Compact representation of type-testing waveforms using wavelets

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Objective

- Define test waveforms for static meters
- Employ the real error-inducing waveform

Challenge

- High fidelity
- Suitability for publication as a normative type-approval test signals (few coefficients, simple definition)

Non-parametric approach

- Complementary to time-domain modelling
- Accurate representation of the measured signals
- Flexibility to adapt to different waveform shapes
- Signal parameters are not arbitrarily set (e.g. slope)

Frequency-domain description

Example (Water Pump)
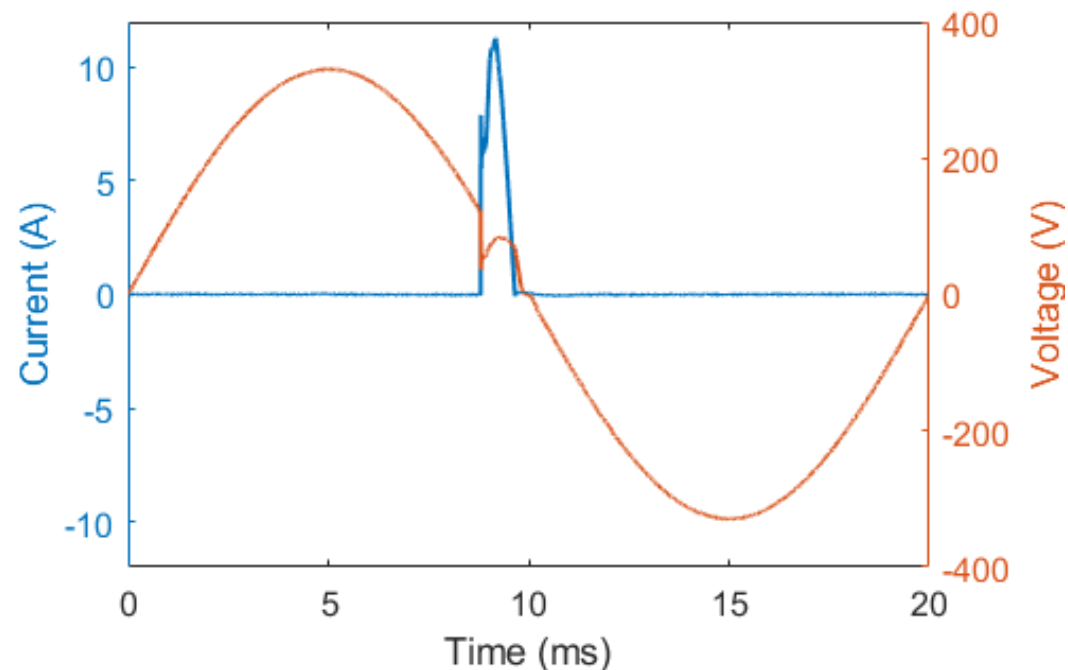
Acknowledgment: Waveform measured by University of Twente

DFT **Discrete Fourier Transform**

- Conventional tool for power systems signal analysis
- Suitable for periodic features (e.g. harmonics)

