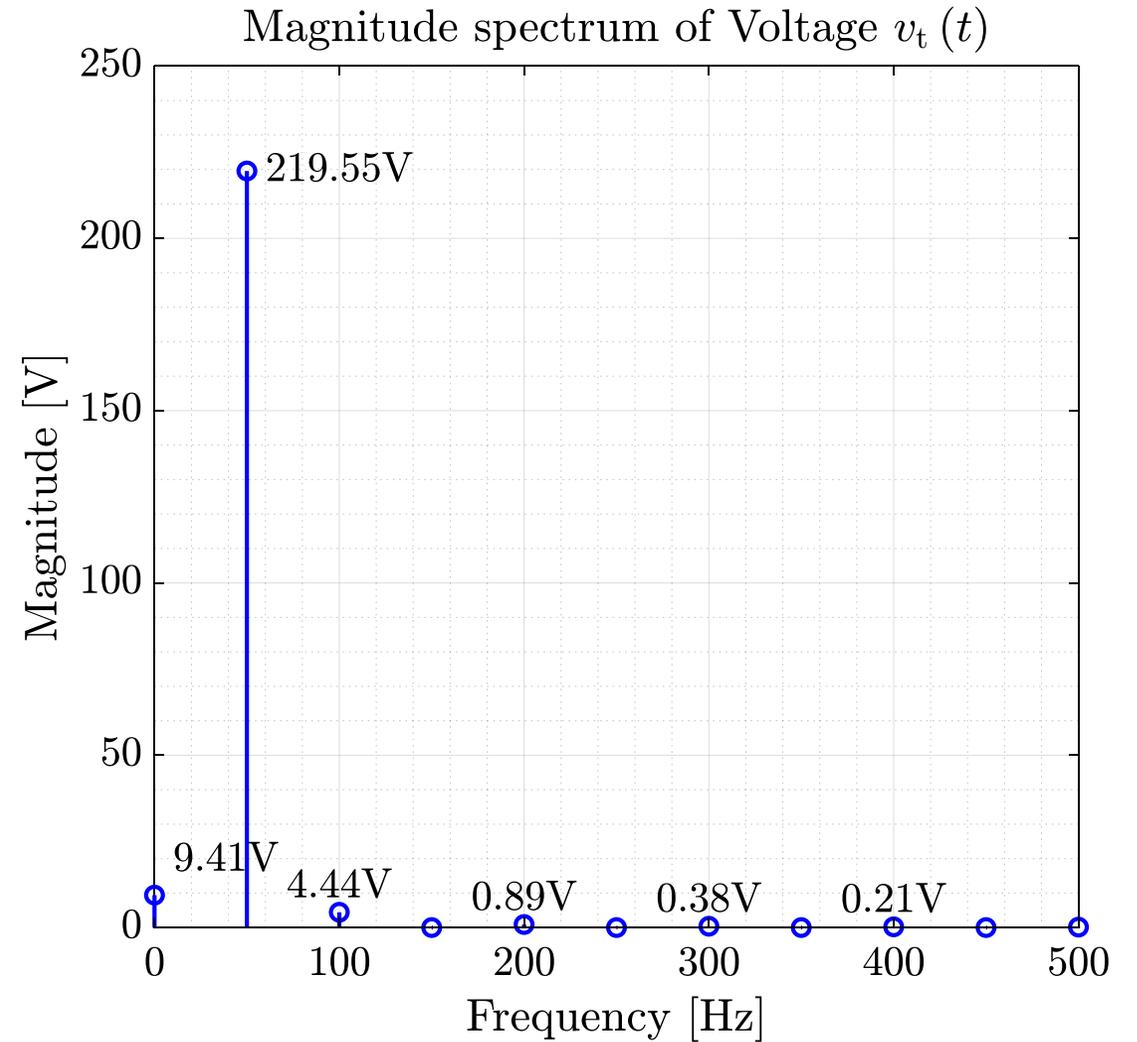
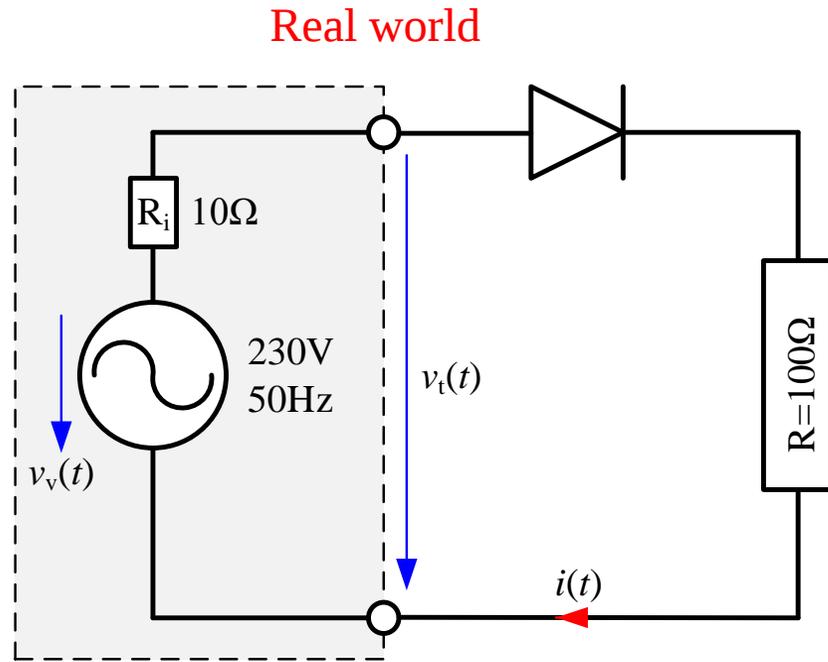
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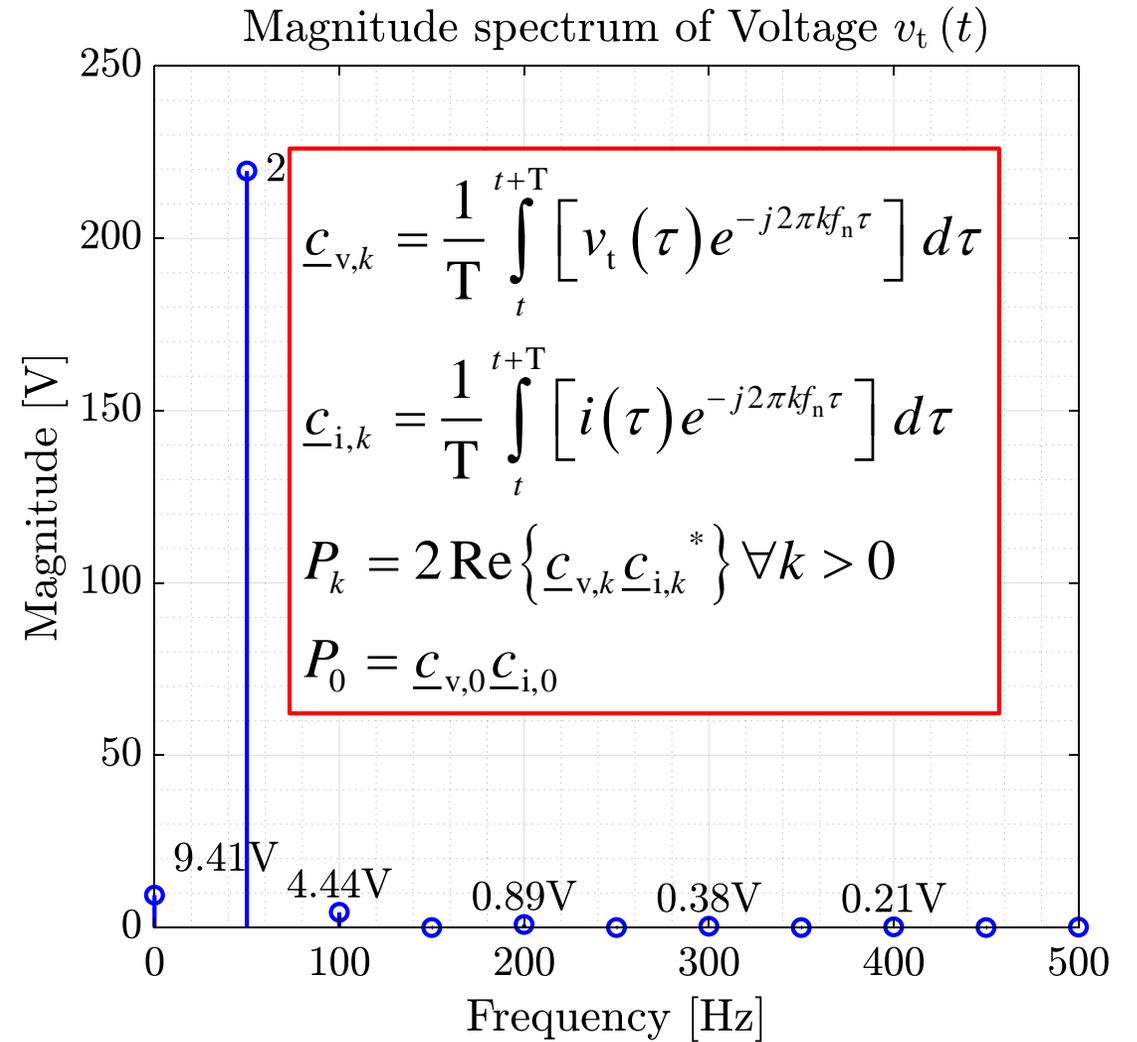
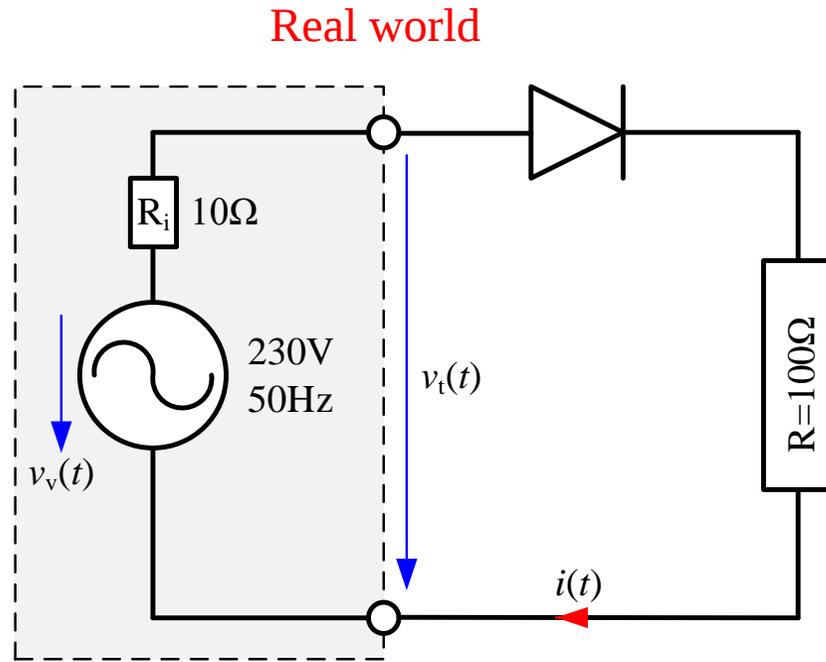
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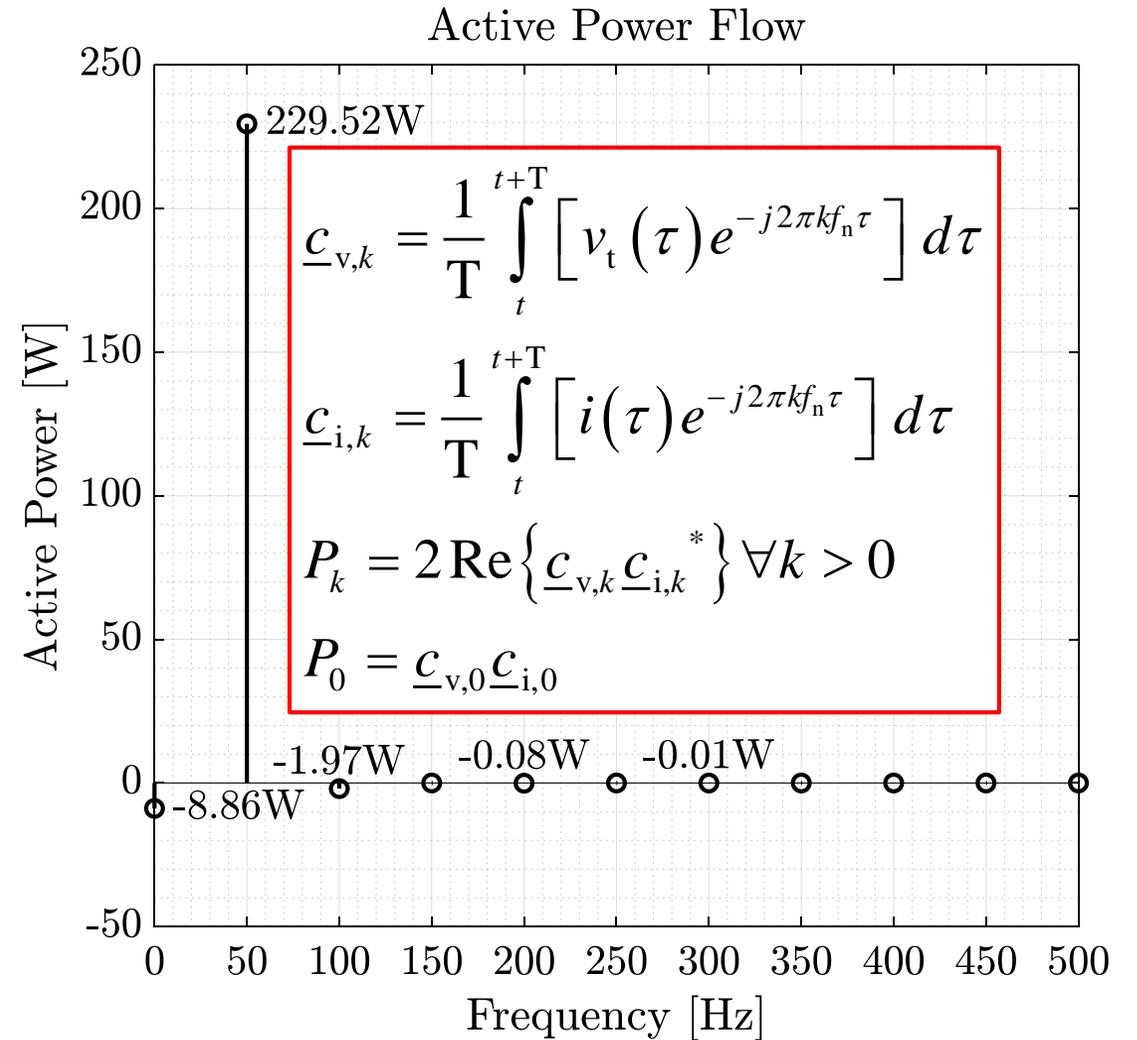
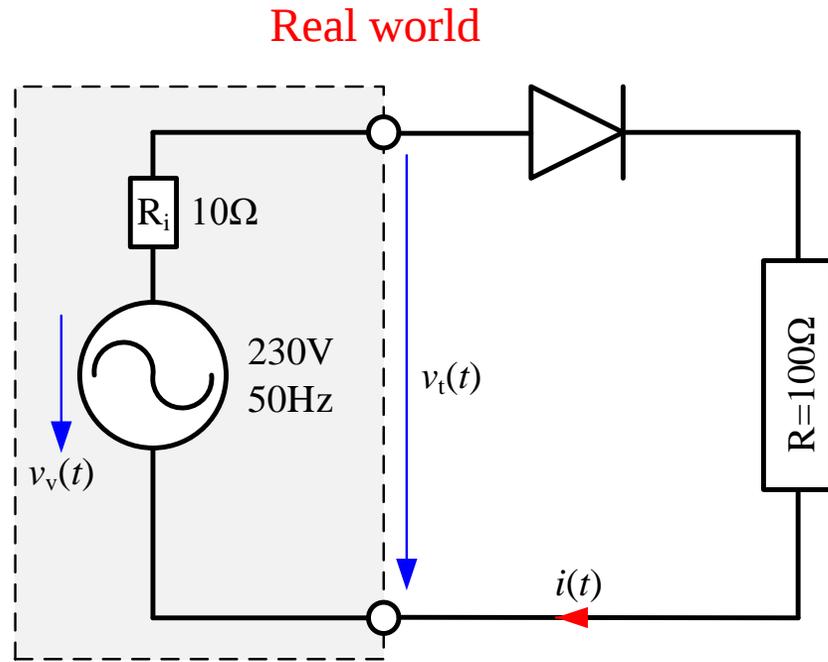
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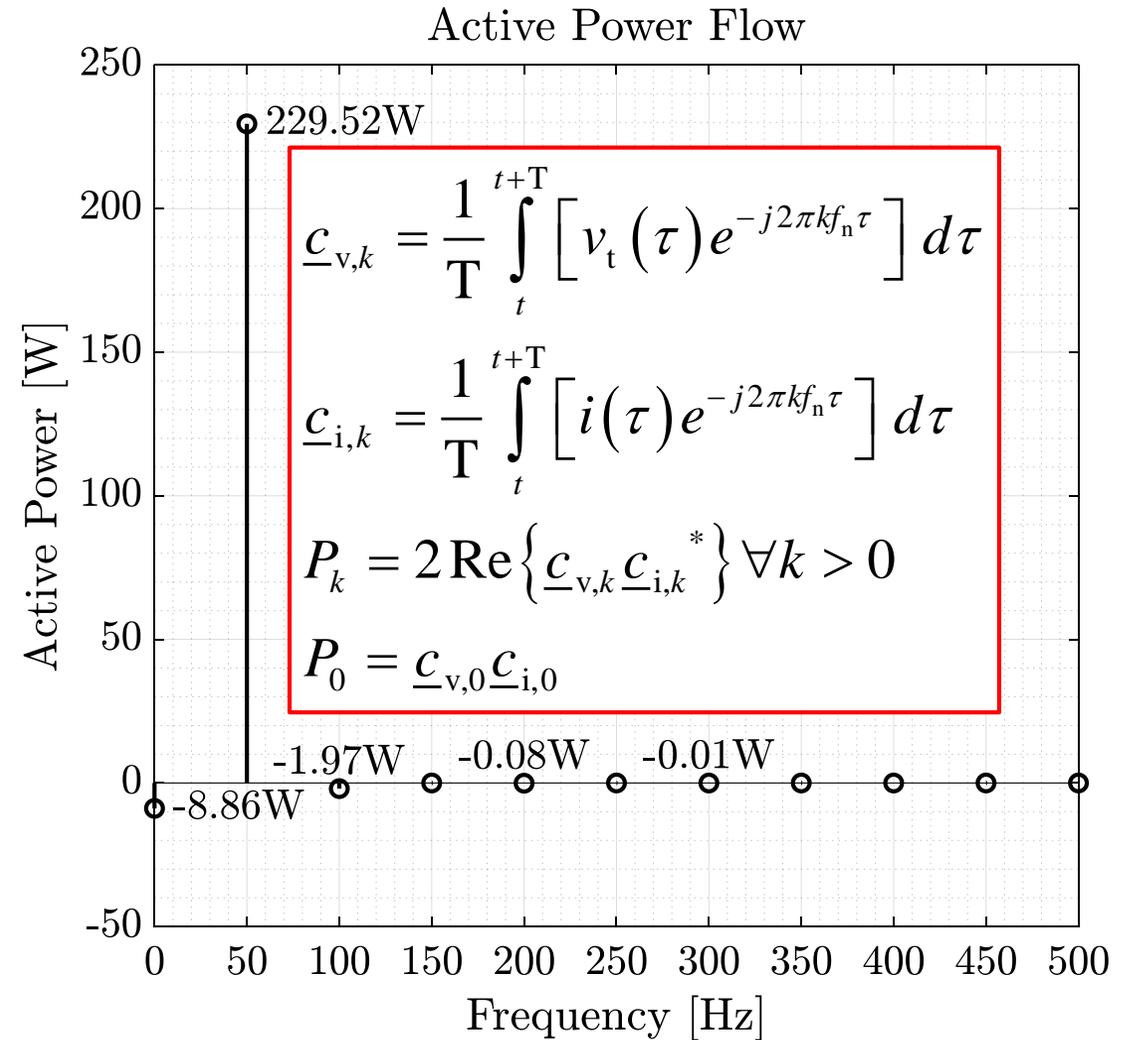
