VSL

National Metrology Institute

EMPIR EURAMET

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DC Grids

On-site measurements in LVDC grids

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20NRM03 DC grids final workshop
16 May 2024, VSL, Delft, NL

20NRM03 DC grids project

AIM: traceable measurement and characterization of PQ parameters to support standardization in further development and deployment of DC grids.

- New **on-site instrumentation** for DC distortions
- Onsite **measurement campaigns** in LVDC grids

- New **definitions of DCPQ** phenomena
- New **analysis algorithms** to categorize DCPQ

- **Traceability** for DC power and DCPQ parameters
- **New reference systems** for DC PQ and DC metering

- New **PQ severity indices** for DC grids
- New **methodologies for PQ level surveys** in DC grids

VSL waveform recorder

- Designed for on-site measurements at metered supply points
- DC waveform recorder:
  - Adapted 3-phase *V* & *I* recorder for 50 Hz
  - Minicomputer with dedicated software
  - 8-channel, 12-bit, 1 MSa/s digitizer (Picoscope 4824)
  - 2000 V, 1:1000, 1.0 %, 10 MHz voltage probe (Hioki 9322)
  - Openable 200 A, 10 mV/A, 0.3 %, 500 kHz current probe (Hioki CT6843-05)
  - Pass-through 50 A, 40 mV/A, 0.03 %, 1 MHz current probe (Hioki CT6862-05)

$$U_{DC} = \frac{1}{n}\sum_{i=0}^{n-1} u_i \qquad U_{rms} = \sqrt{\frac{1}{n}\sum_{i=0}^{n-1} u_i^2}$$

$$U_{rpl} = \sqrt{U_{rms}^2 - U_{DC}^2}$$

Lelystad Airport (NL)

- Lelystad airport business park
- 750 V unipolar voltage
- Non-configurable grid
- Only streetlights connected
- Operated by Alliander & Dynniq