DWT **Discrete Wavelet Transform**

- Suitable for localized events
- Time resolution

Theory

DFT
Discrete Fourier Transform

- $Y = \sum$

- Basis functions: sinusoids
  - Infinite support
  - Perfectly periodic
  - Constant in amplitude
  - Stationary
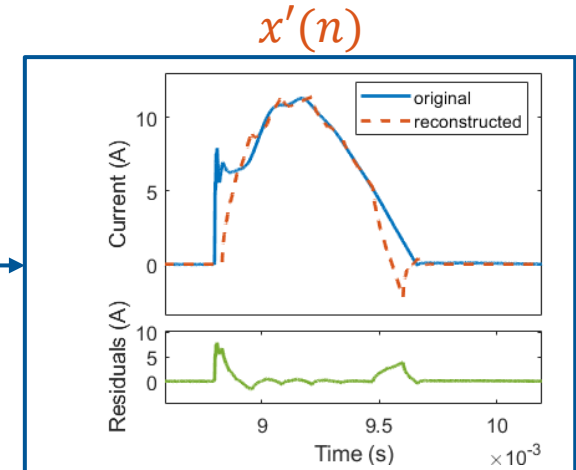
DWT
Discrete Wavelet Transform
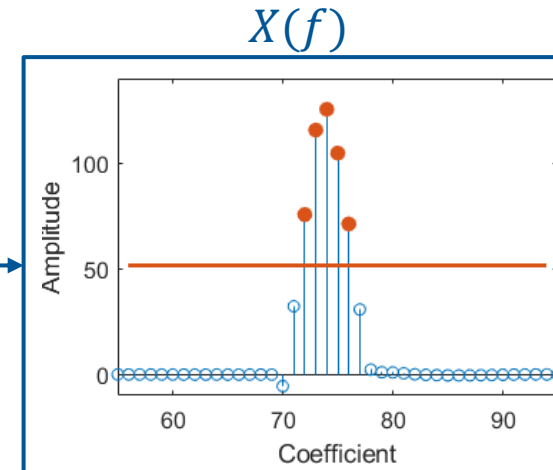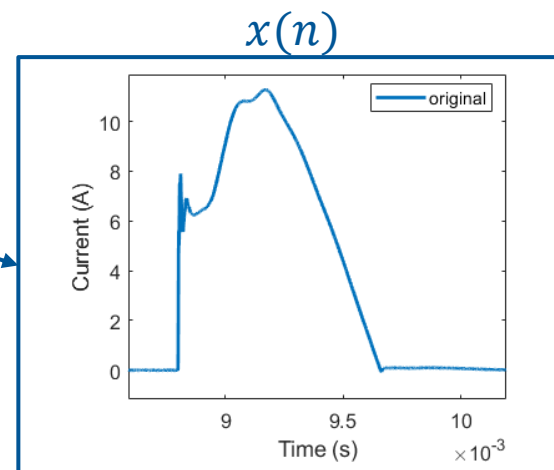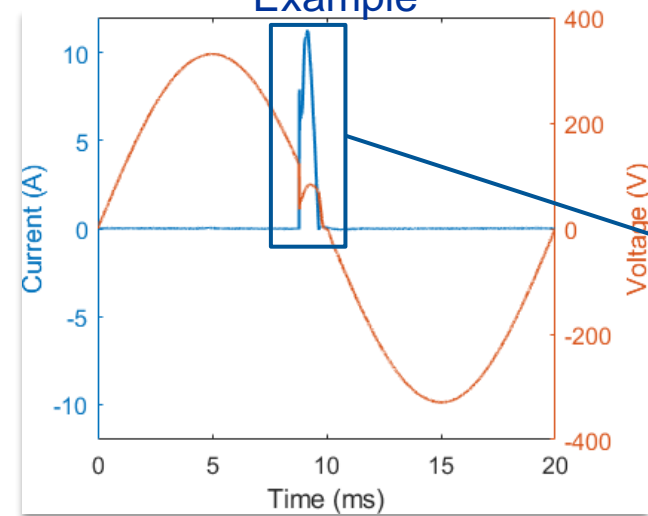
- $Y = \sum$

- Basis functions: wavelets
  - Finite support
  - Impulsive
  - Scaled and shifted
  - Temporal resolution