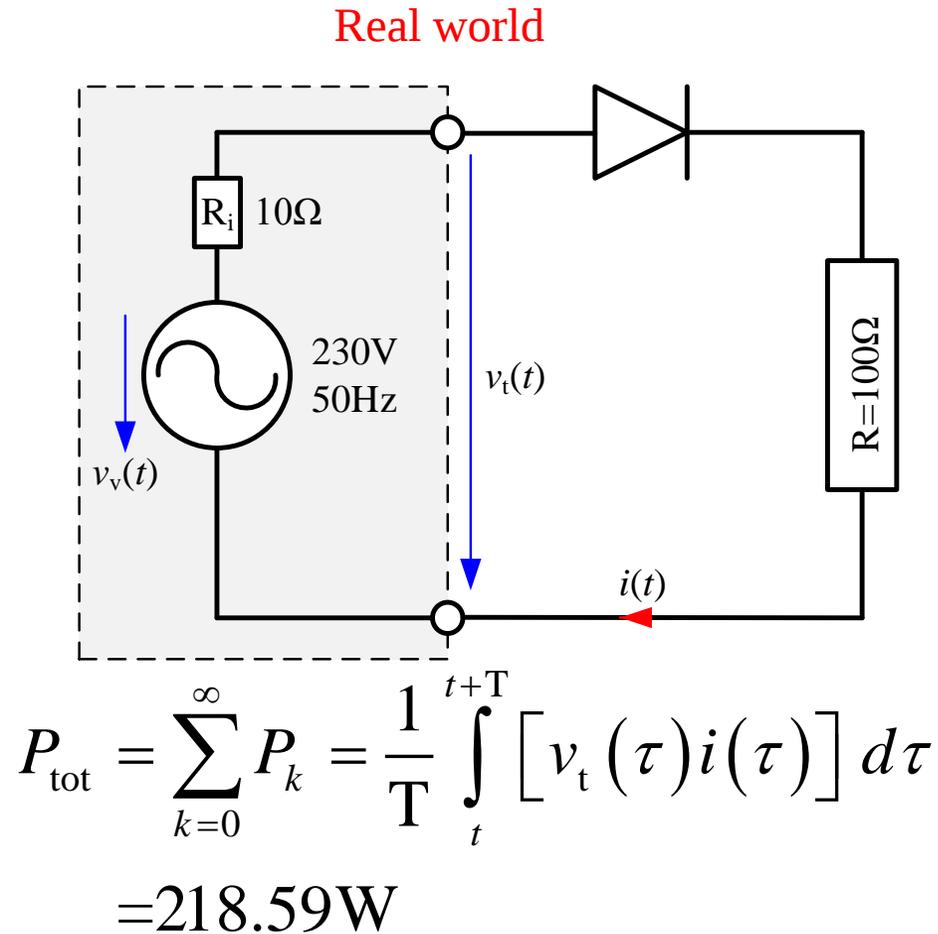
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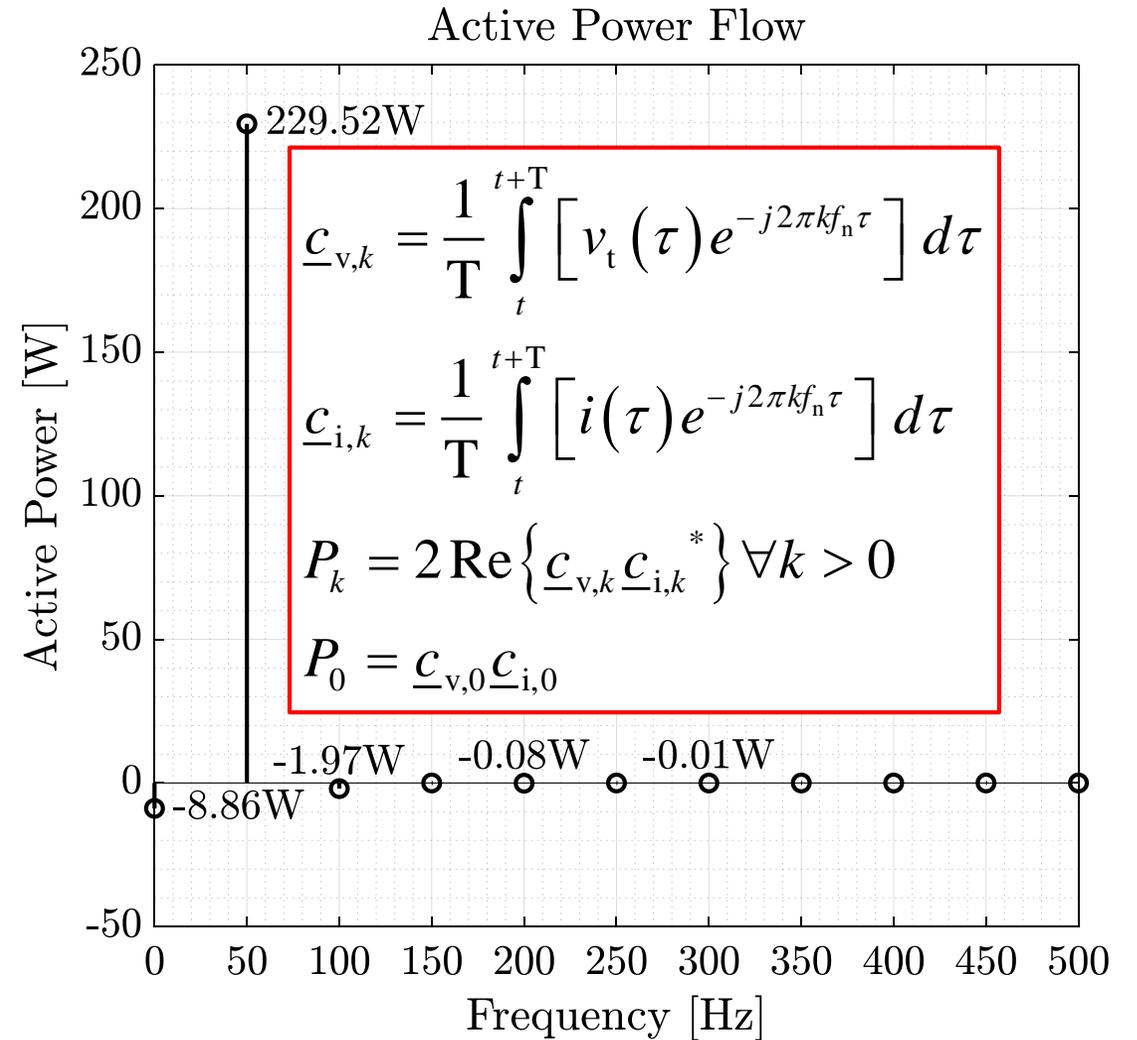
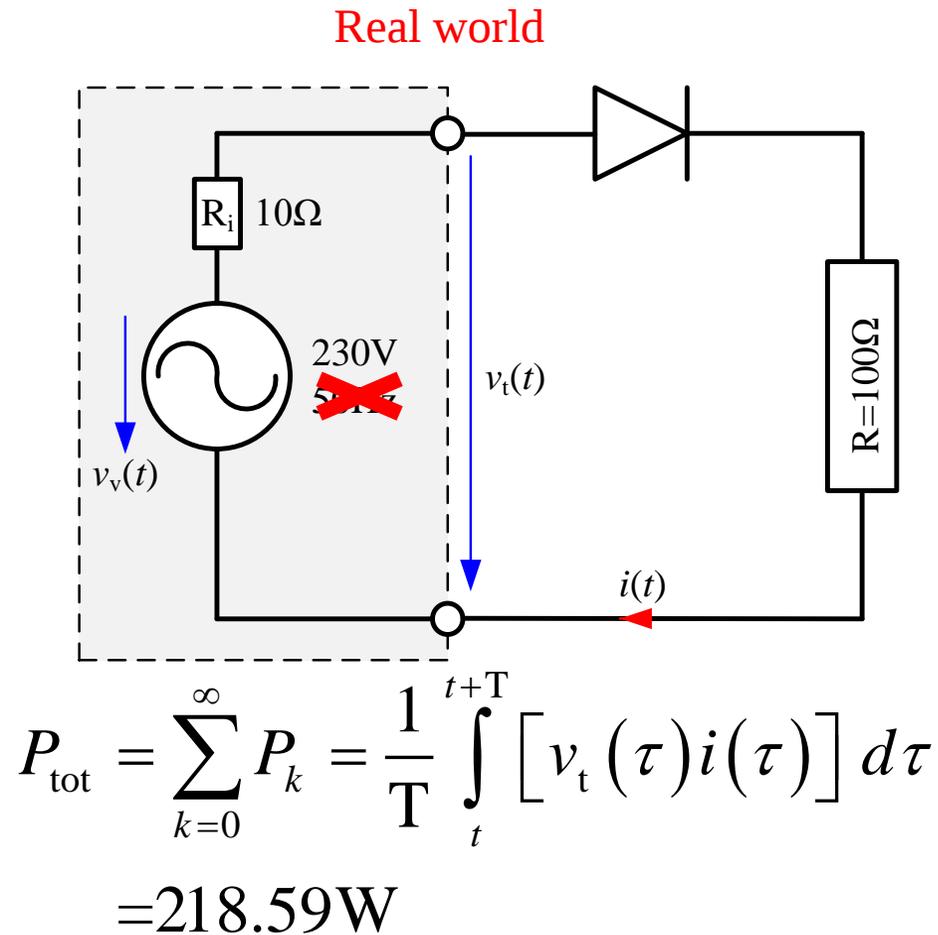
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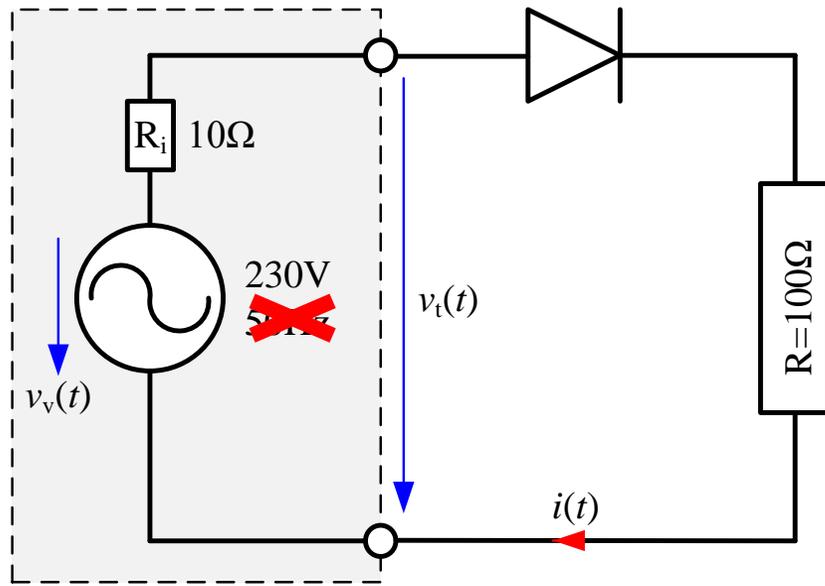
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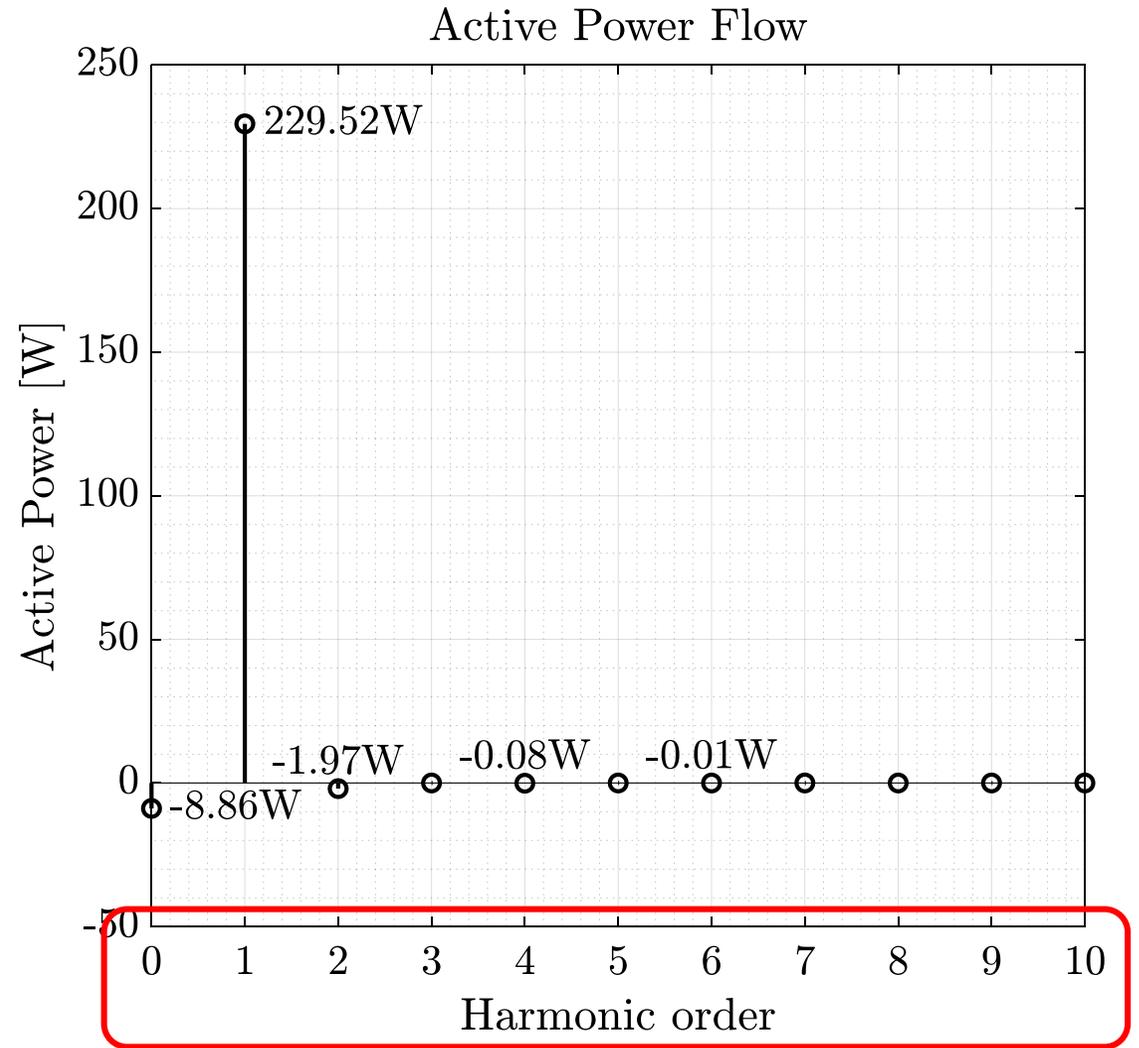
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Real world