- 12 hours of gapless 1-second windows (1 MSa/s)
- Current ripple ~15 %

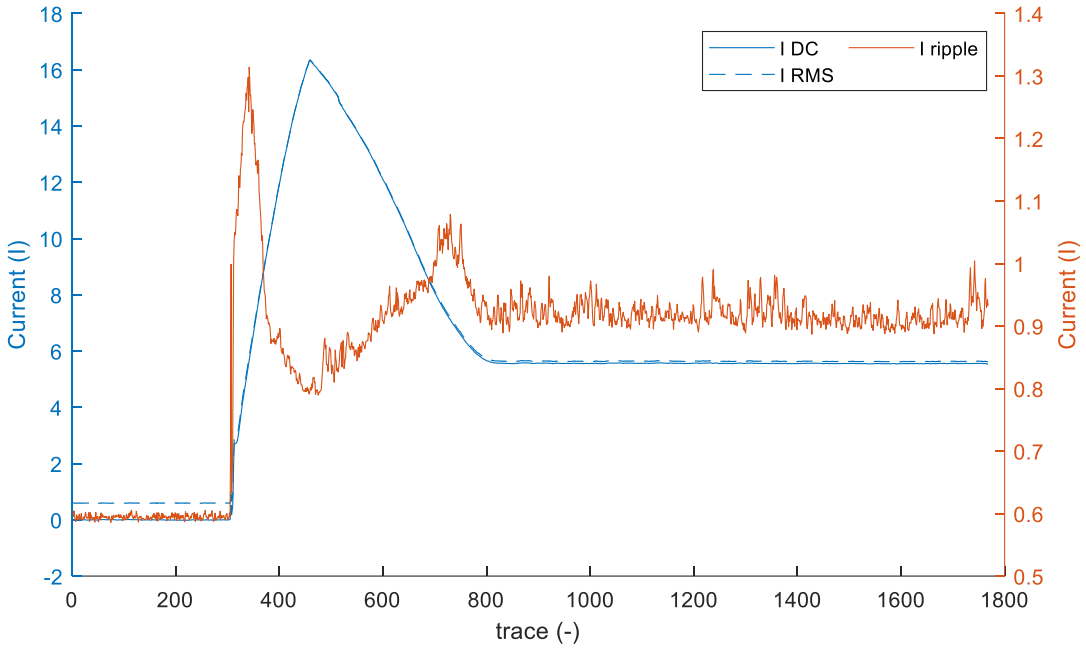
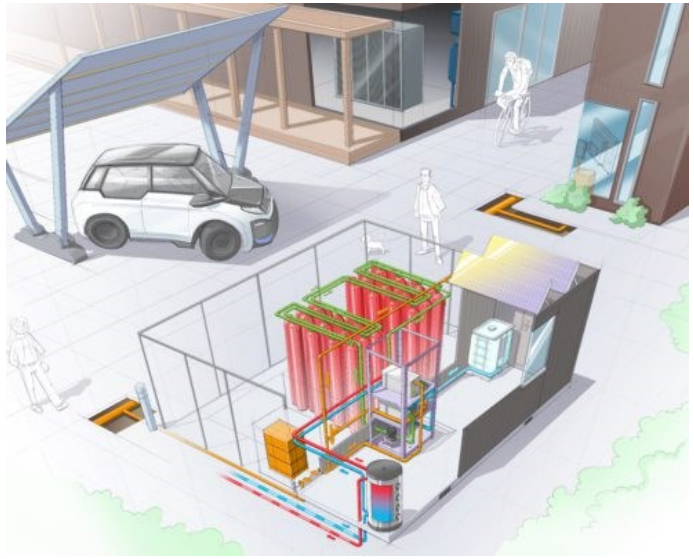
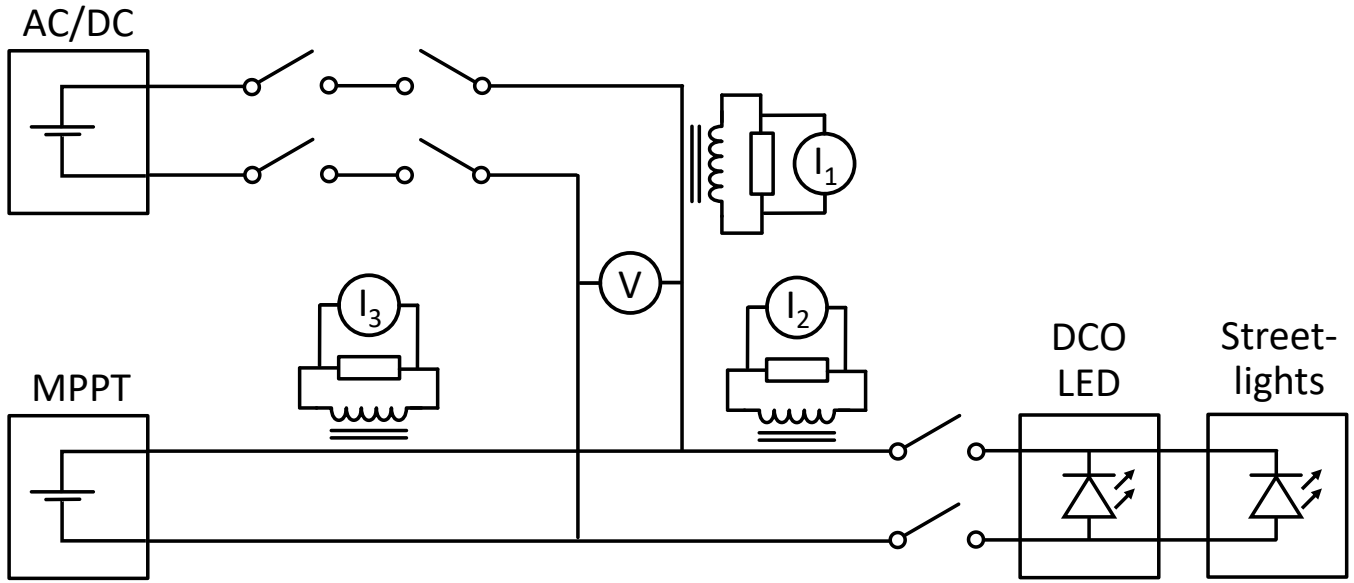


Figure: DC current (left axis) and ripple (right)

The Green Village, Delft (NL)