Method
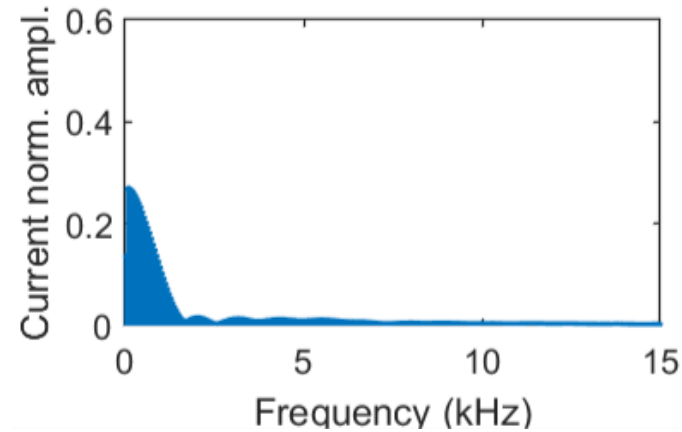
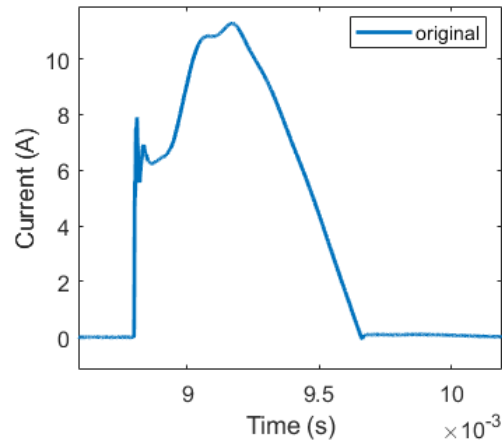## Strategy used for denoising, data compression, etc.

Example

$x(n)$ → **Transform** DFT / DWT → $X(f)$ → **Select m highest coefficients** → $X'(f)$ → **Inverse transform** IDFT / IDWT → $x'(n)$

$x(n)$

$X(f)$

$x'(n)$

Max of the residuals (%) metrics for accuracy of reconstruction
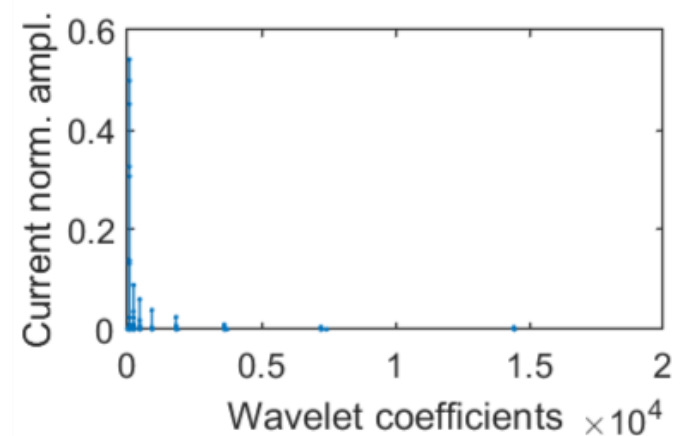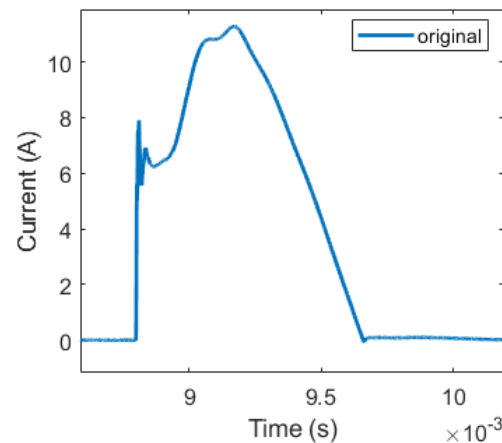
Method