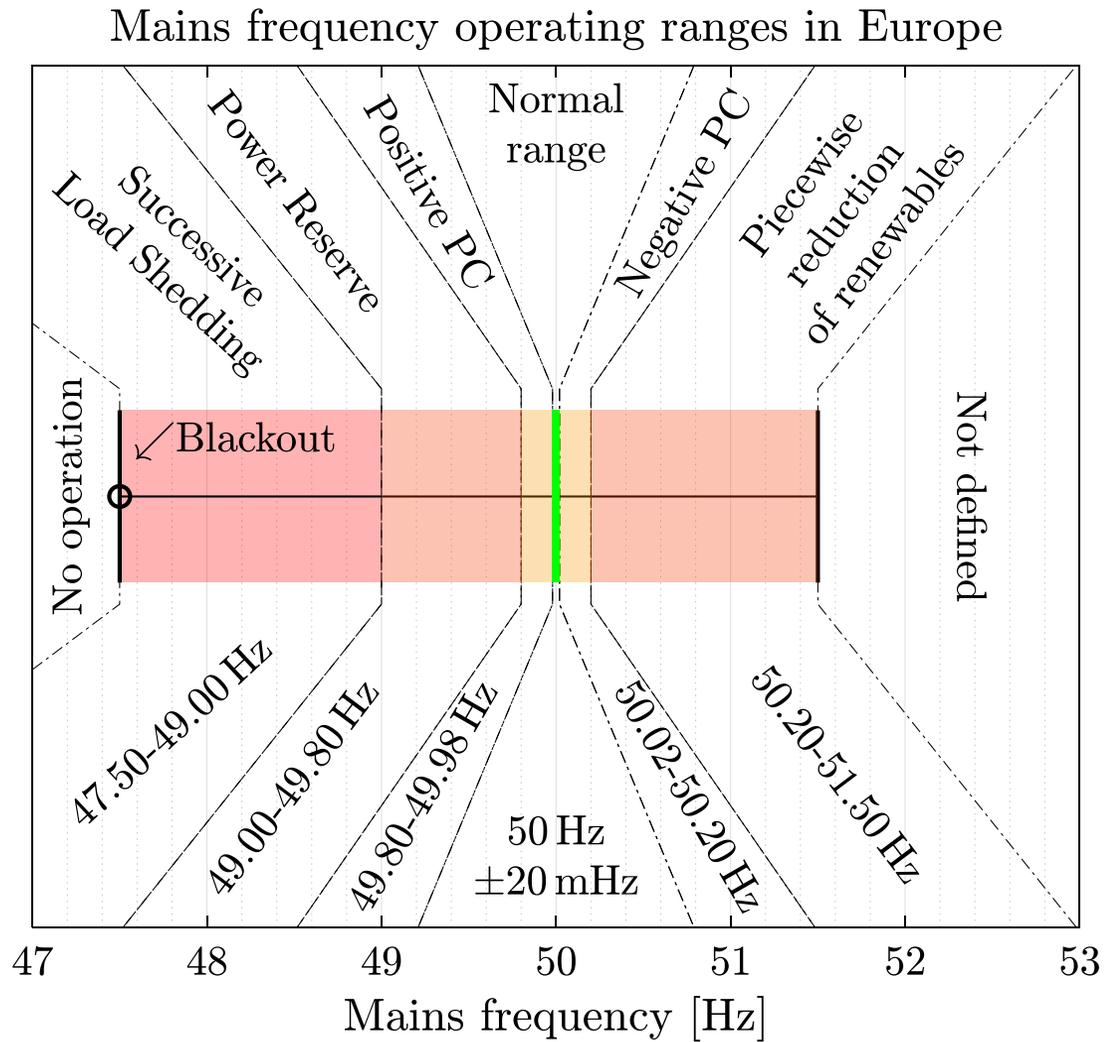


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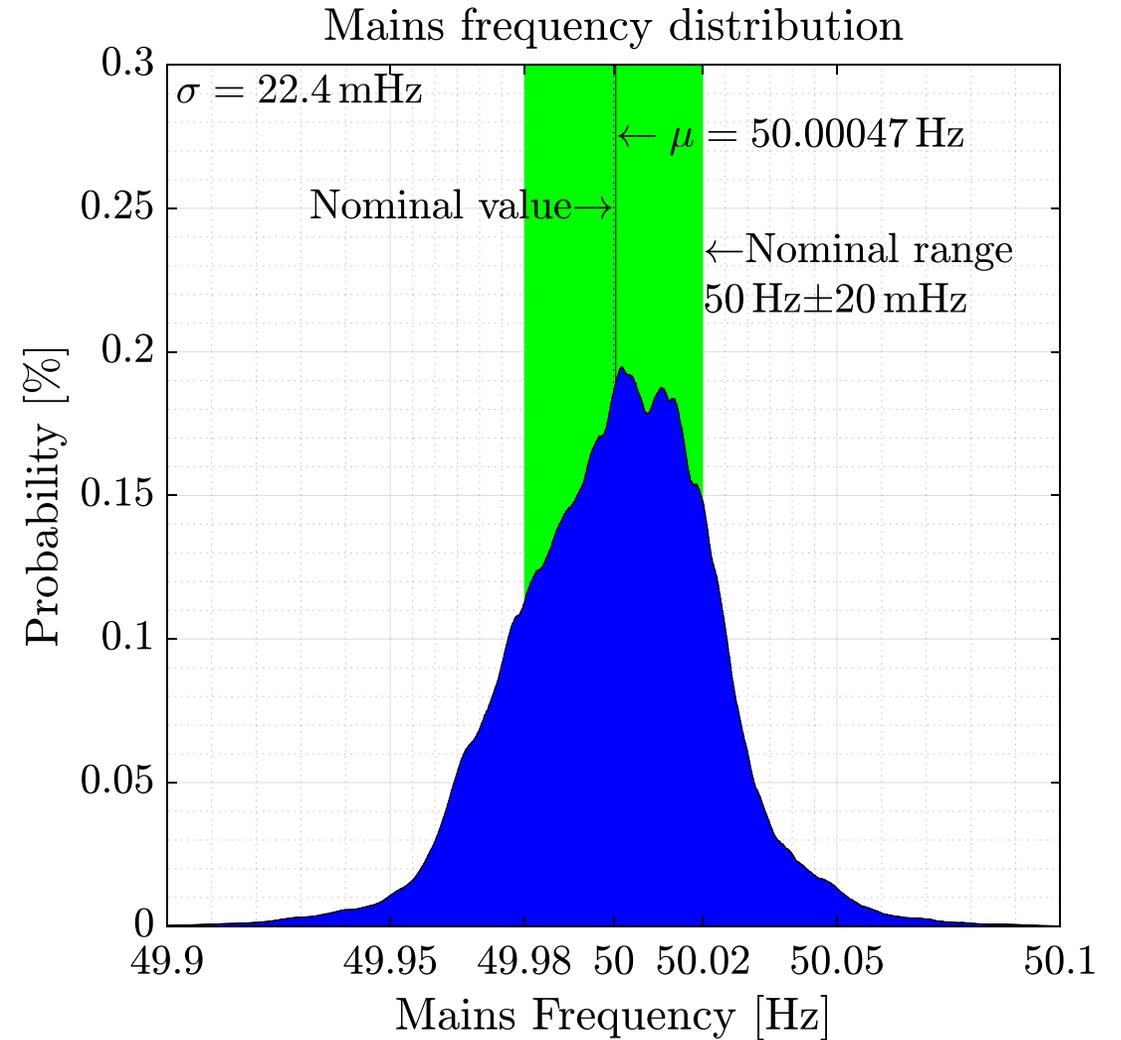
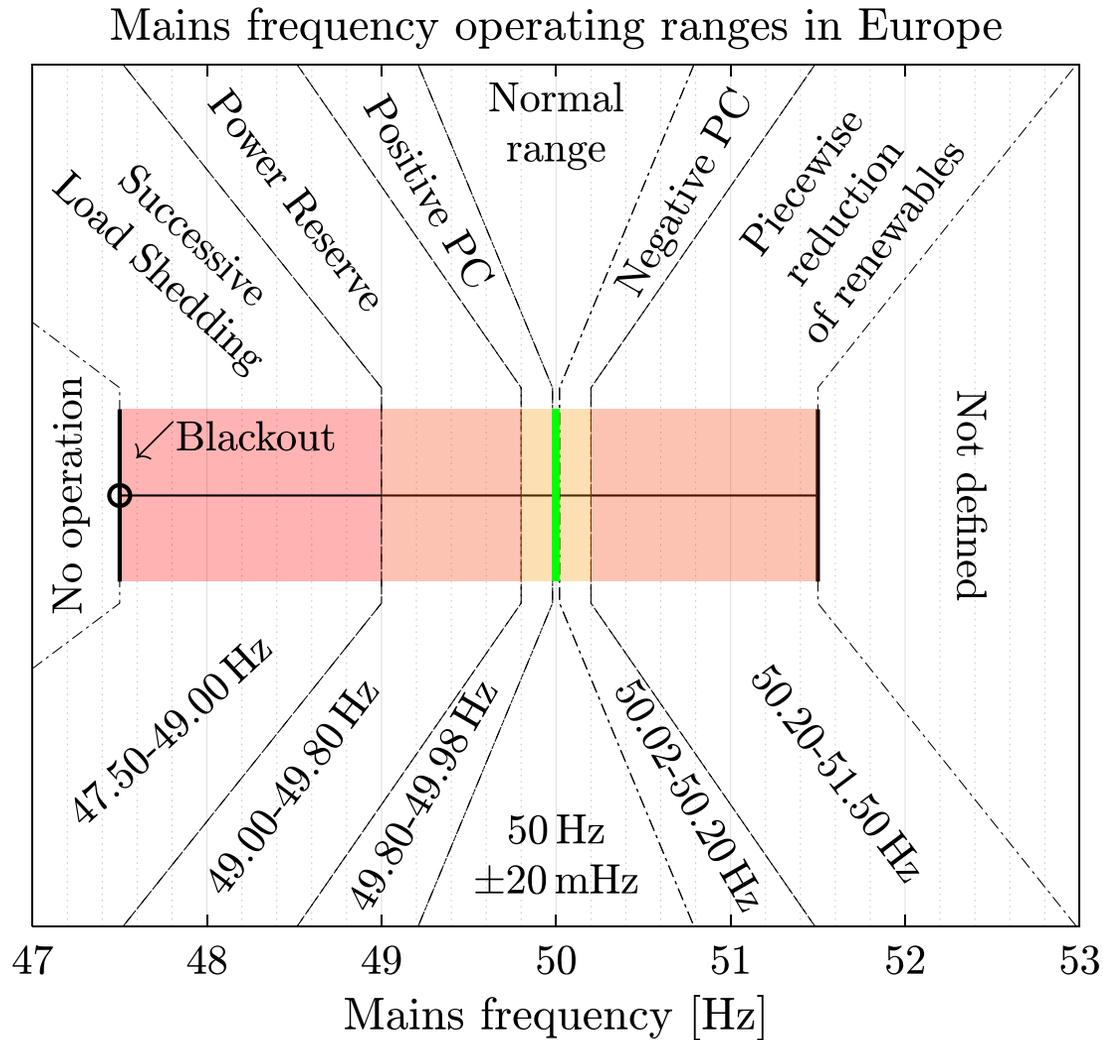
$$= 218.59\text{W}$$



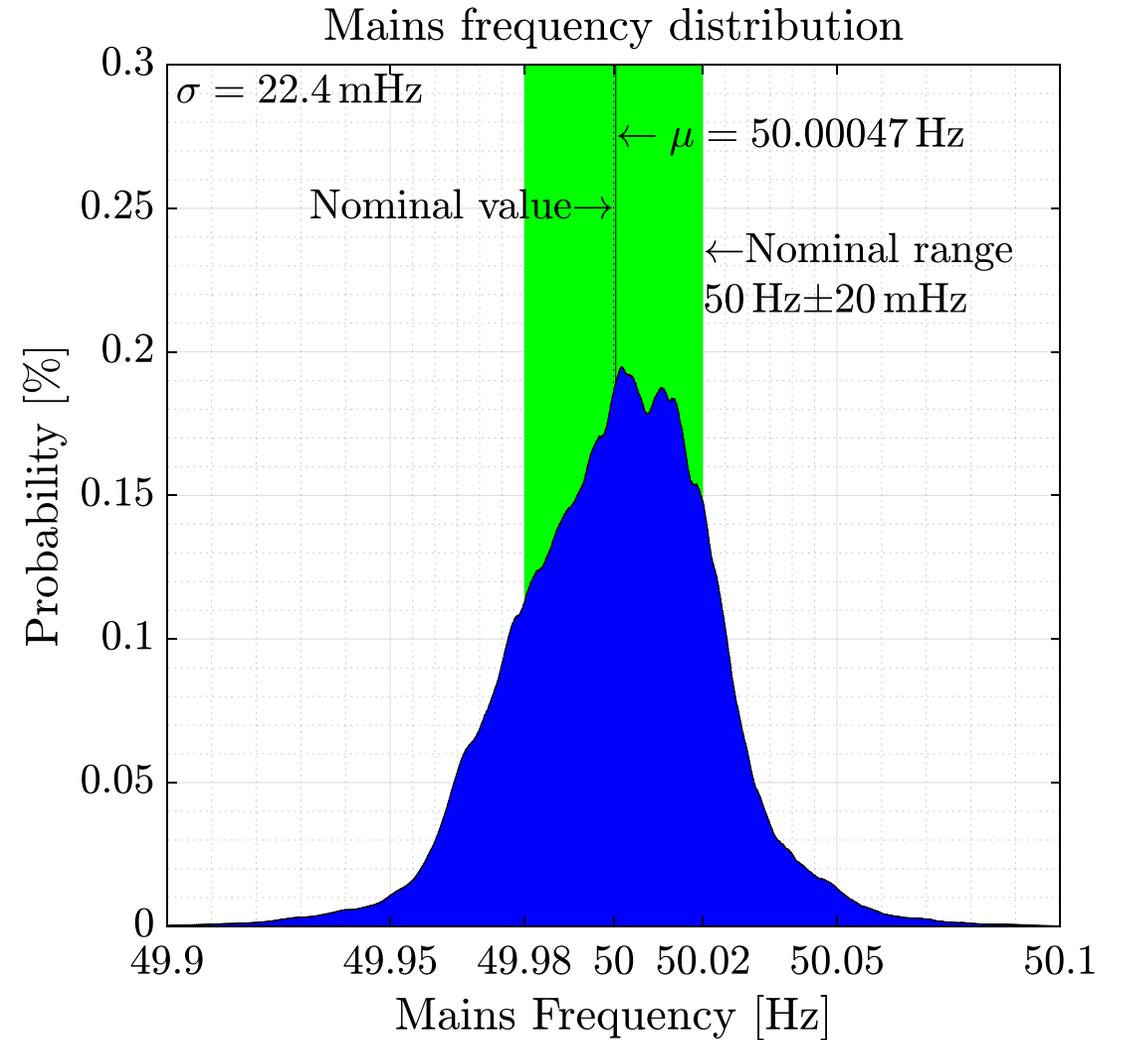
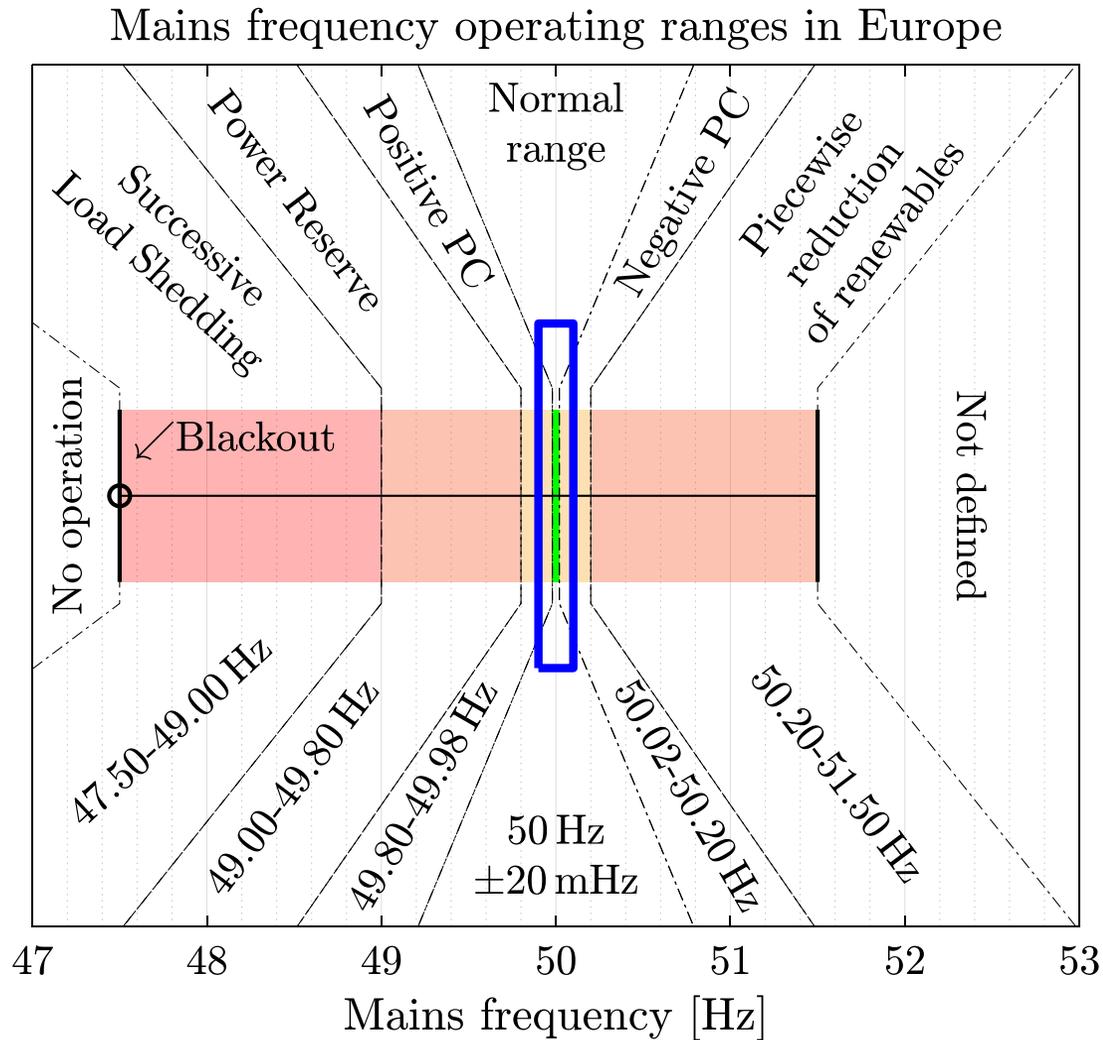
Mains frequency operating ranges



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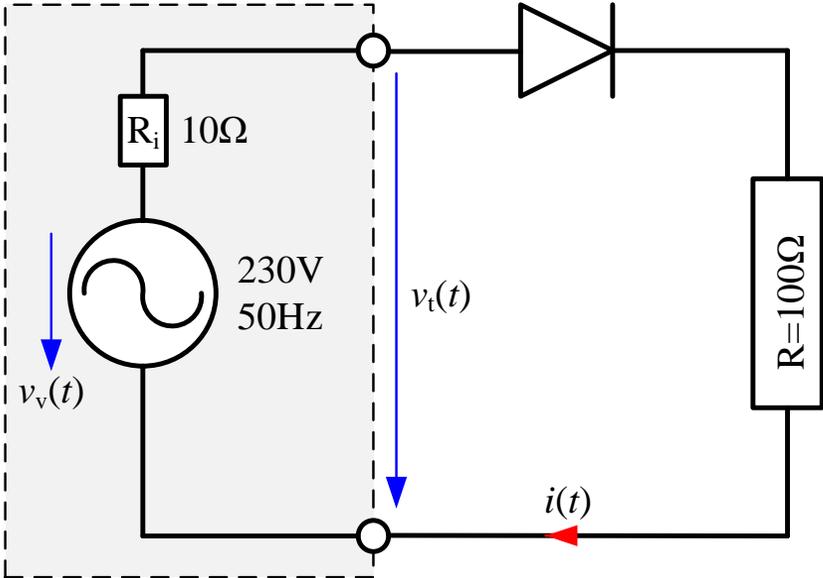