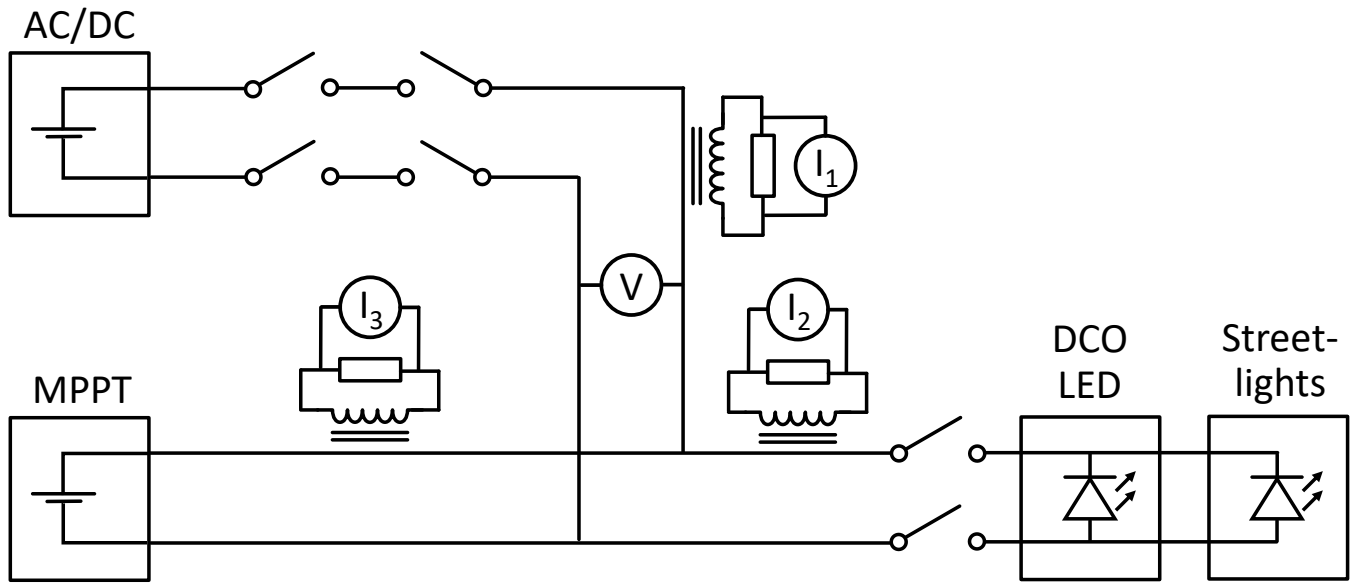




- Configurable grid in urban environment
- 350 V bipolar voltage
- Grid-connected (bidirectional) or islanding mode
- Operated by DC Opportunities

The Green Village, Delft (NL)

- About 1 hour of measurements of gapless 2-second windows (500 kSa/s)
- Heavily cloudy day, December 2022
- Measured different situations, e.g.
  - Grid-connected or islanding
  - PV/MPPT feeding the grid
  - Connected/disconnected streetlights
  - Dimmed DCO LED



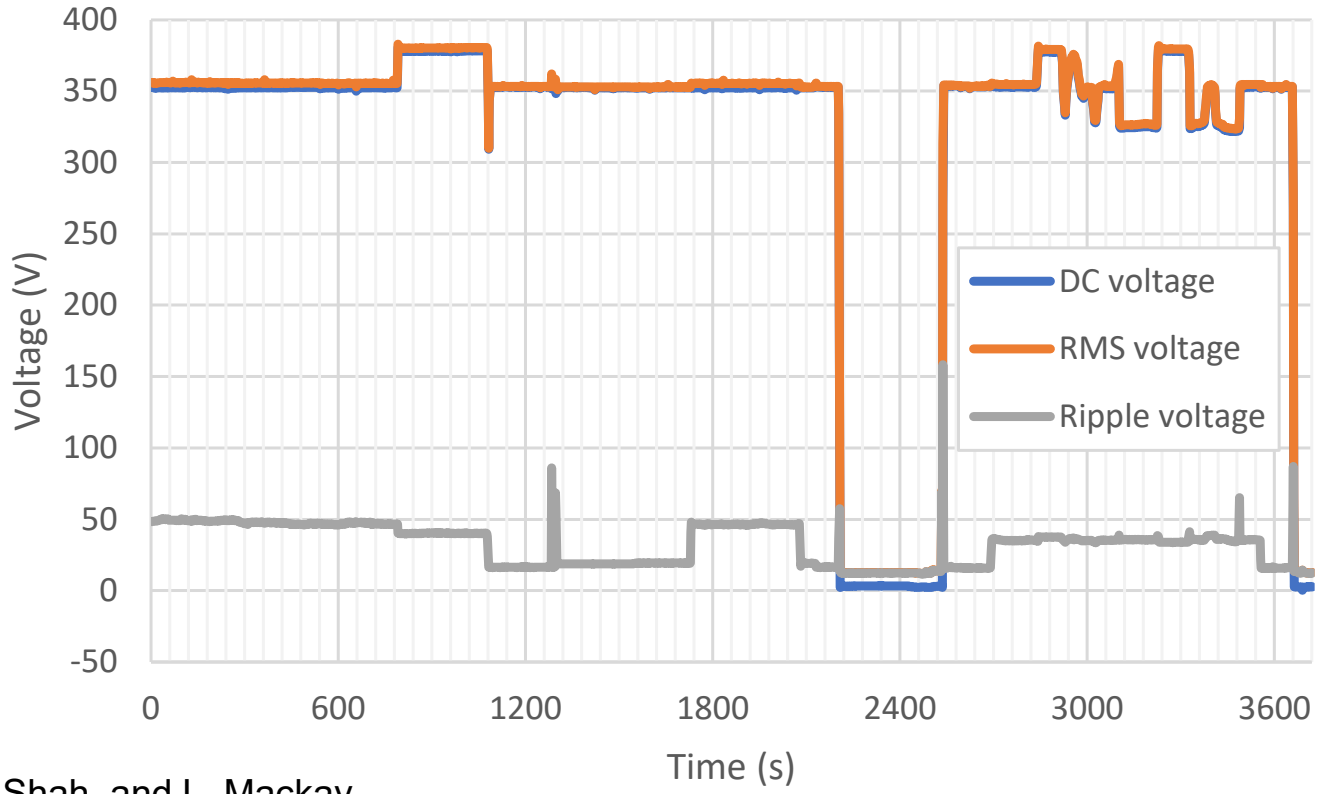
H.E. van den Brom, R. van Leeuwen, G. Maroulis, S. Shah, and L. Mackay, "Power Quality Measurement Results for a Configurable Urban Low-Voltage DC Microgrid", Energies 2023, Vol. 16, p. 4623