Sparsity of the representation

DFT

- Many coefficients with low amplitude
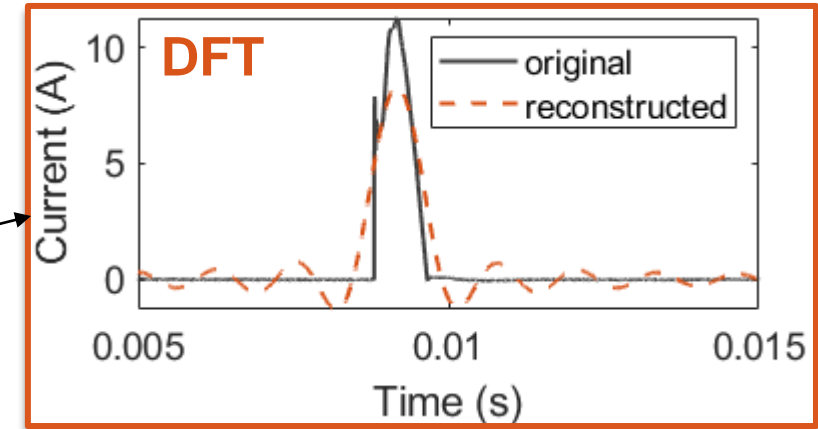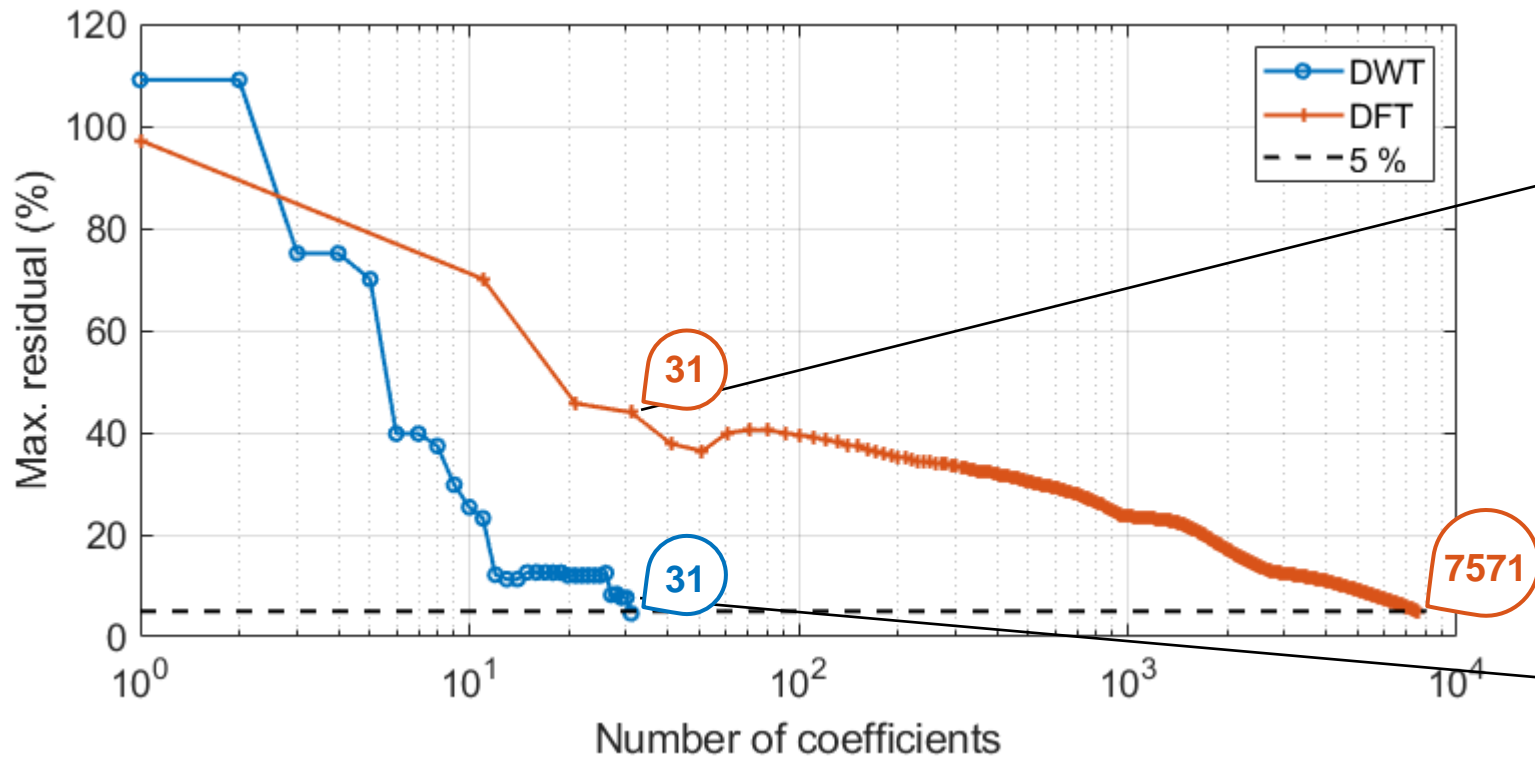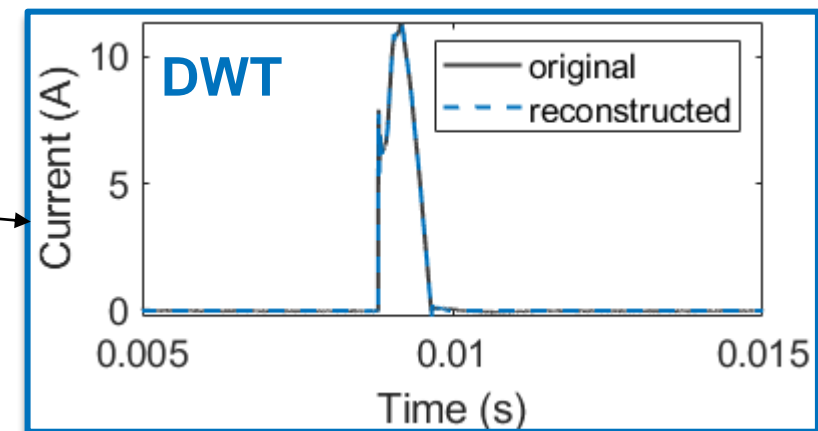- Signal energy is spread