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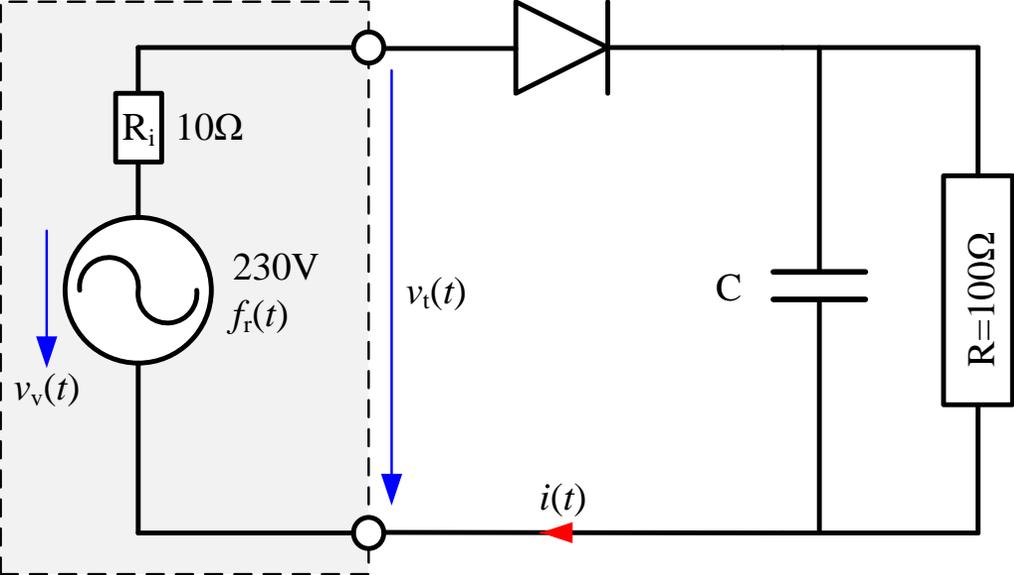


Measurements in Transient Conditions

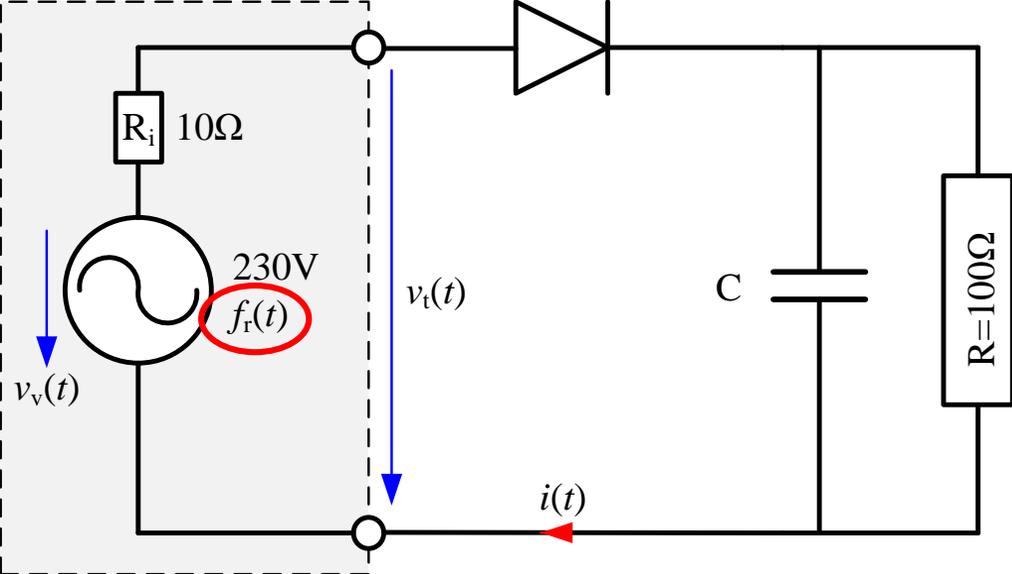
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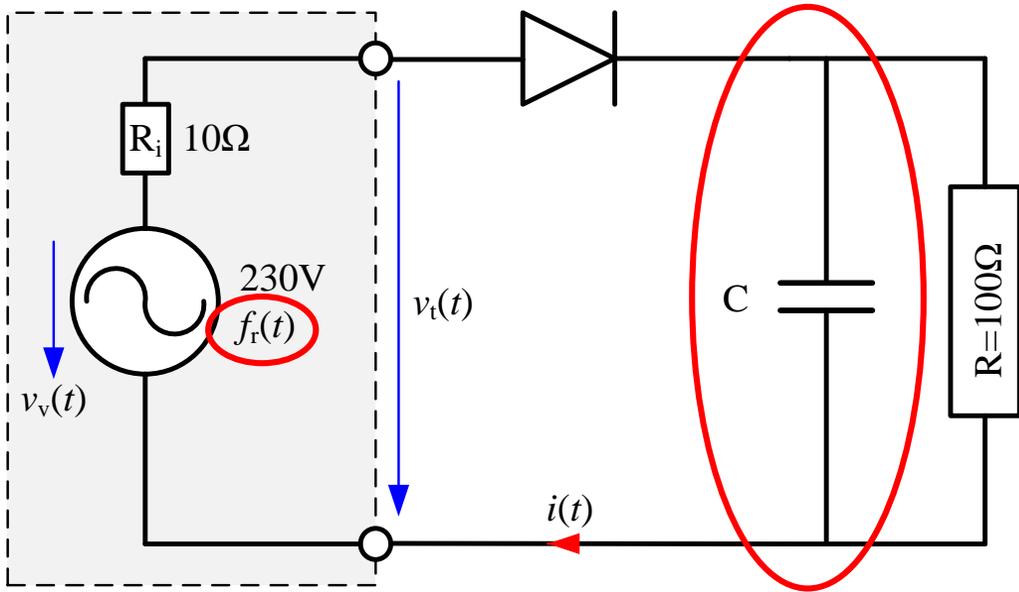
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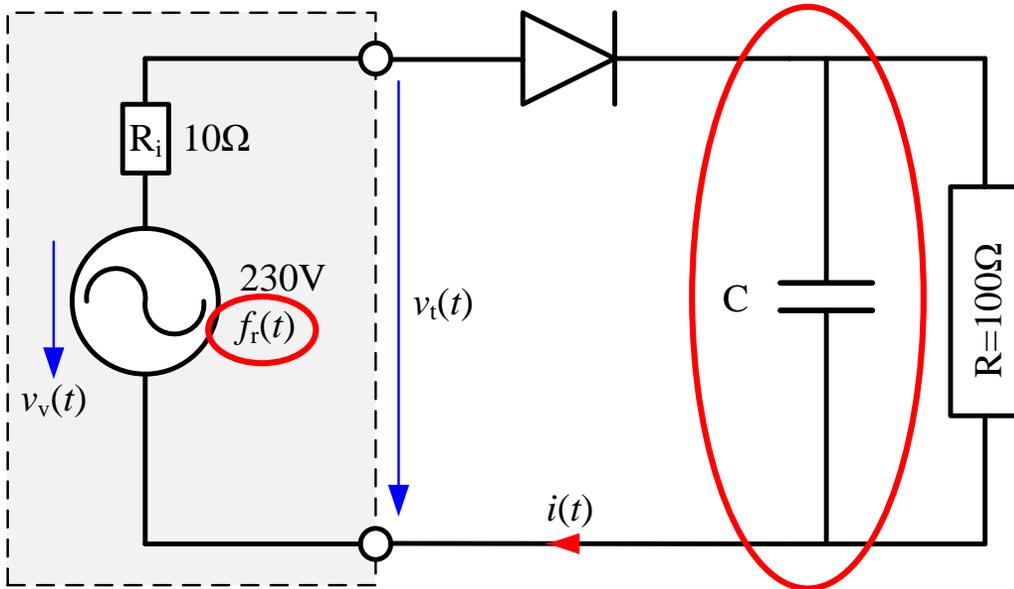


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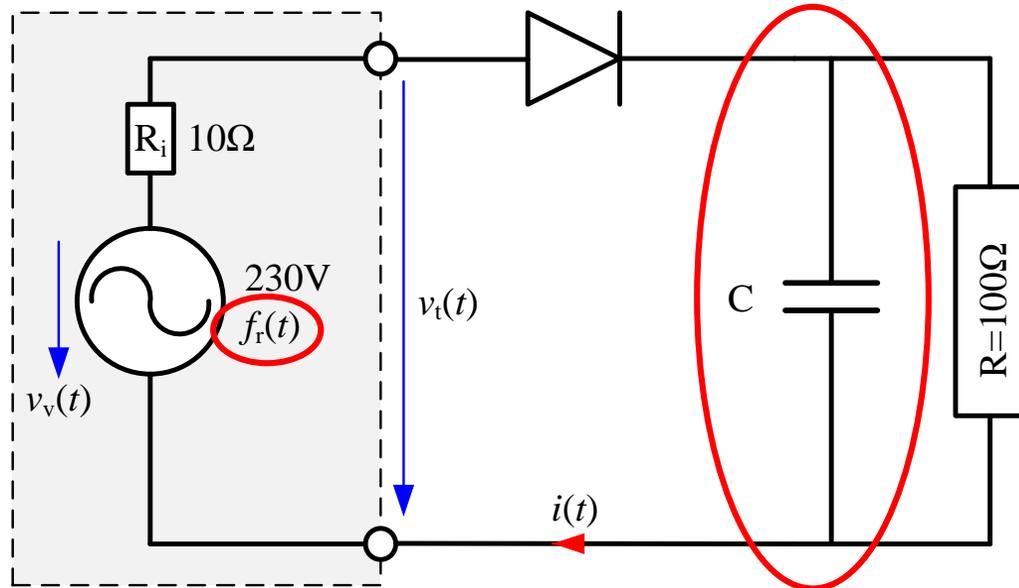


Measurements in Transient Conditions

- Harmonic voltage and current highly frequency dependent

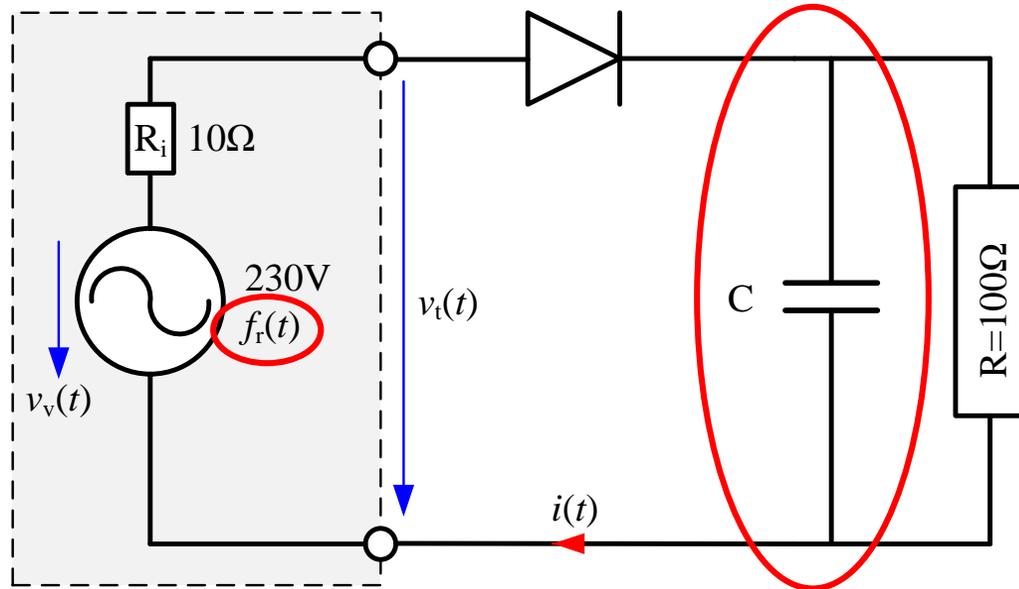


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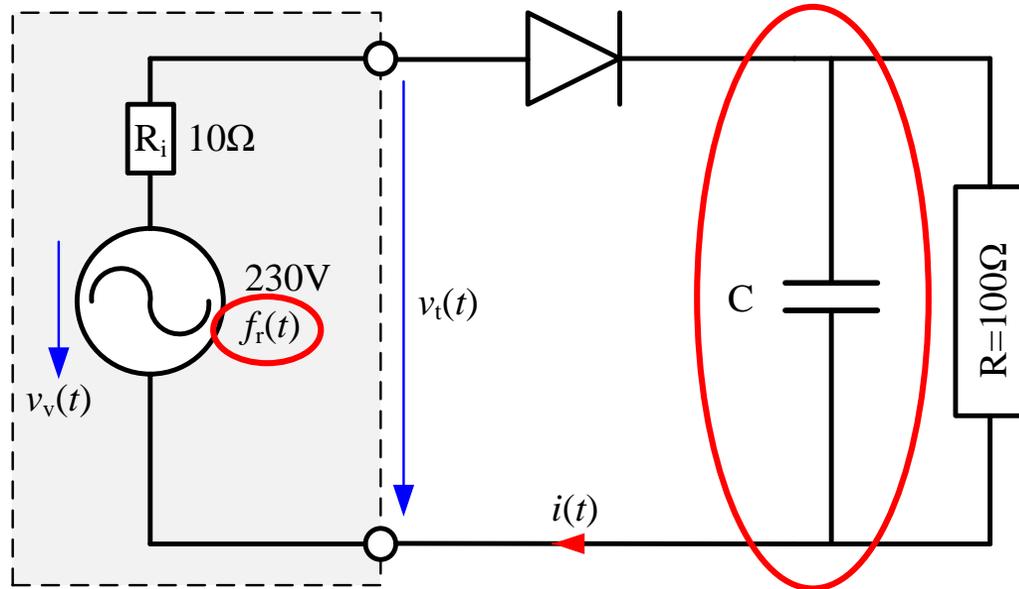
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- No simple impedance function $\underline{Z}(f)$
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- Current PQ standards not applicable

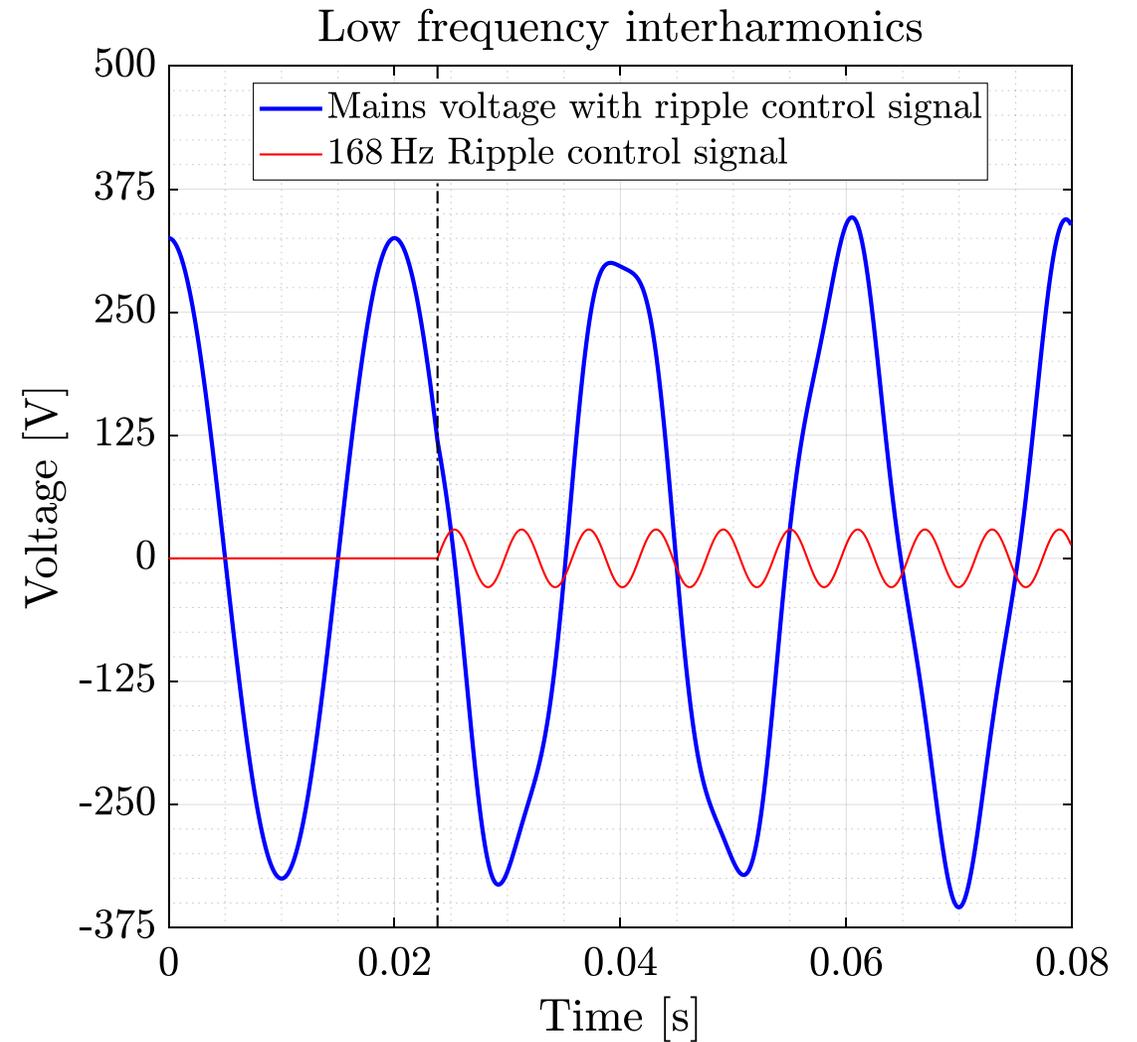
Metrological Challenges: External Influences

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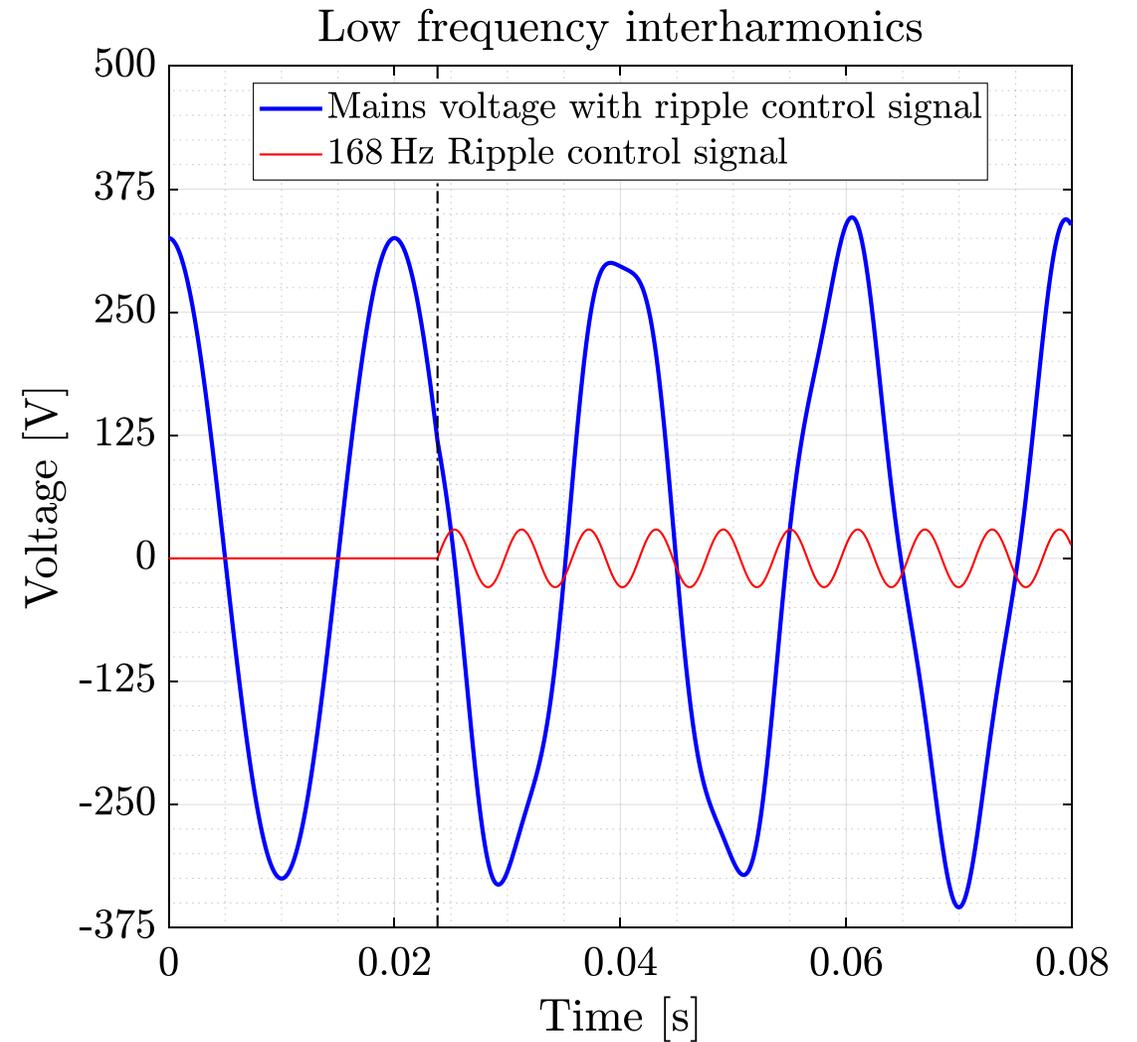
Metrological Challenges: External Influences