The Green Village: voltage

- Voltage samples averaged over 2-second windows

- DC voltage 325 V to 380 V
- Ripple ~ 13 V to 50 V
  - Might be due to large bandwidth

$$U_{rpl} = \sqrt{U_{rms}^2 - U_{DC}^2}$$



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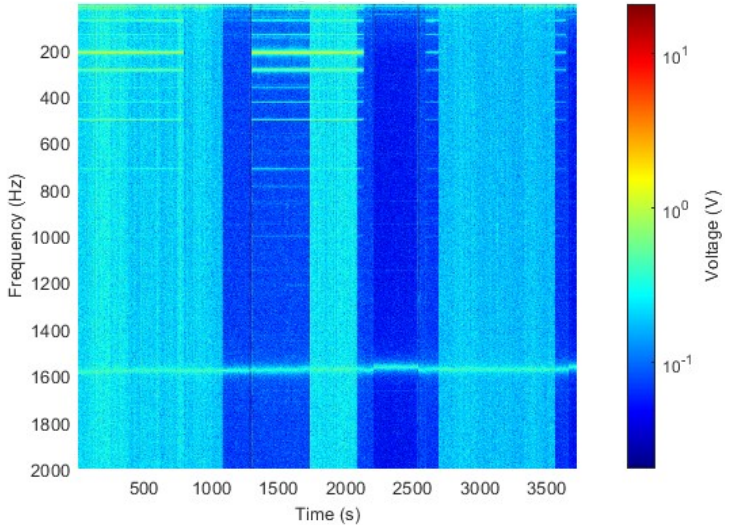
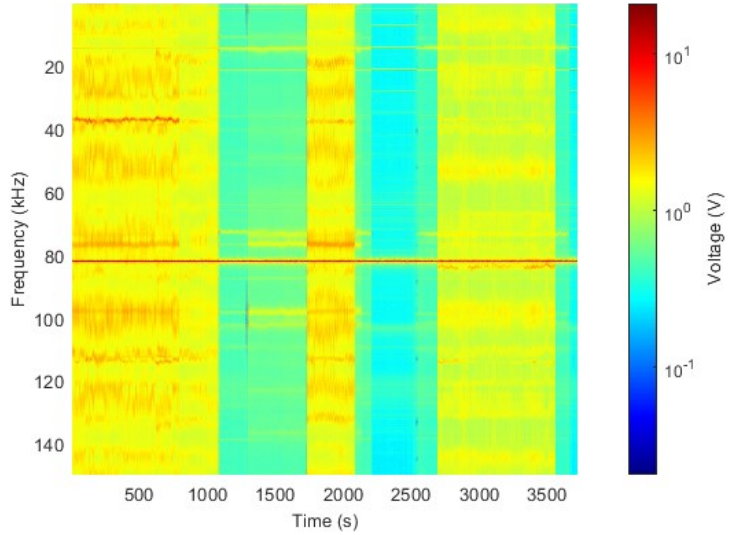
The Green Village: voltage

- Fourier Transforms of voltage samples
  - 5 Hz resolution up to 2 kHz
  - 200 Hz resolution up to 150 kHz

- Background noise changes with configuration
- Spectral components:
  - Clear peaks at 75 Hz, 210 Hz, 290 Hz
  - Persistent peaks at 1.6 kHz and 82 kHz