DWT

- Few coefficients with high amplitude
- Signal energy is concentrated
- Sparse representation

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Method

Number of coefficients needed for accurate reconstruction

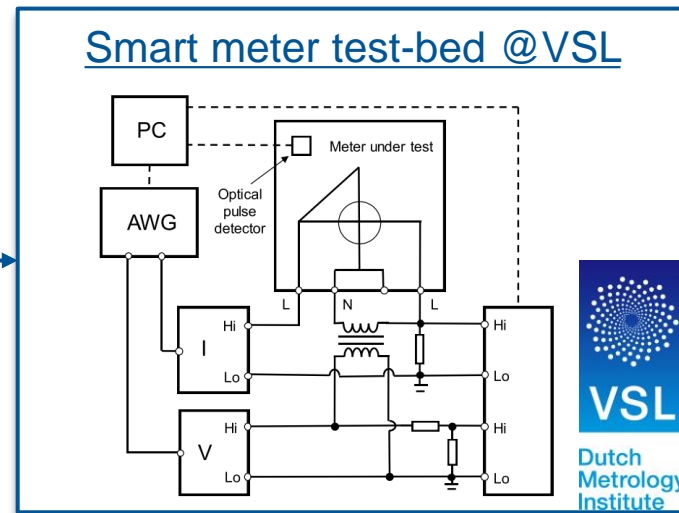Max. residual = 44 %

Max. residual = 4.6 %

Experimental analysis

Verification: does the sparse DWT-representation preserve error-inducing features?