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 - Low frequency communication signals



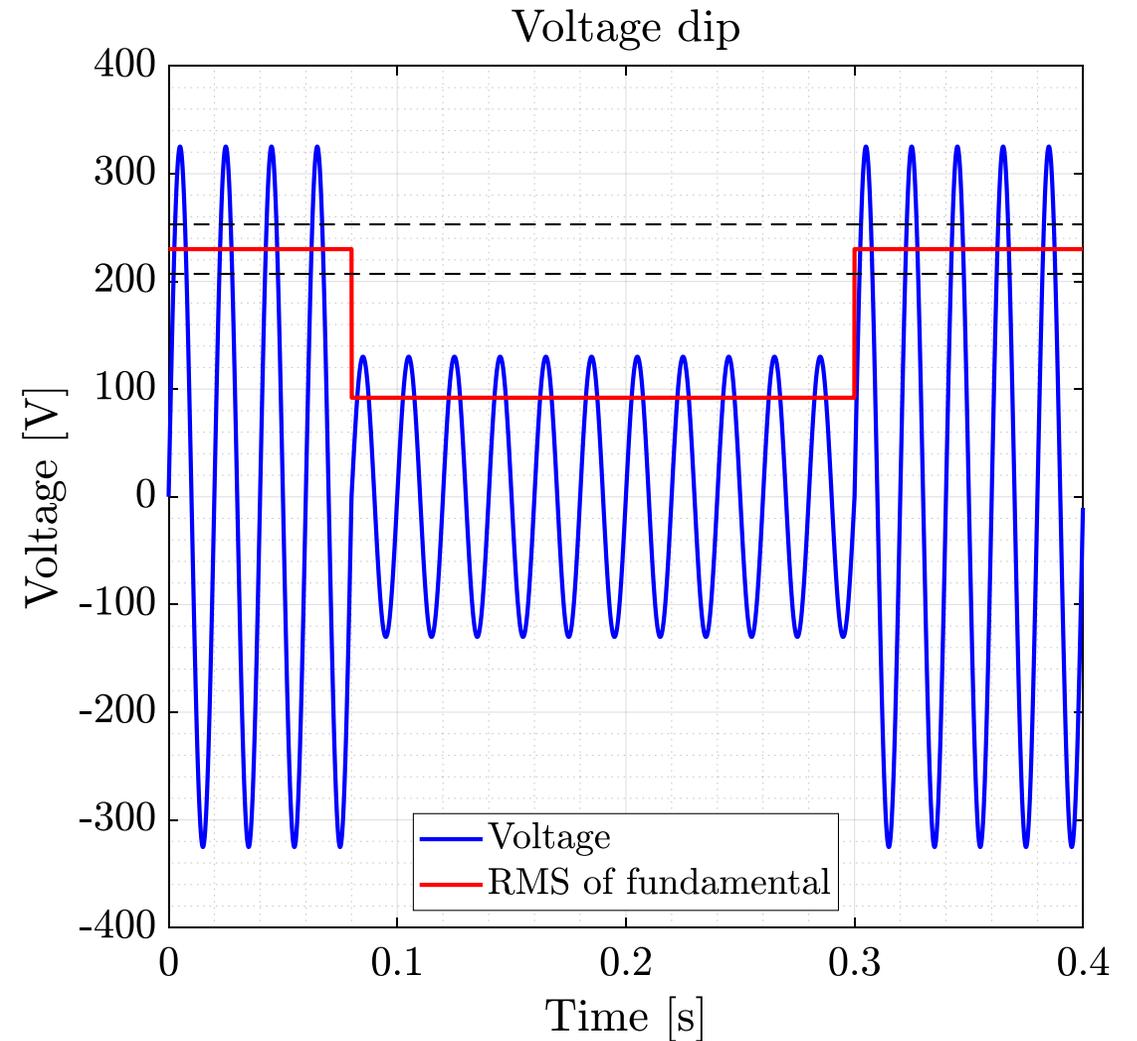
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- Interharmonics
 - Low frequency communication signals
 - Switch mode power supplies and inverters



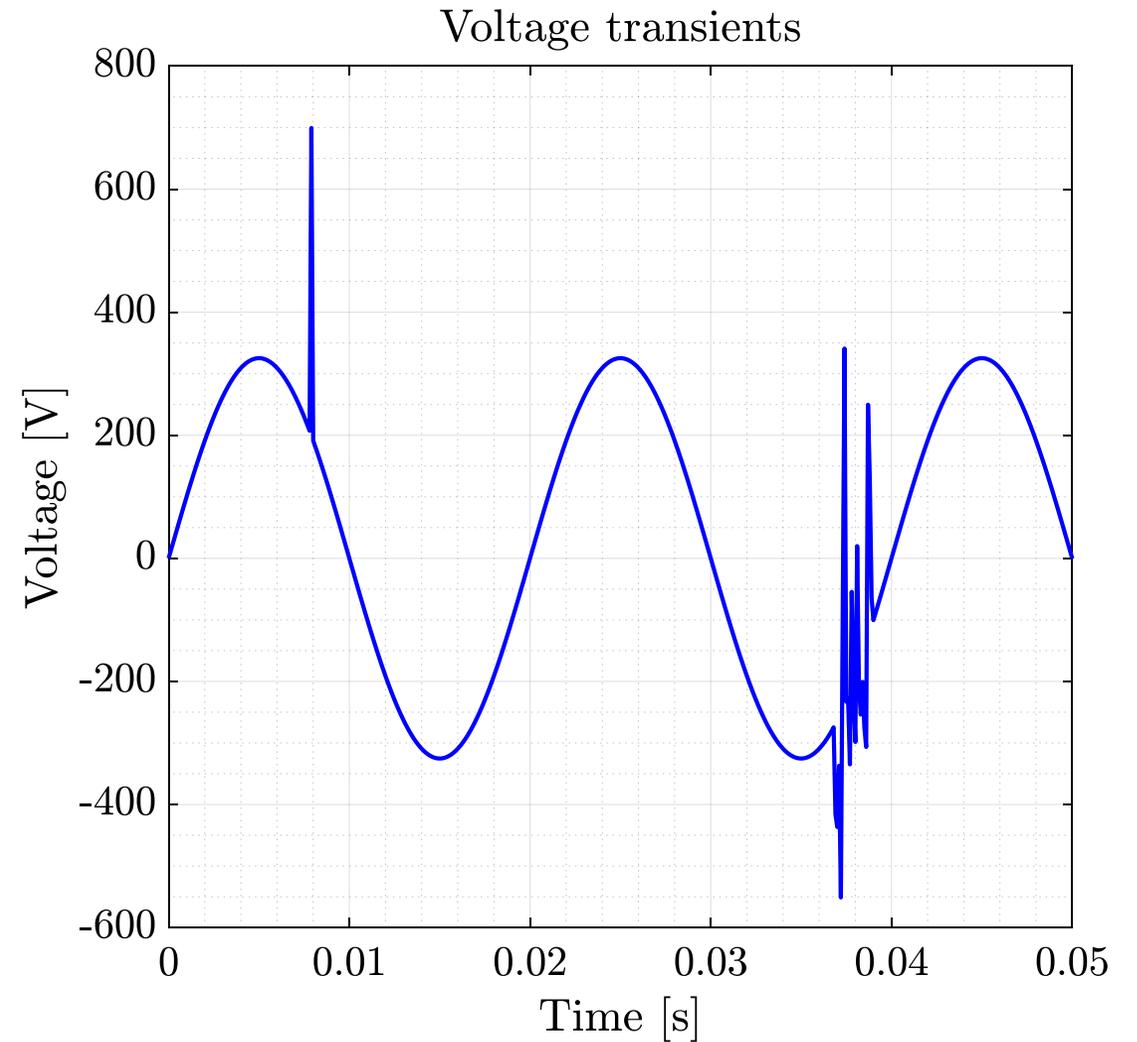
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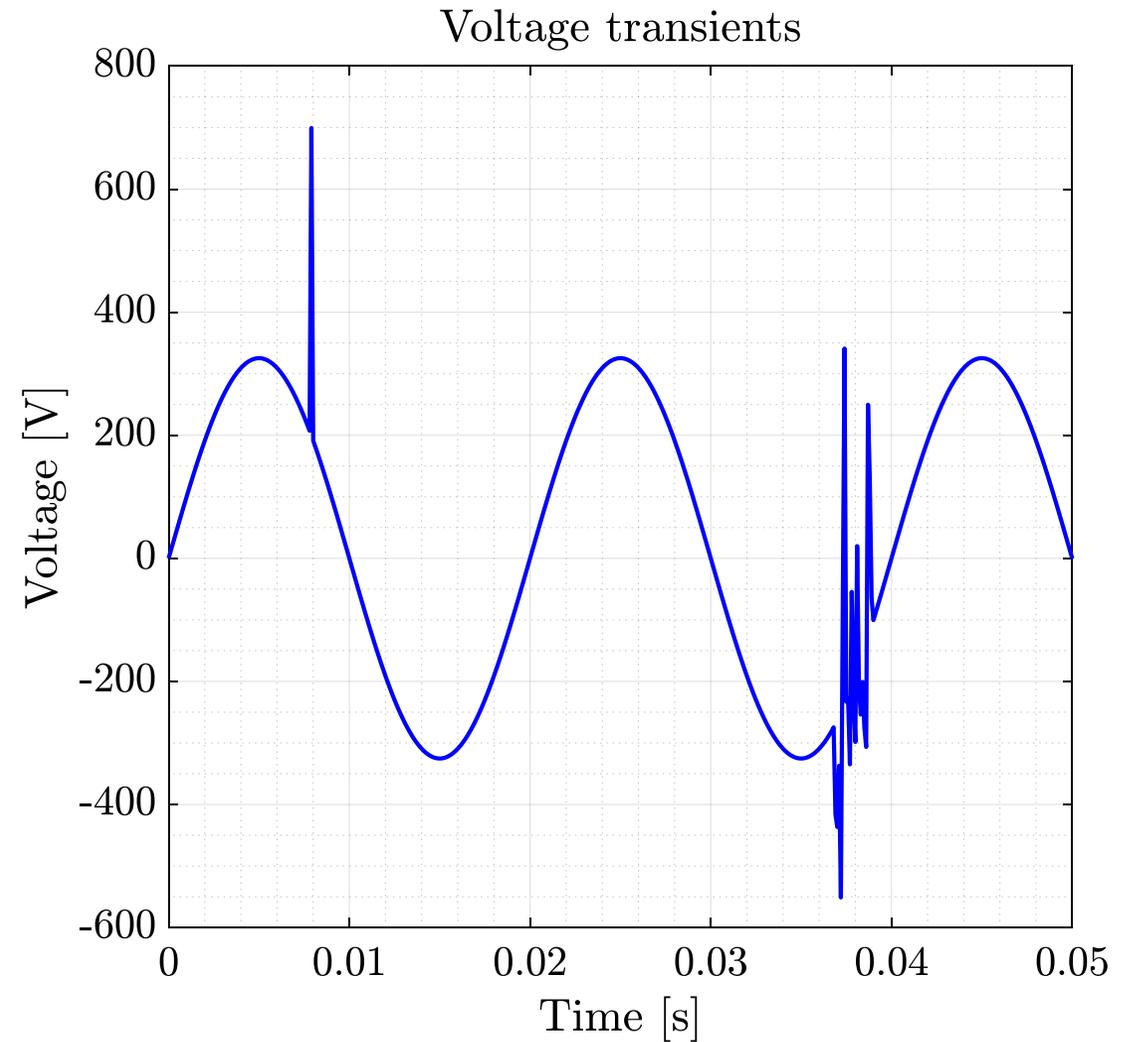
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- Fast voltage transients



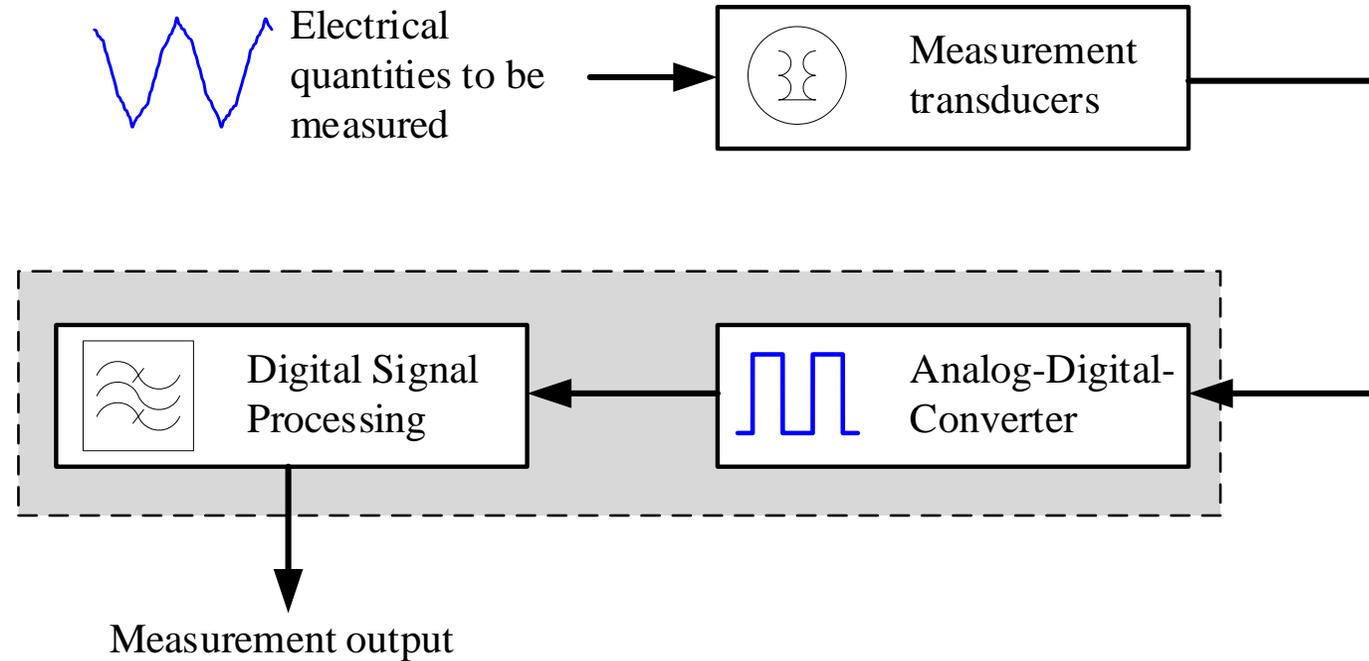
Metrological Challenges: External Influences

- Interharmonics
 - Low frequency communication signals
 - Switch mode power supplies and inverters
- Voltage dips and swells
- Fast voltage transients
- Deviations of the mains frequency