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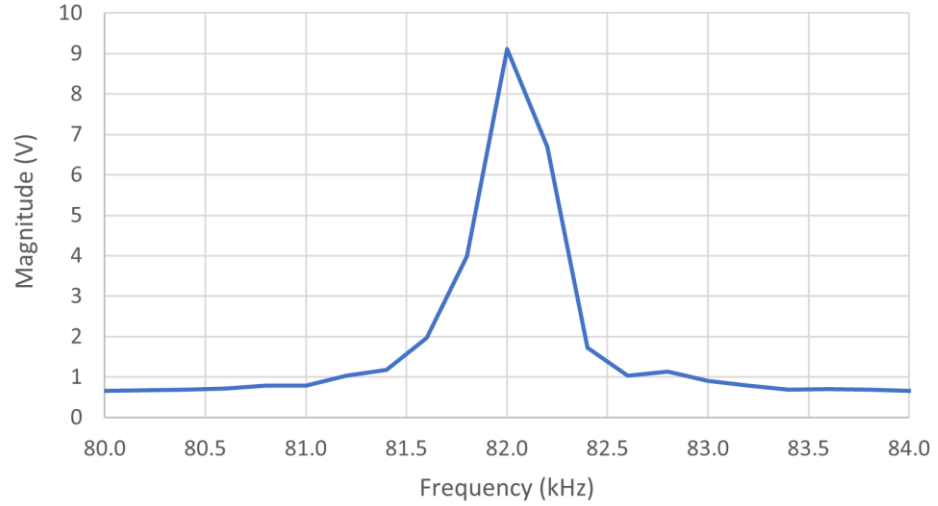
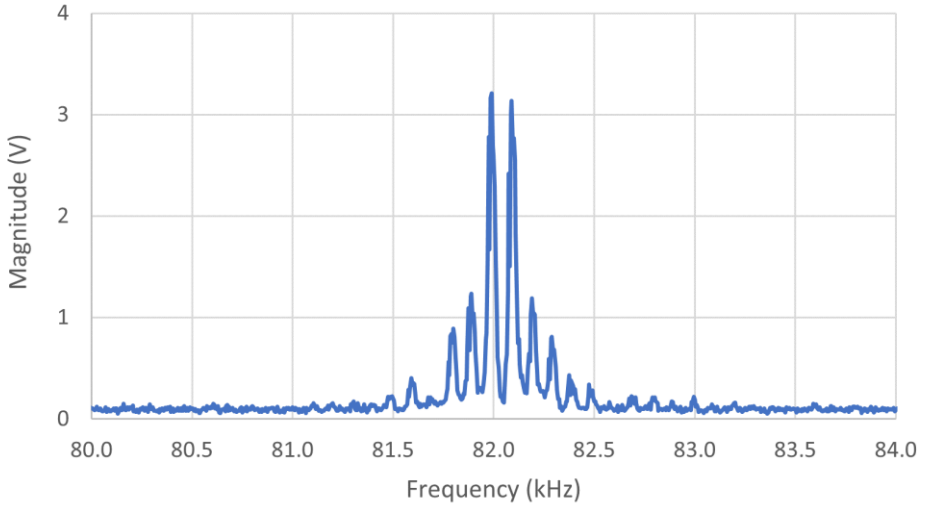
The Green Village: spectrum

- Single frequency component of 82 kHz with a resolution of 200 Hz
  - 9.0 V amplitude



- Multiple frequency components around 82 kHz with a resolution of 5 Hz
  - 3.2 V maximum



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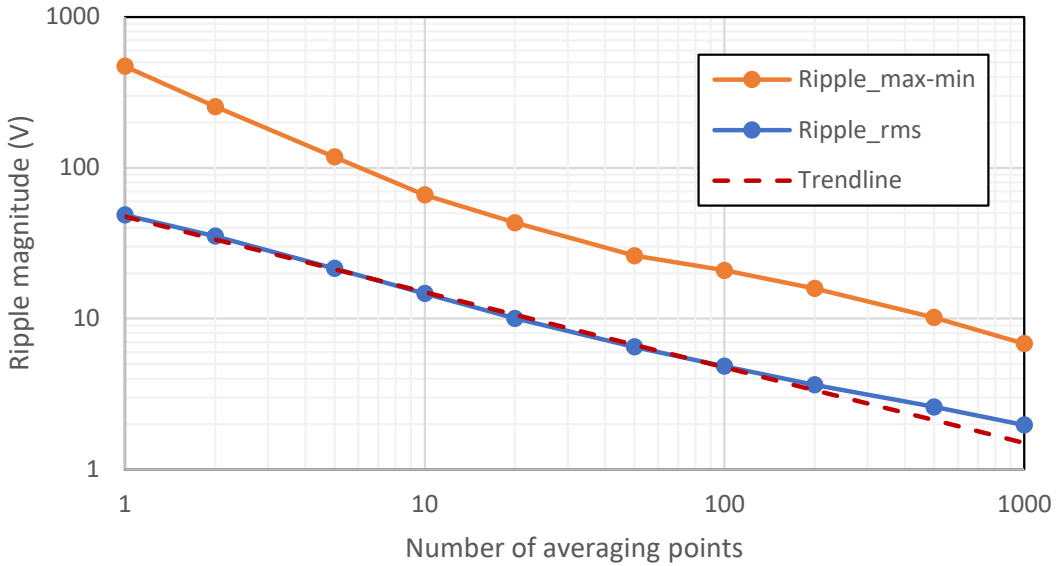
The Green Village: sampling rate

- Reducing the sampling rate: averaging *N* successive samples
  - Ripple content scales with $1/\sqrt{N}$