<u>Tested waveforms:</u>

1 cycle at 1MS/s – 20k samples

- ▪ Original
- ▪ Reconstruction from:
  - • 100 coefficients
  - • 50 coefficients
  - • 20 coefficients
  - • 10 coefficients

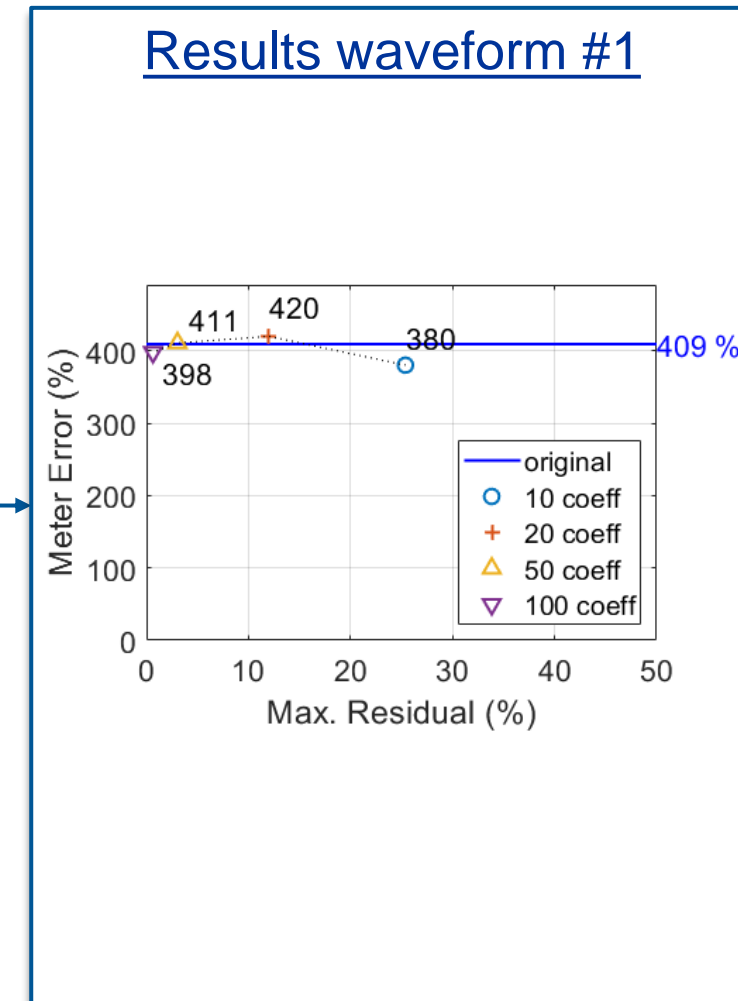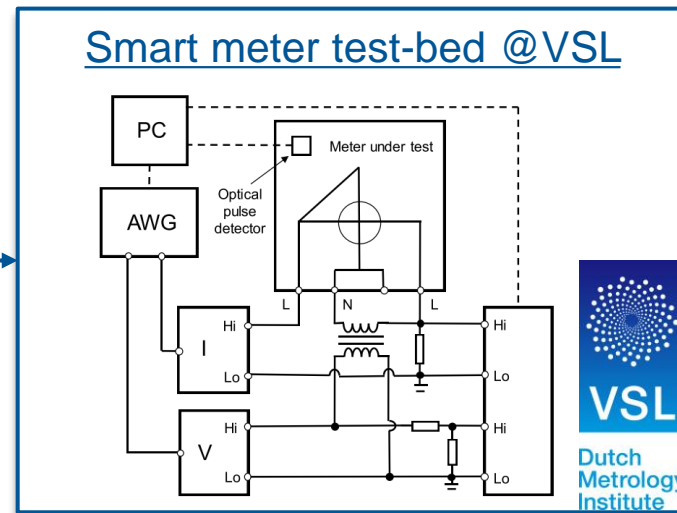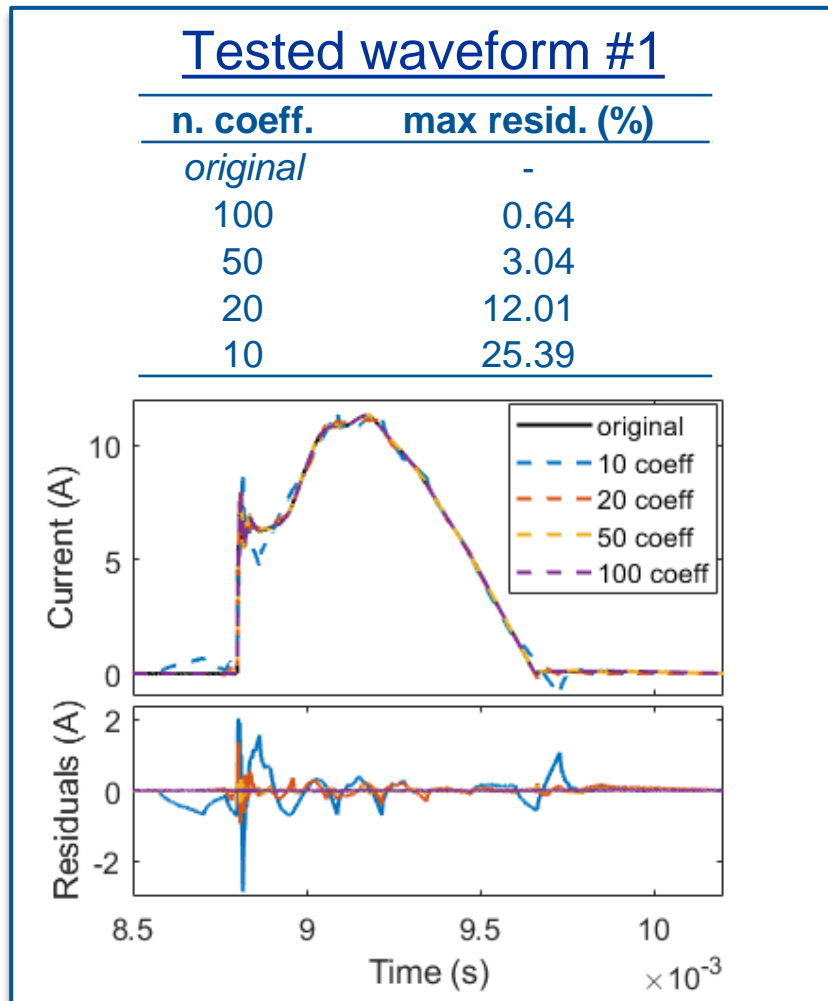<u>Smart meter test-bed @VSL</u>