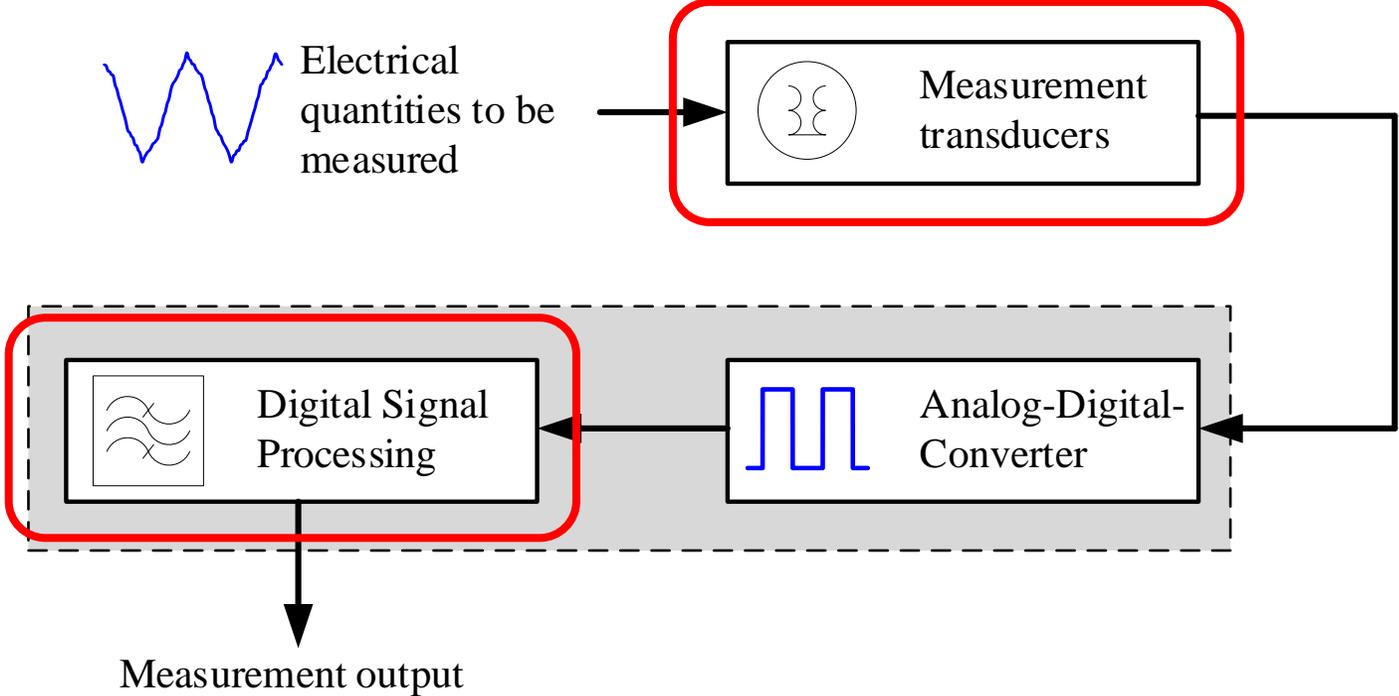


Metrological Challenges: The Measurement Chain

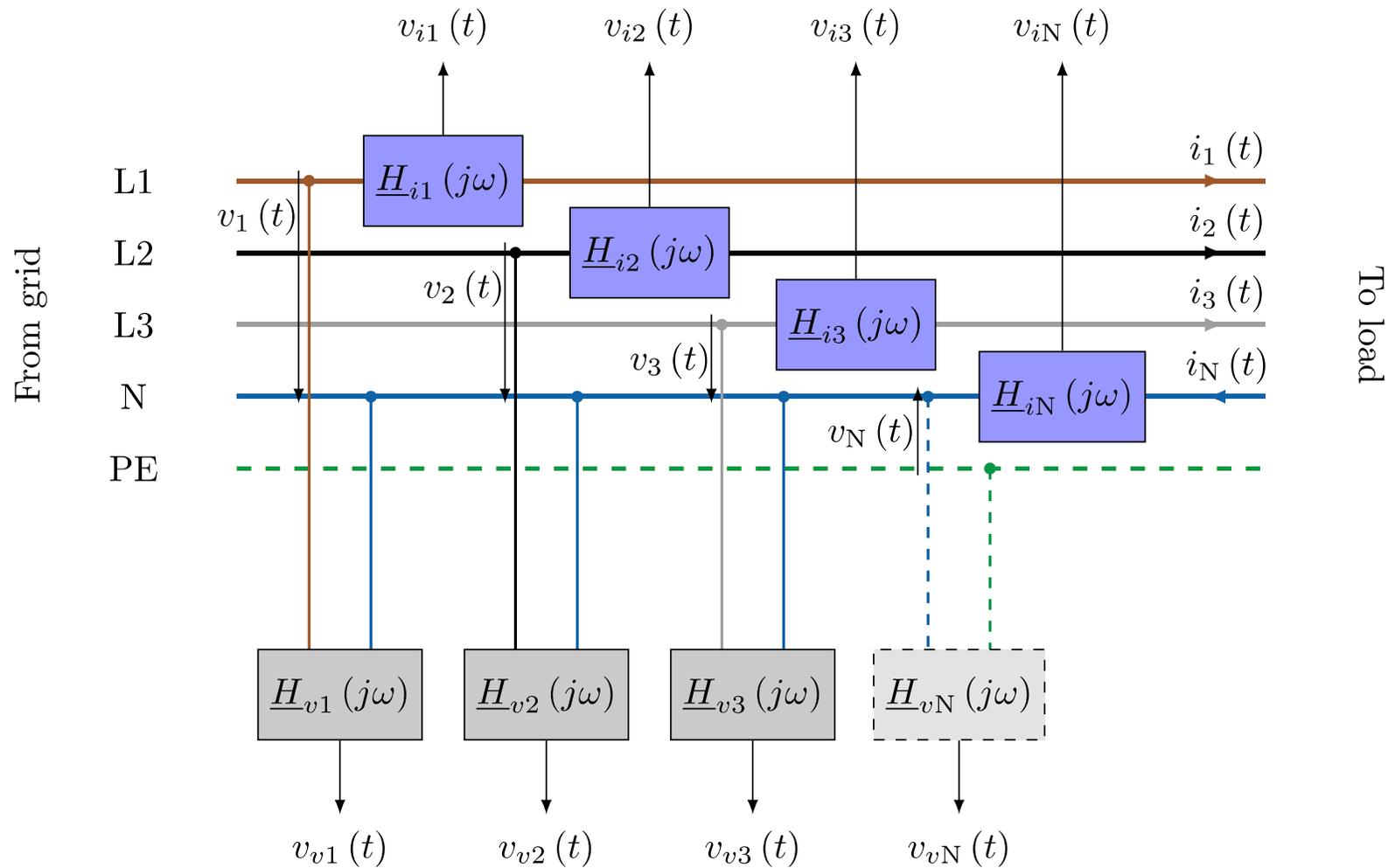
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Metrological Challenges: Characterization of measurement transducers



Metrological Challenges: Digital Spectral Analysis

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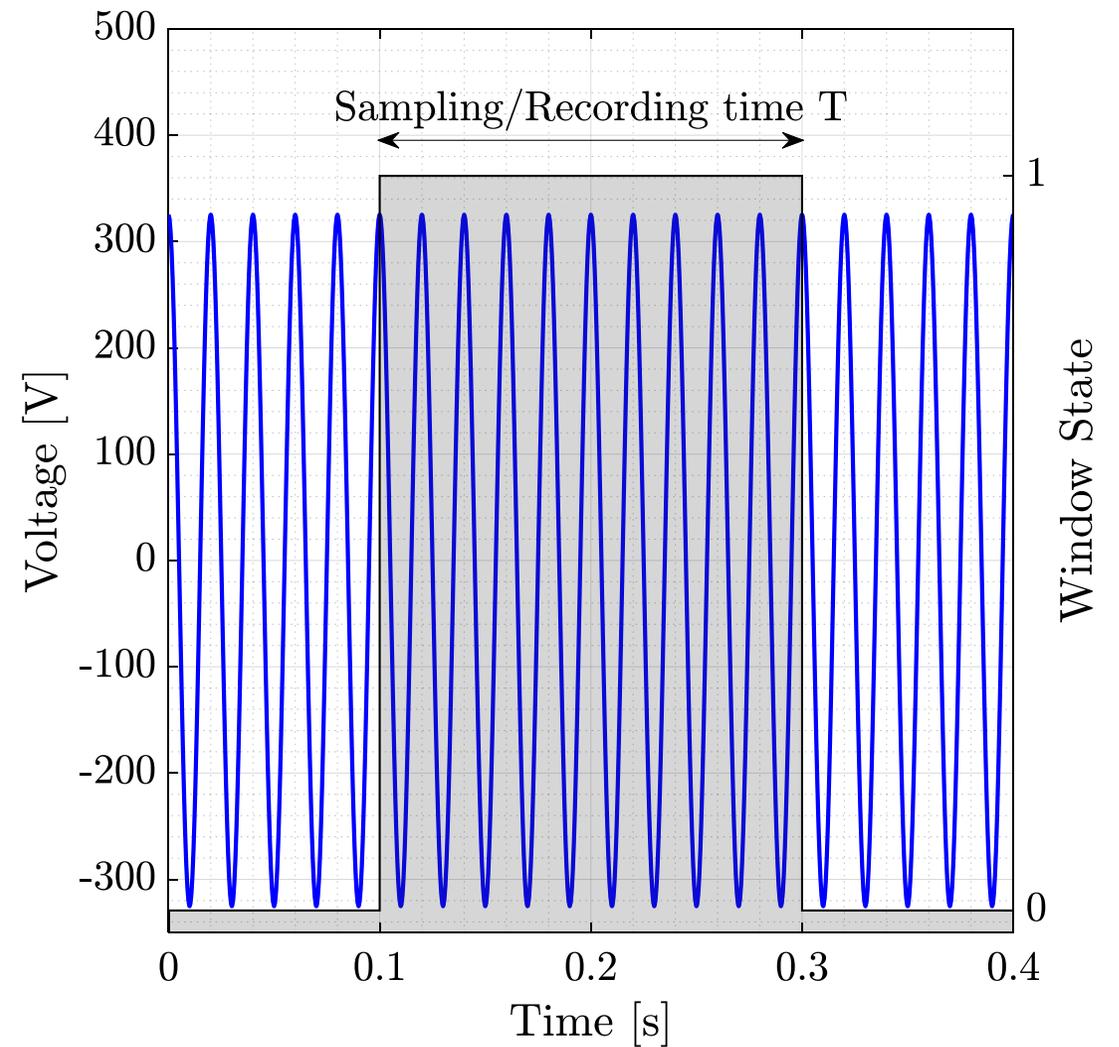


$$v[n] \longrightarrow \underline{V}[m] = \frac{1}{N} \sum_{n=0}^{N-1} v[n] \cdot e^{-j2\pi \frac{mn}{N}}$$

Metrological Challenges: Digital Spectral Analysis

- Discrete Fourier Transform instead of Fourier Series
- Multiplication with rectangular window
 - Spectral resolution

$$\Delta f = \frac{1}{T}$$

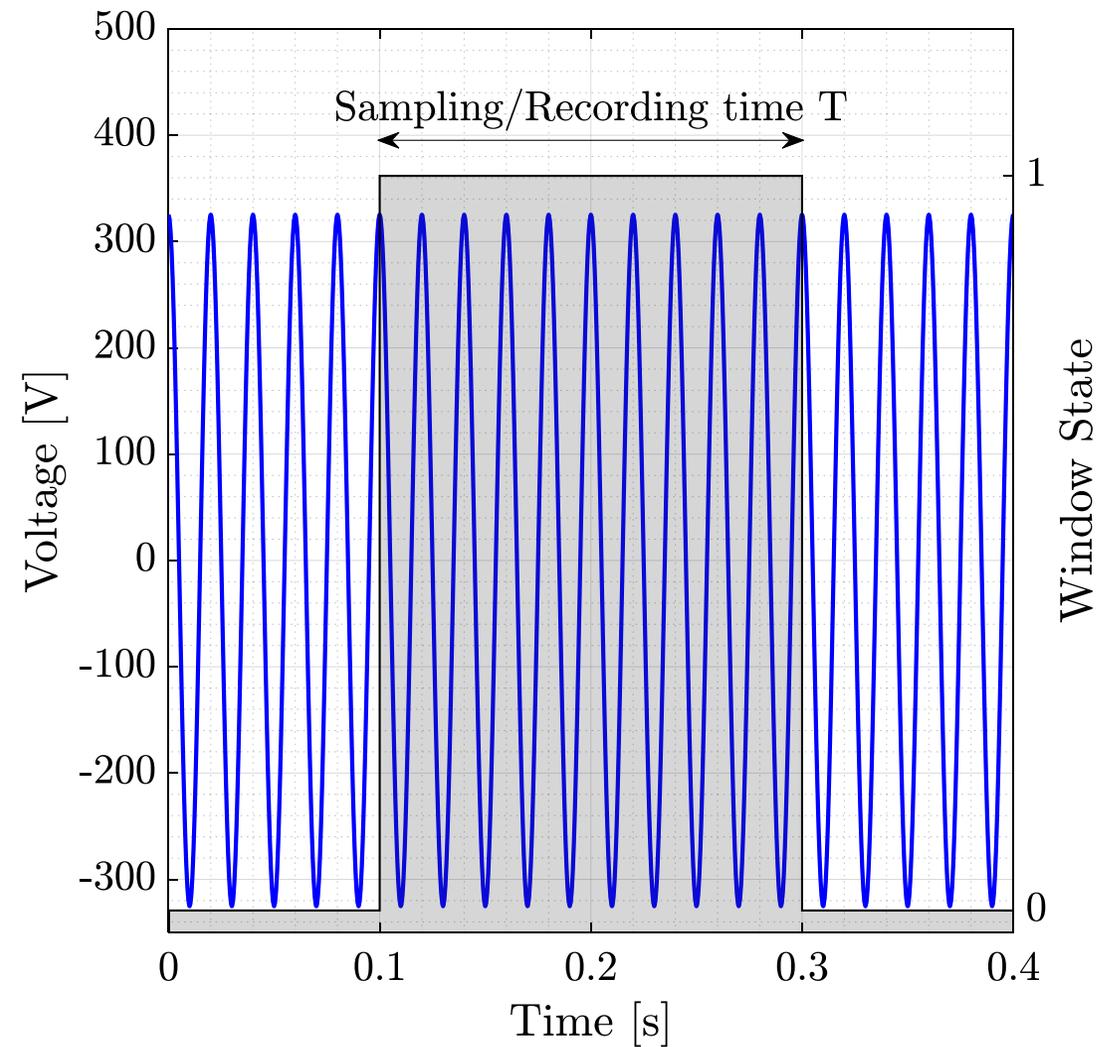


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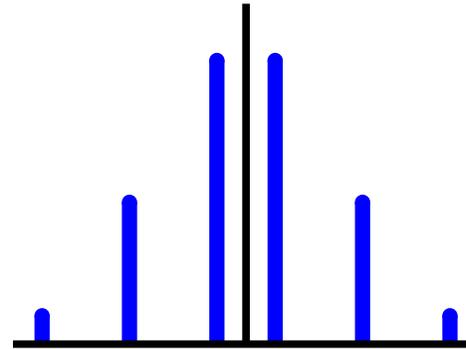


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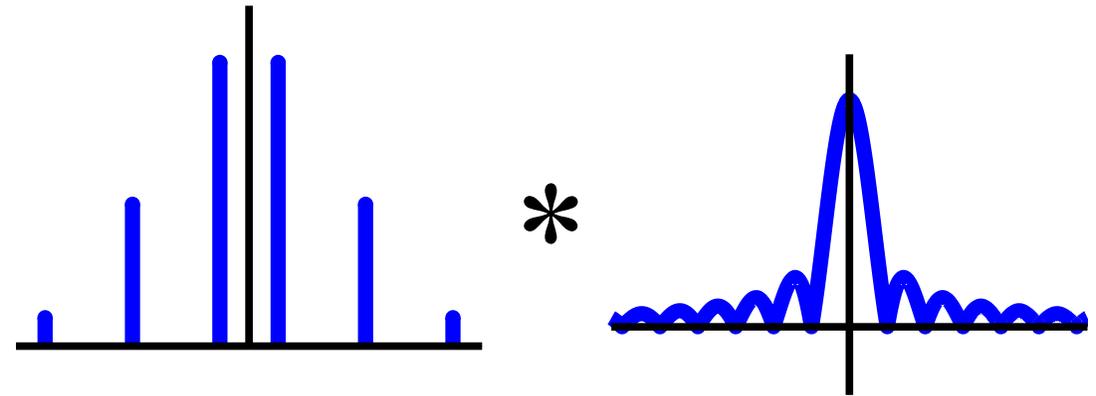


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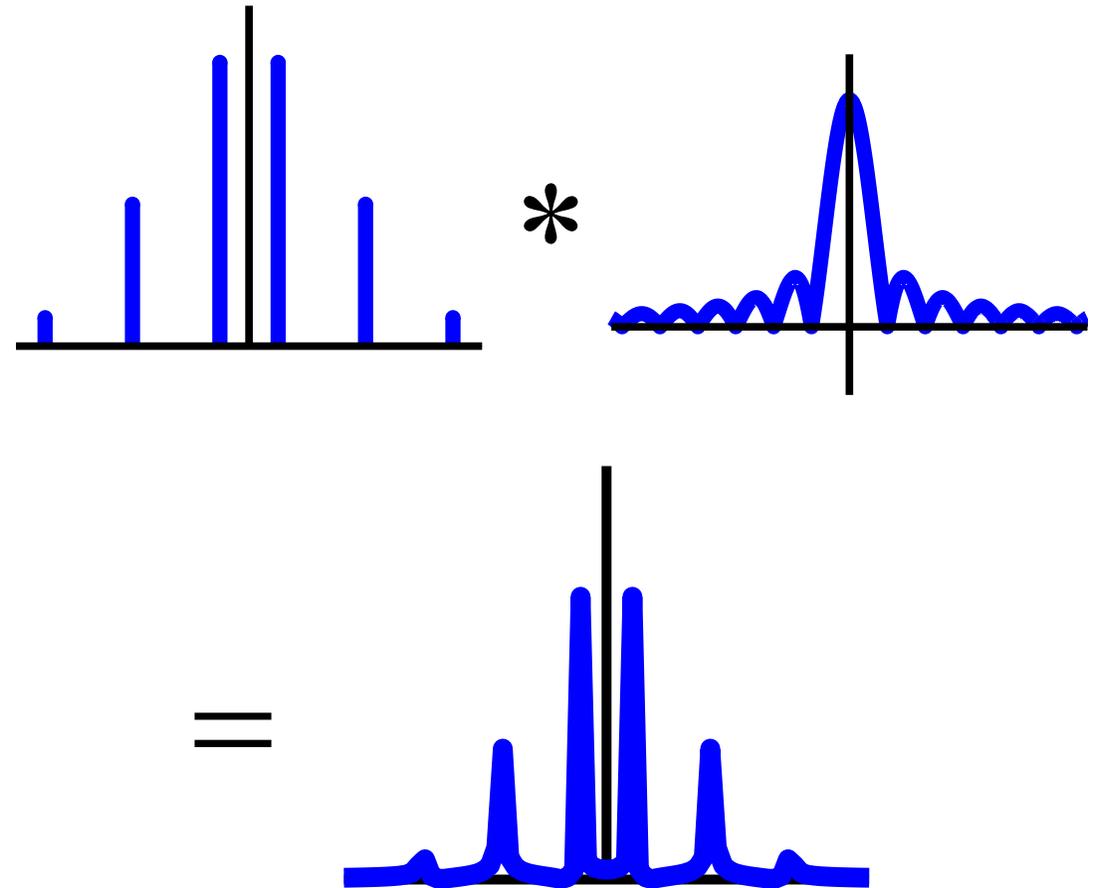