→ Reducing bandwidth reduces the ripple content



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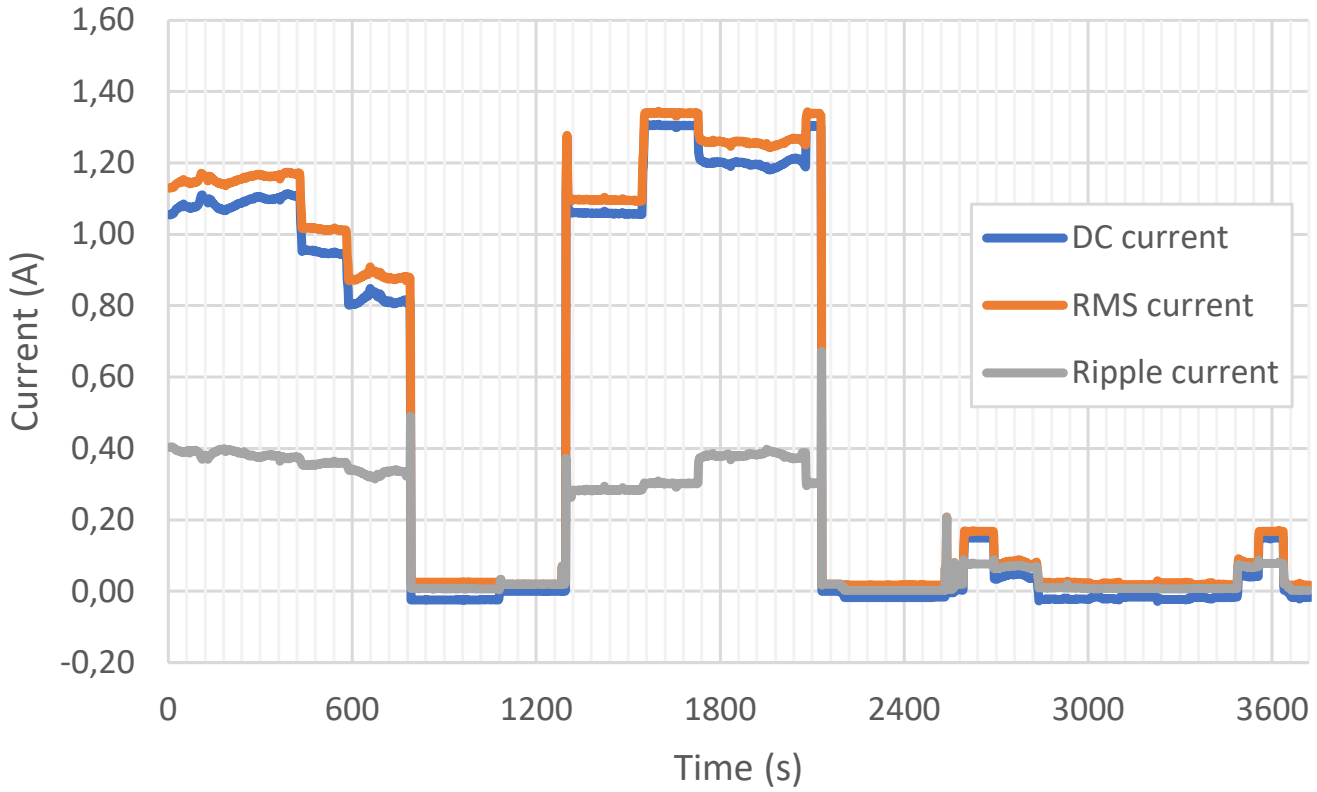
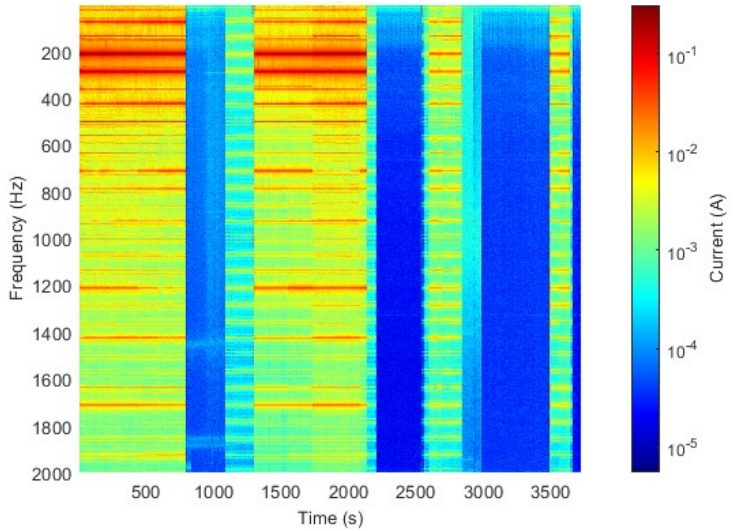
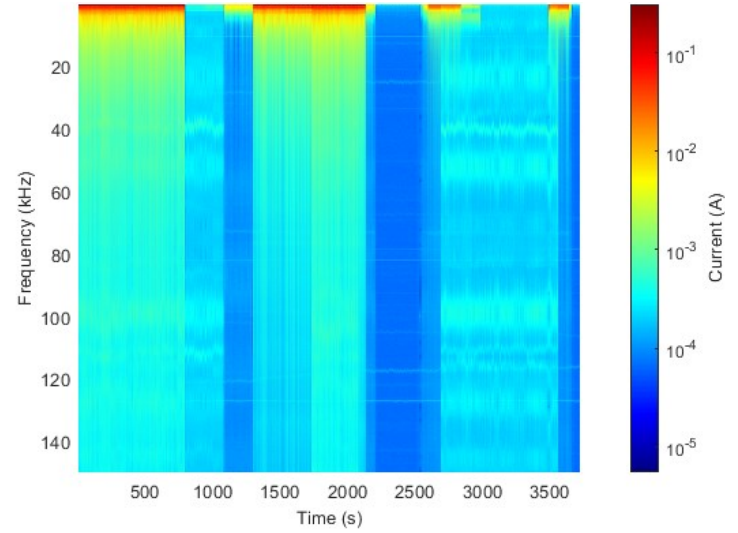
The Green Village: current