*Arbitrary waveform-based rig
for meter testing (11.20h CET)*

<u>Comparison of obtained
errors</u>

Experimental analysis

Verification: does the sparse DWT-representation preserve error-inducing features?

Tested waveform #1

n. coeff.	max resid. (%)
original	-
100	0.64
50	3.04
20	12.01
10	25.39

Smart meter test-bed @VSL

VSL
Dutch
Metrology
Institute

Results waveform #1
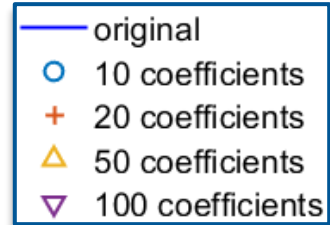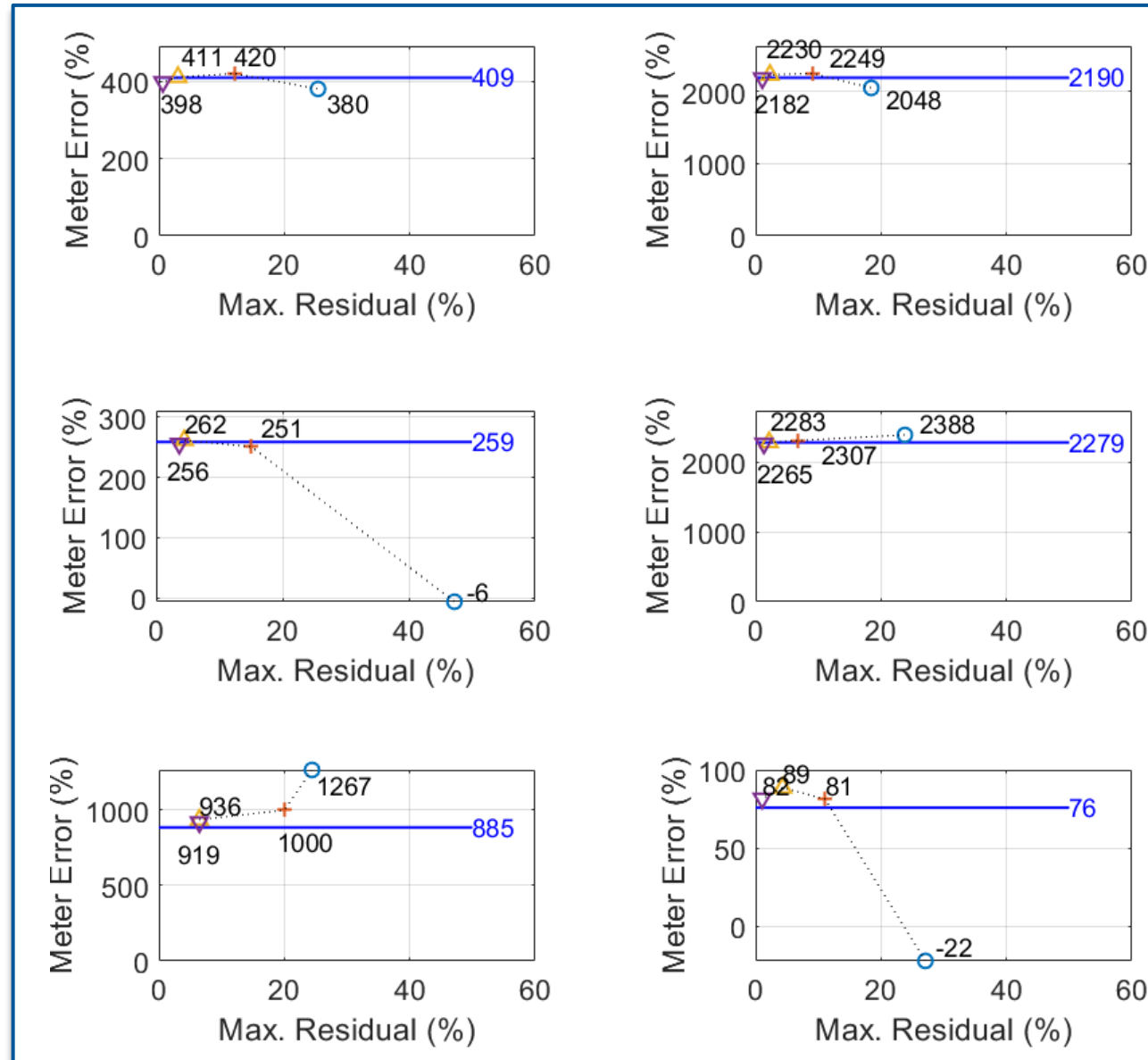
Experimental analysis

6 different waveforms

- Max. residuals less than 20% is acceptable

- 10 coefficients is unsatisfactory

- Error inducing features can be preserved with ~20 coefficients = 0.1% of all coefficients

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Conclusion

Summary

- DFT is unsuitable to represent impulsive waveforms

- DWT is an effective strategy for a sparse representation of current waveforms that induce errors in smart meters

- Few coefficients (tens) are sufficient to preserve error-inducing features

Outcome

- 'Toolbox' of new test waveforms based on measured signals

  - Simple, practical method for reconstruction from wavelet coefficients

Thank You for Your Attention