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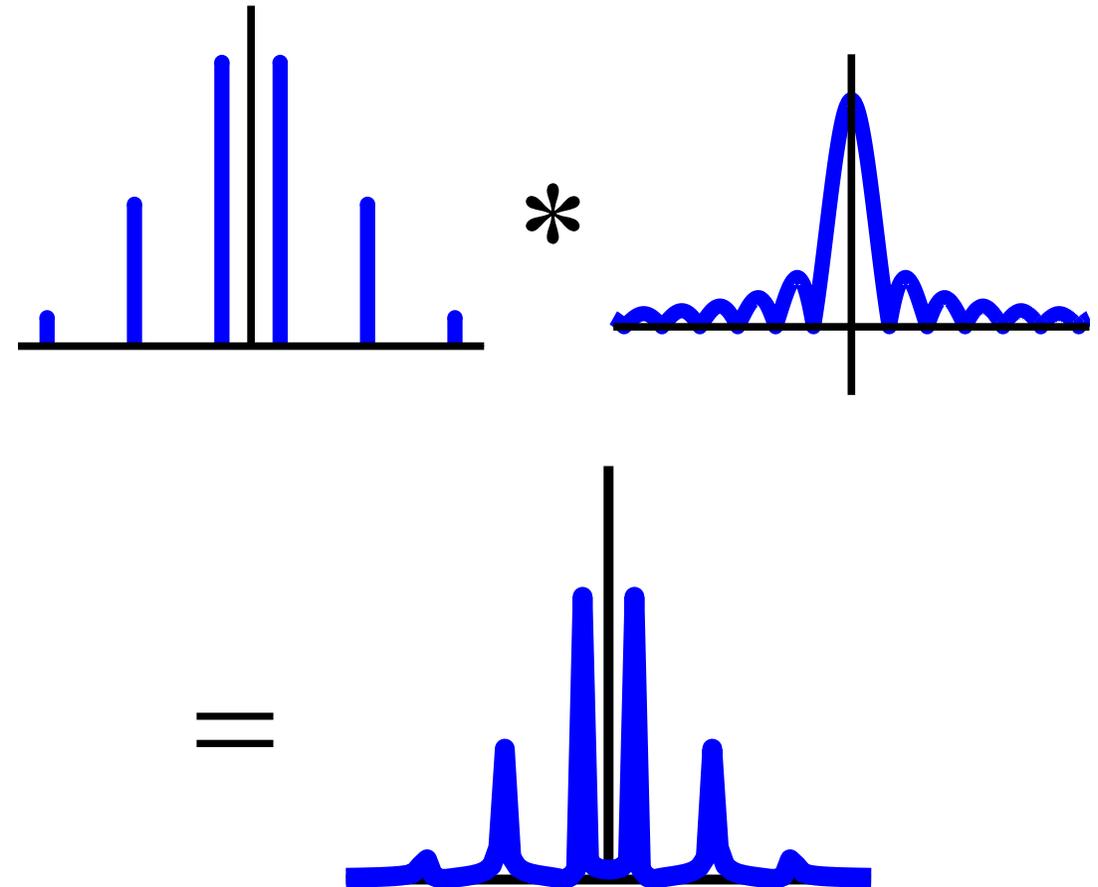


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- Possible distortion of spectrum
 - Spectral leakage



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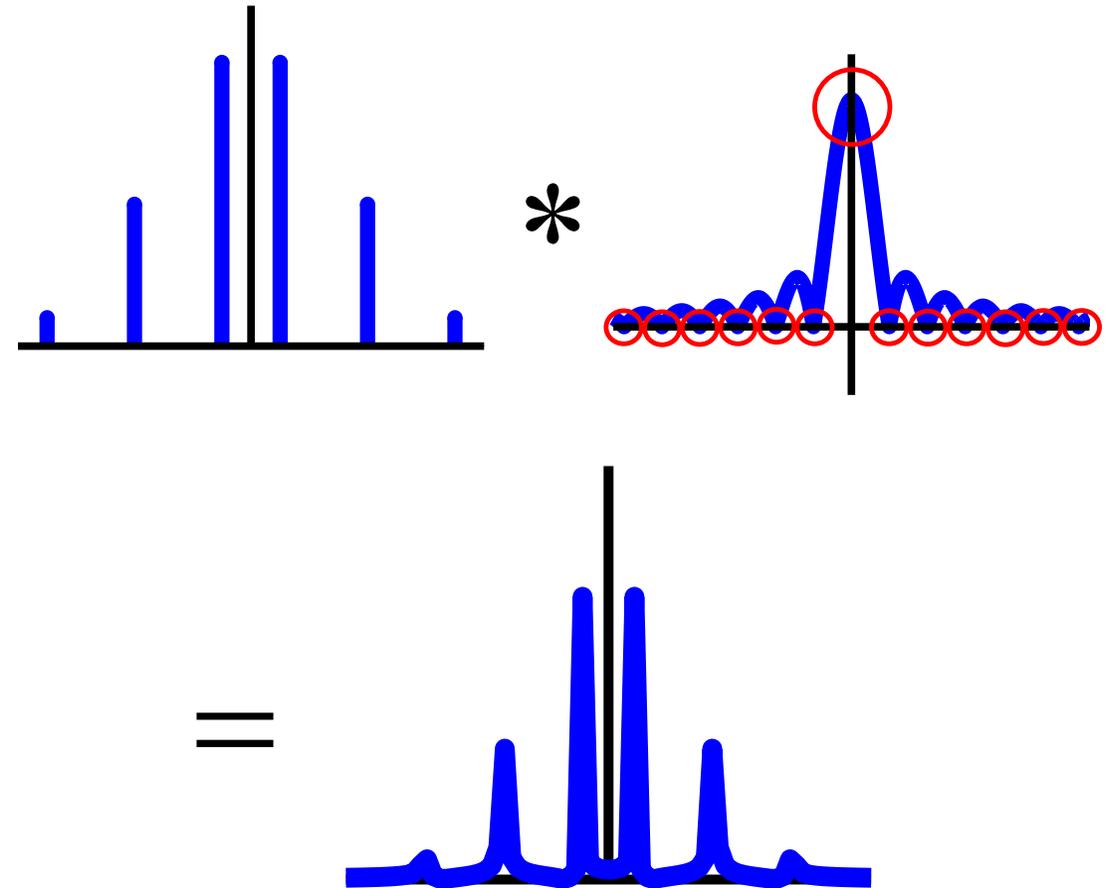
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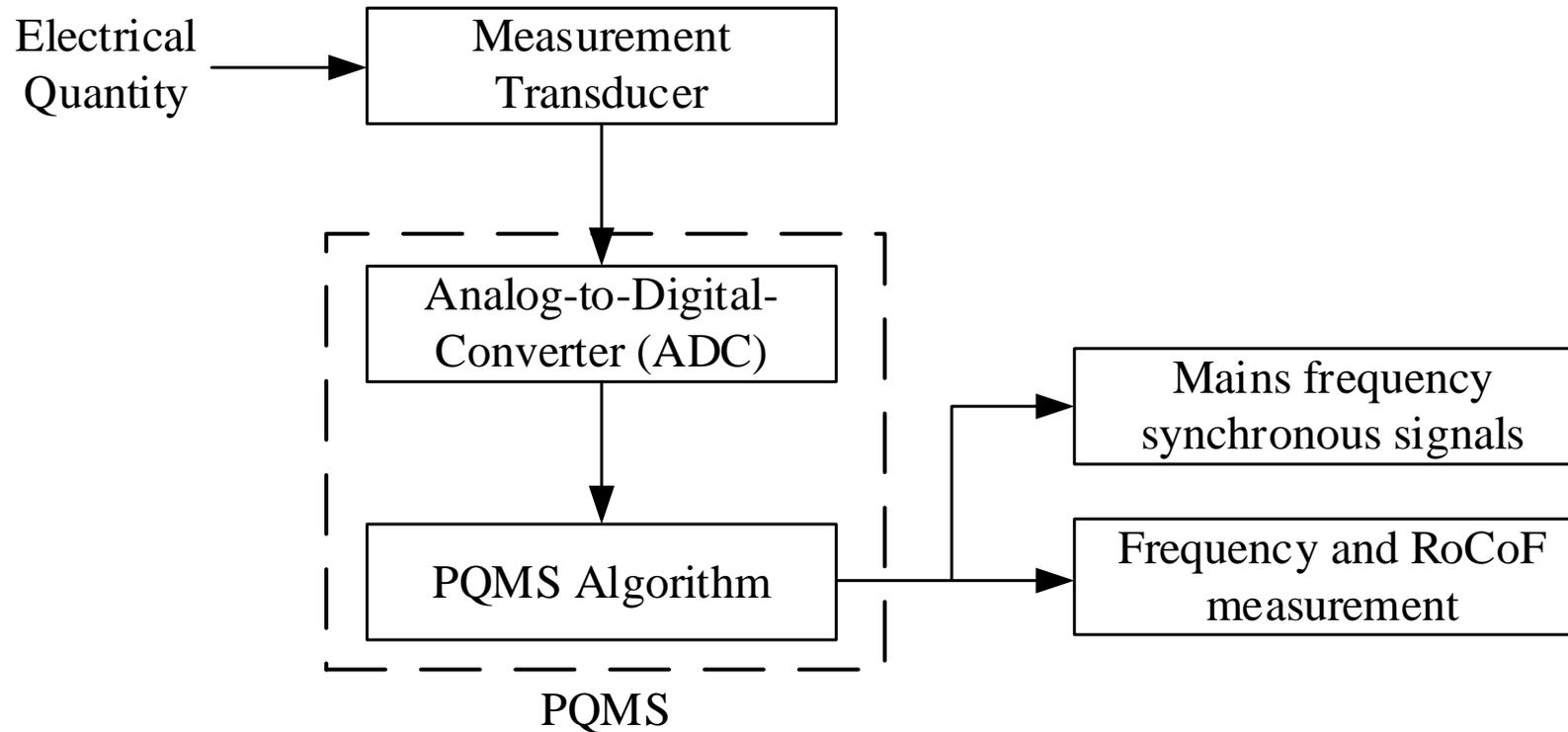
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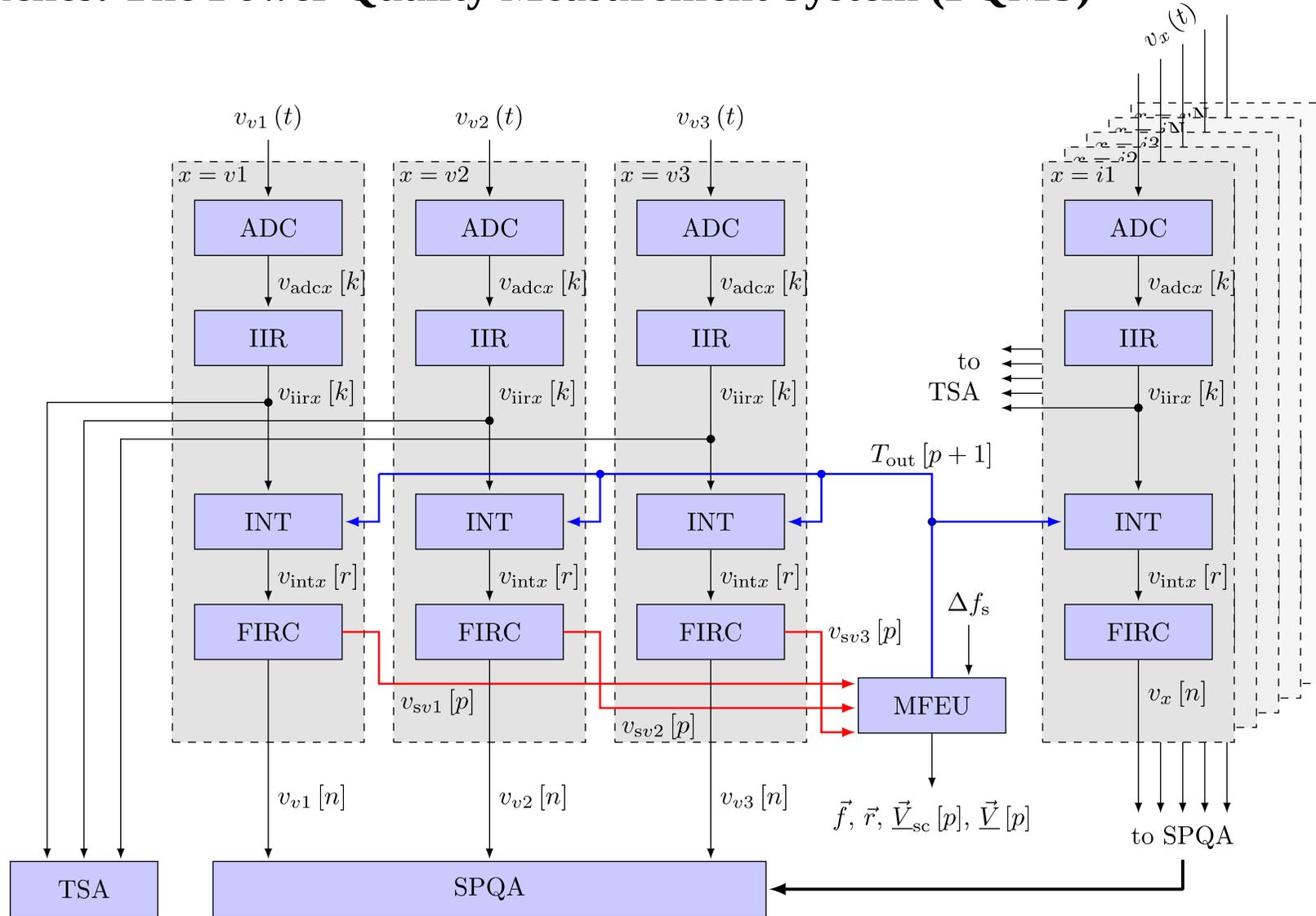
- Synchronization of T with notches in spectrum of rectangular window



New Approaches: The Power Quality Measurement System (PQMS)



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Measurements: Test Stand



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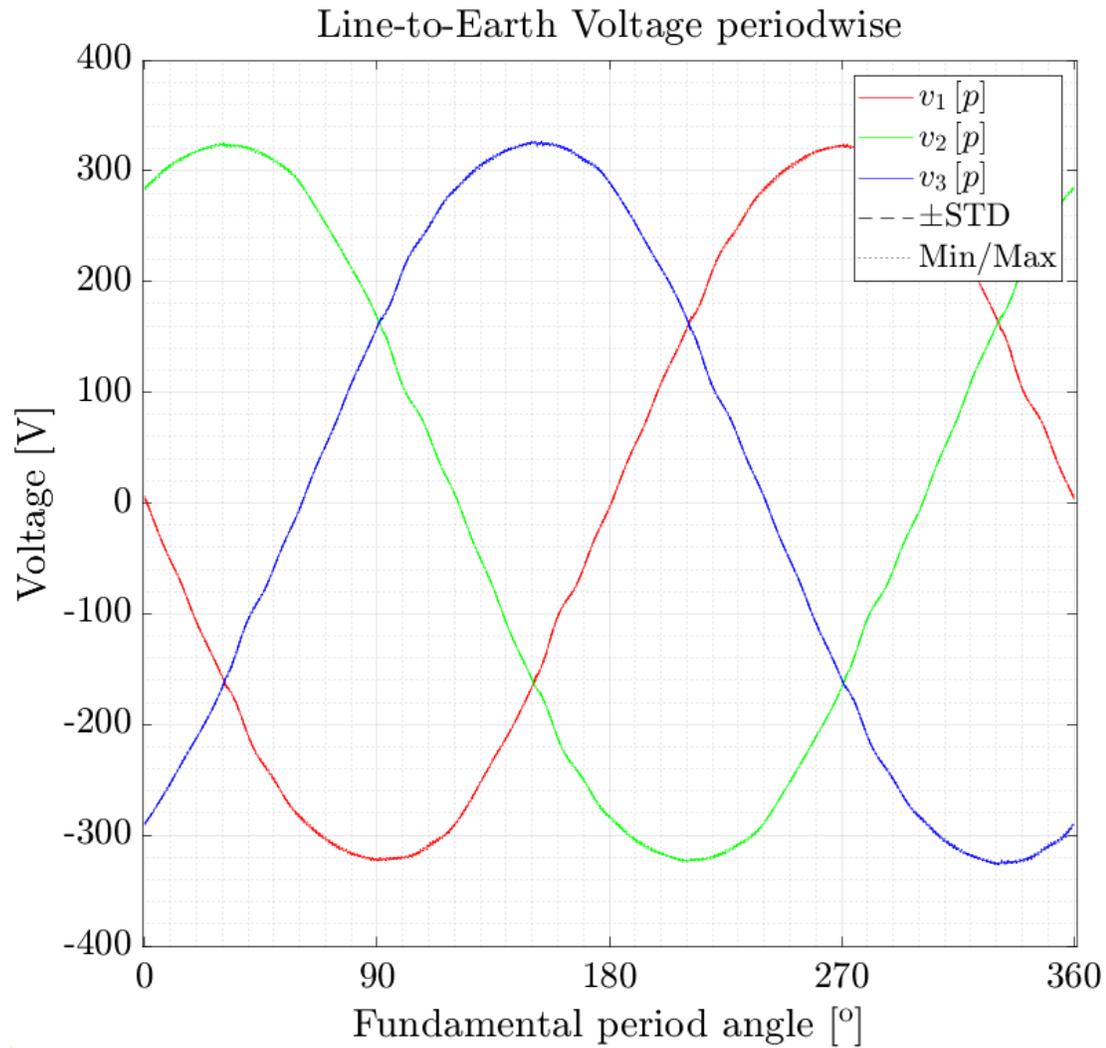