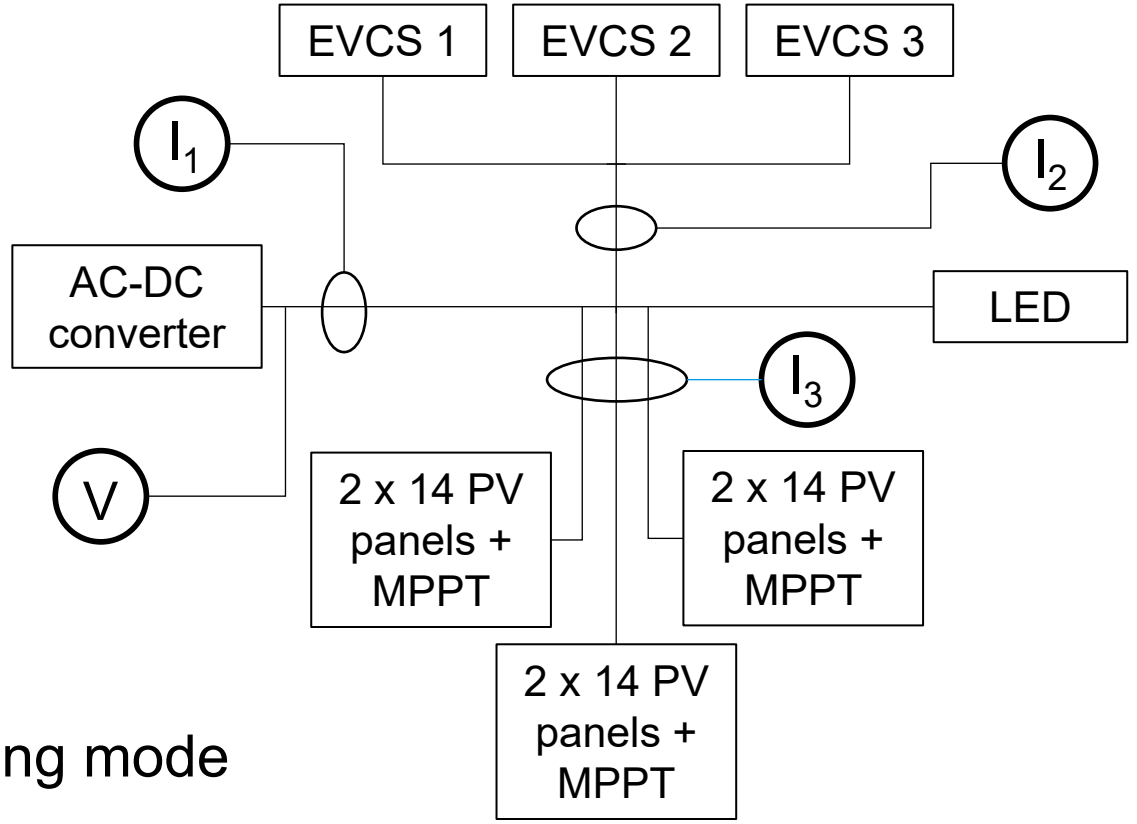
- Current samples averaged over 2-second windows
- Significant ripple up to 30 % of DC value
- Many LF spectral components, no persistent peaks