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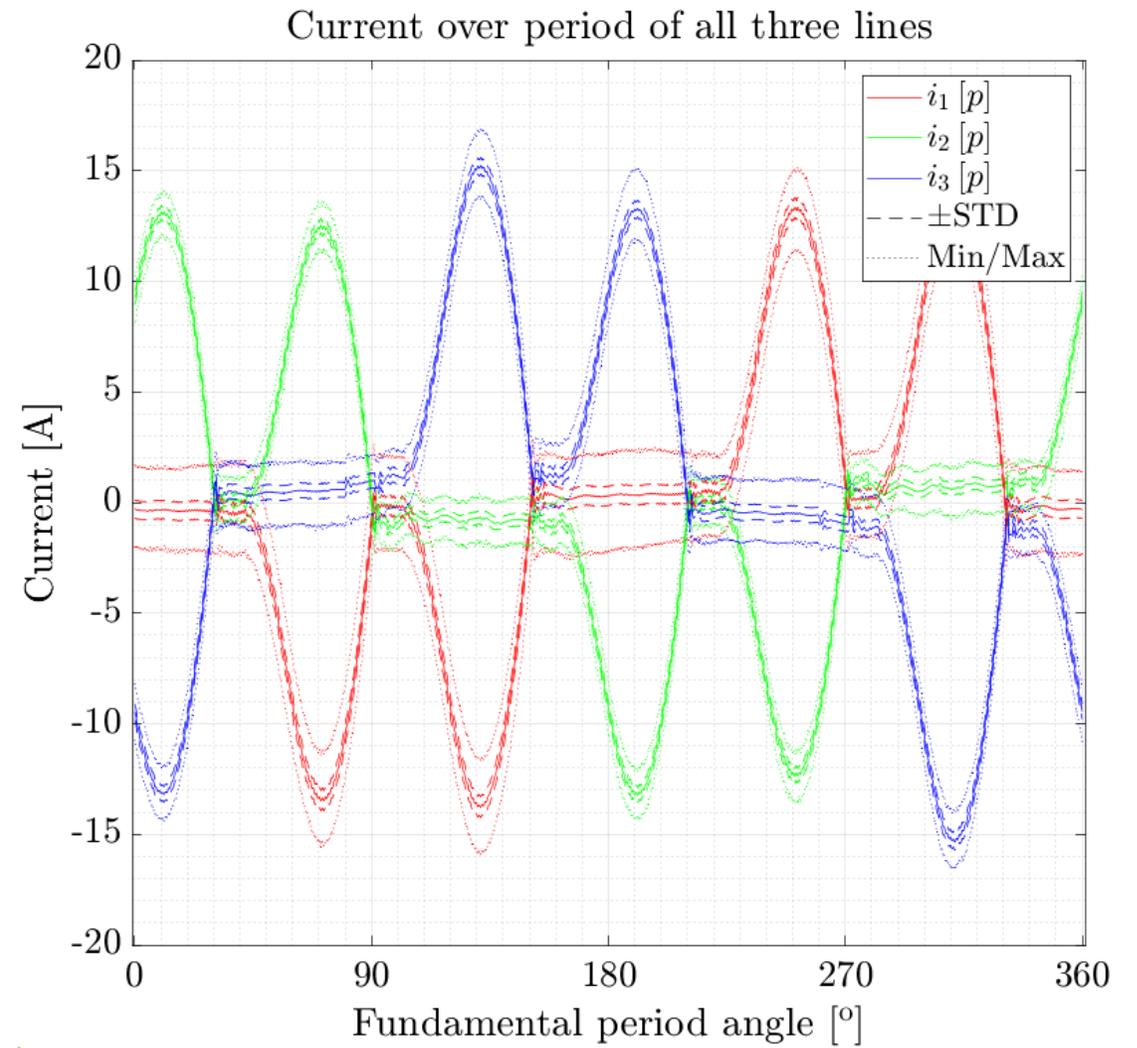
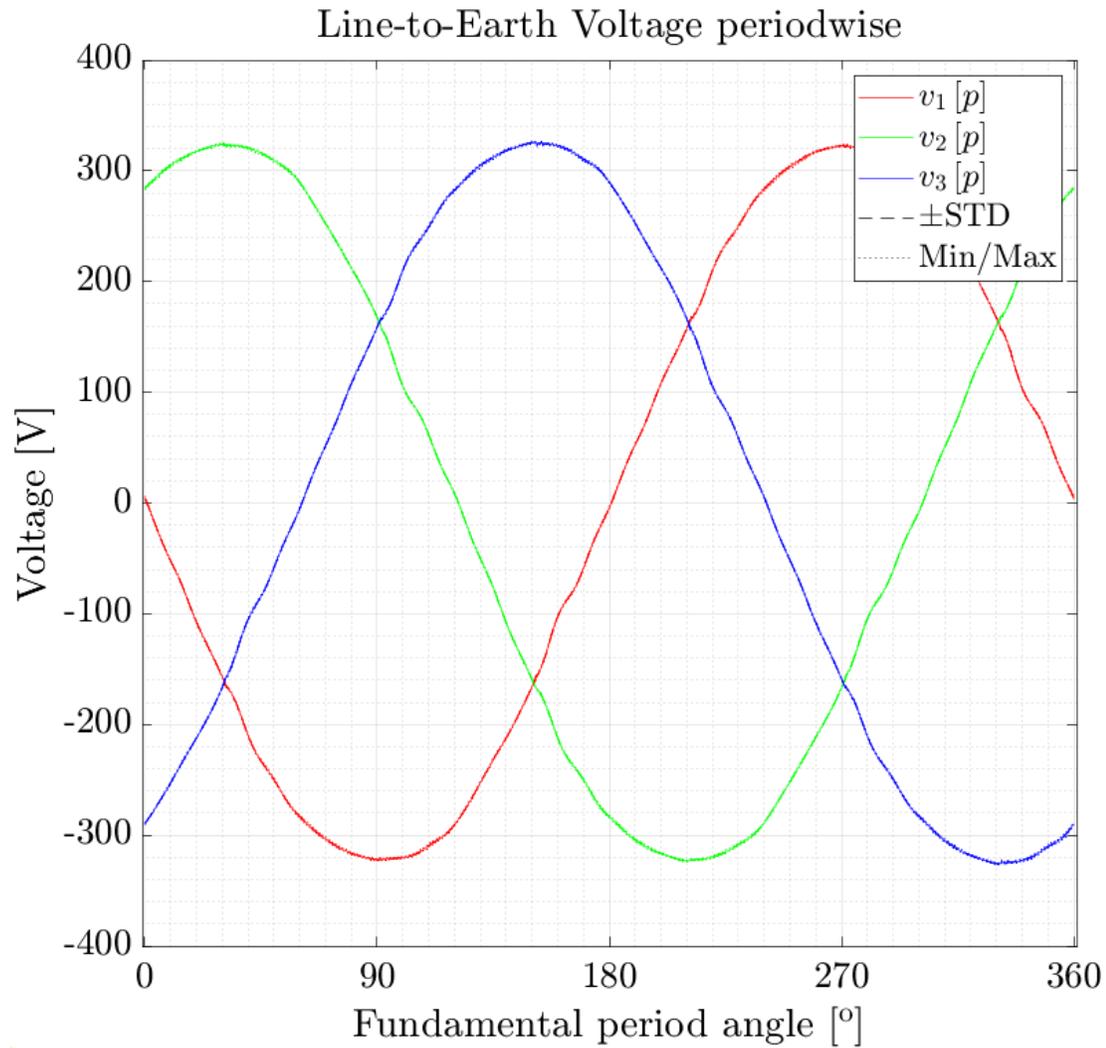


Measurements: Voltage and Current over time

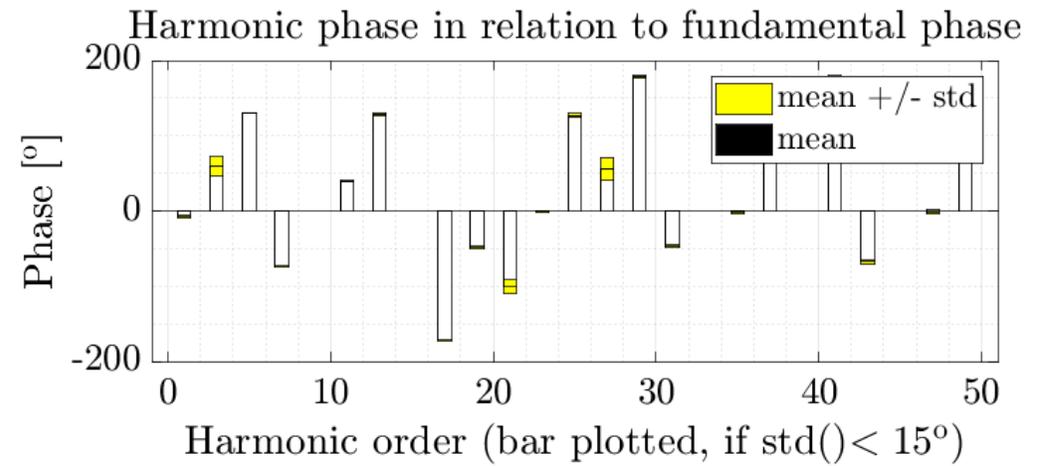
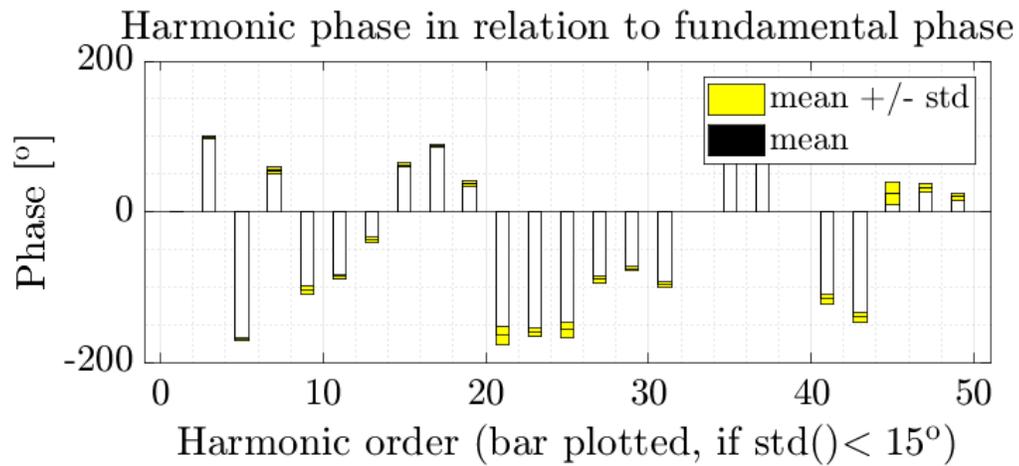
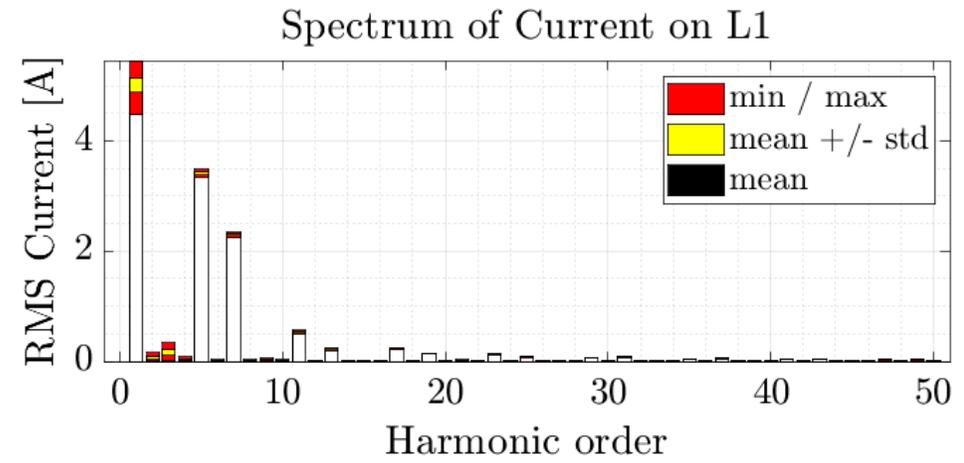
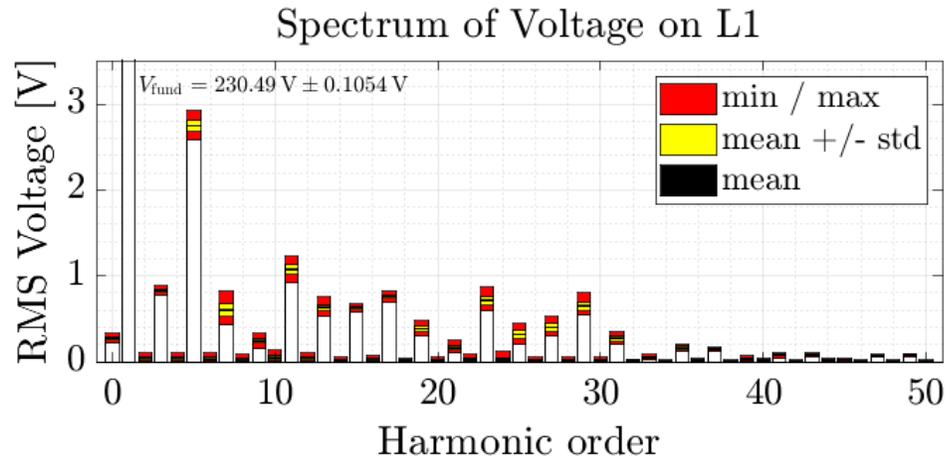
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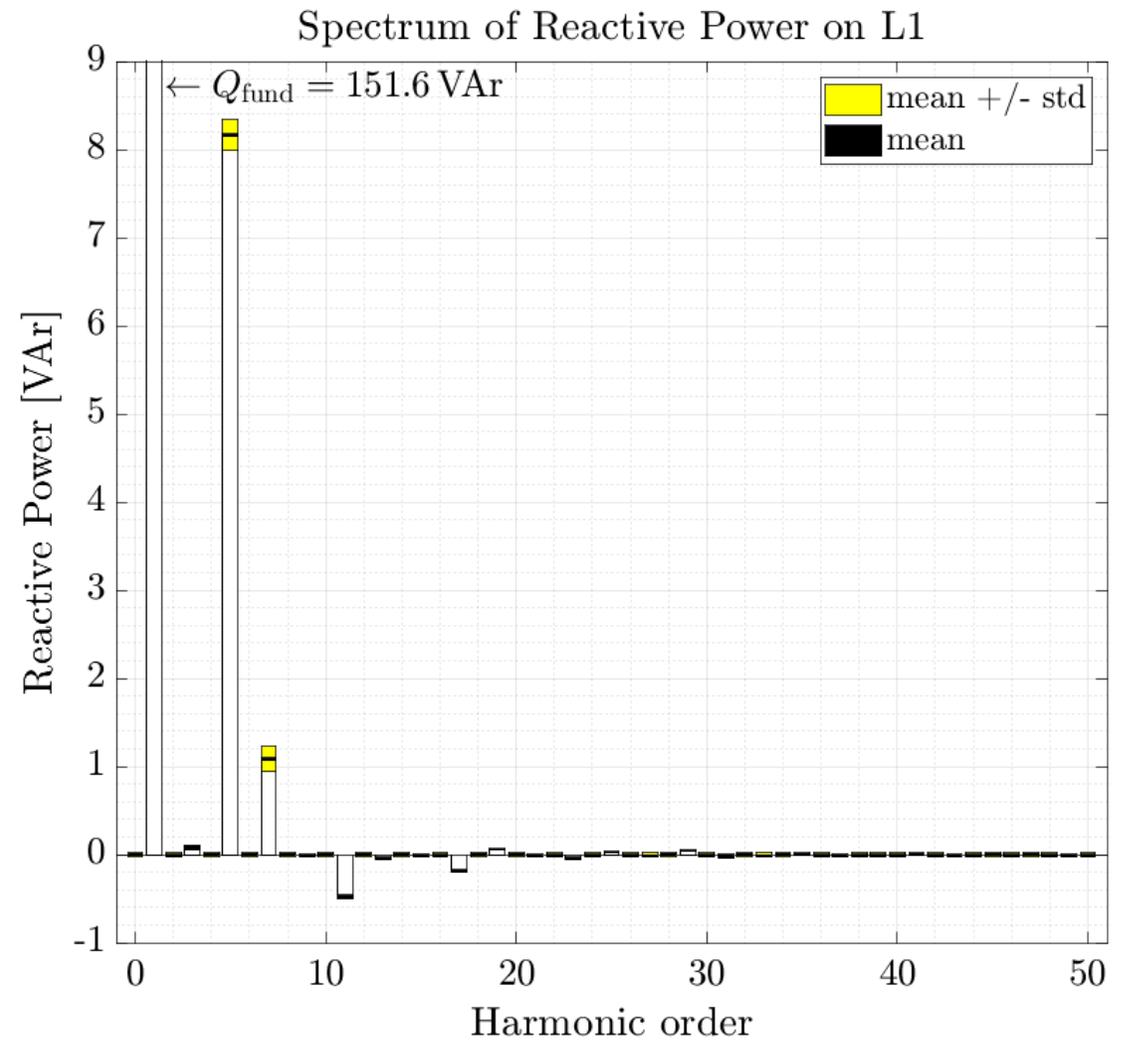
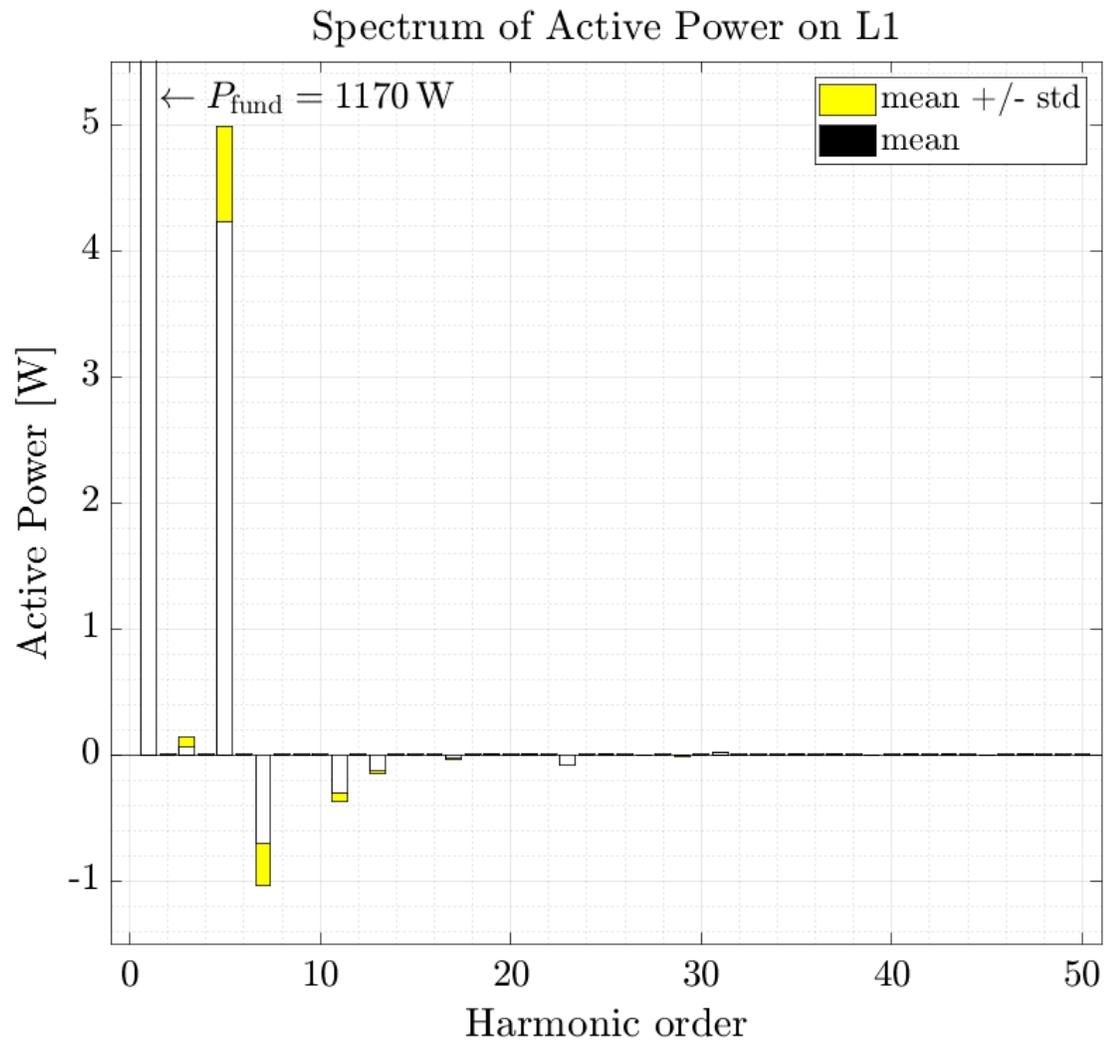
Measurements: Voltage and Current over time



Measurements: Spectrum of Voltage and Current



Measurements: Spectrum of Active and Reactive Power



References

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Thank you
for your attention!

Interessenverband
Netzimpedanz



2021