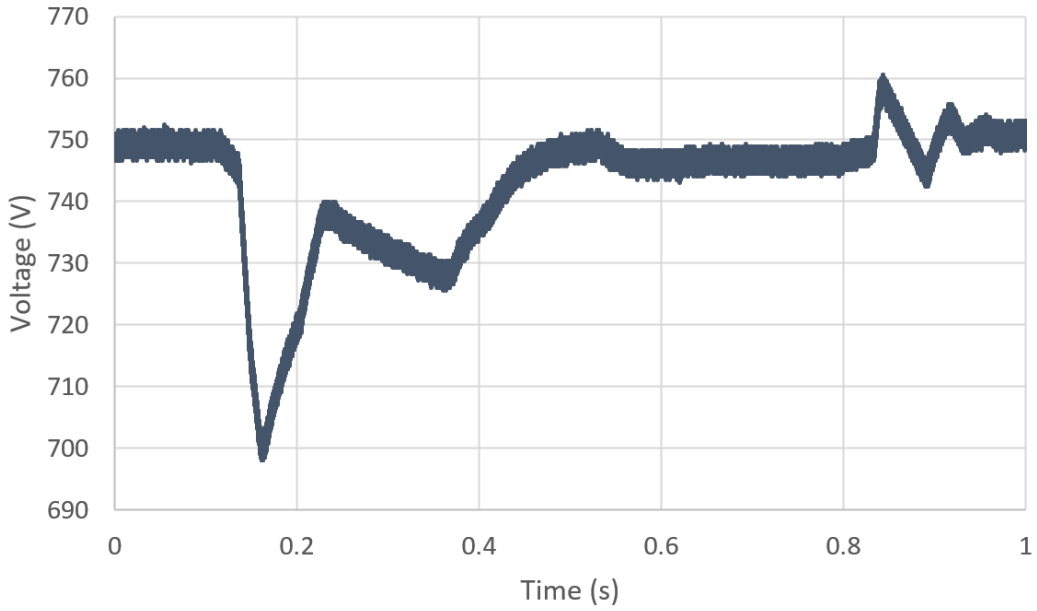
ASR building, Utrecht (NL)



- Operated by HvA & Kropman
- Open parking garage
- 700 V unipolar voltage
- Grid-connected (bidirectional) or islanding mode

ASR building, Utrecht (NL)

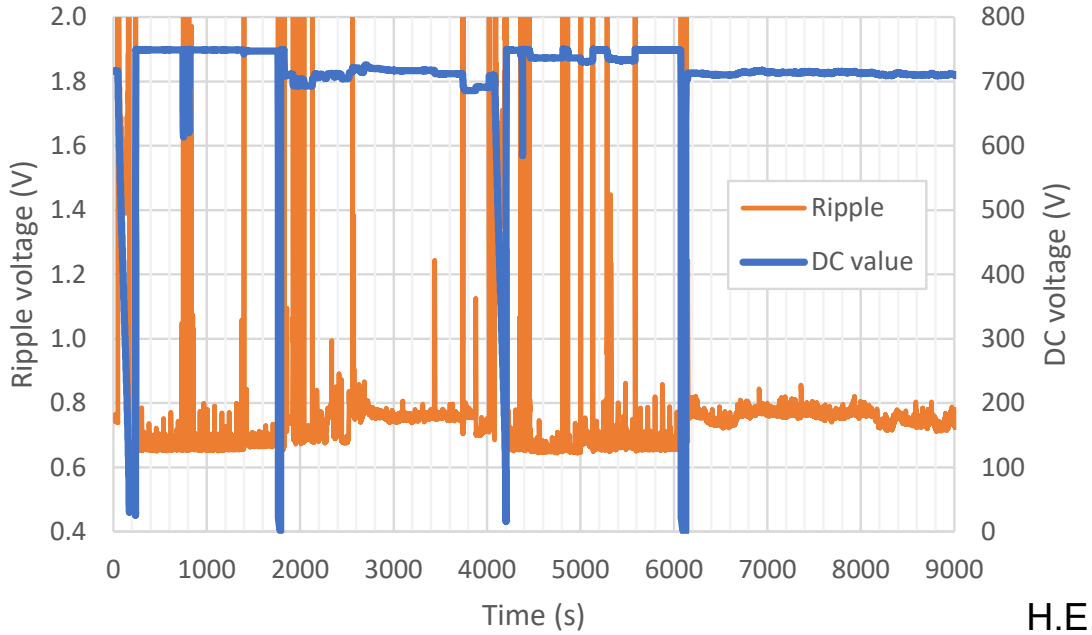
- About 2.5 hours of measurements of gapless 1-second time windows, 1 MSa/s
- Partially cloudy day with sunshine, afternoon in September 2023
- Reduced voltage bandwidth to 500 kHz by additional 2-stage RC-filter
- Measured different situations, e.g.:
  - EV charging (islanding and grid-connected)
    - Different charging power (max 10 kW)
    - Hyundai Ioniq (CCS) / Nissan Leaf (CHAdeMO)
  - PV feeding the AC grid
  - EV feeding the AC grid

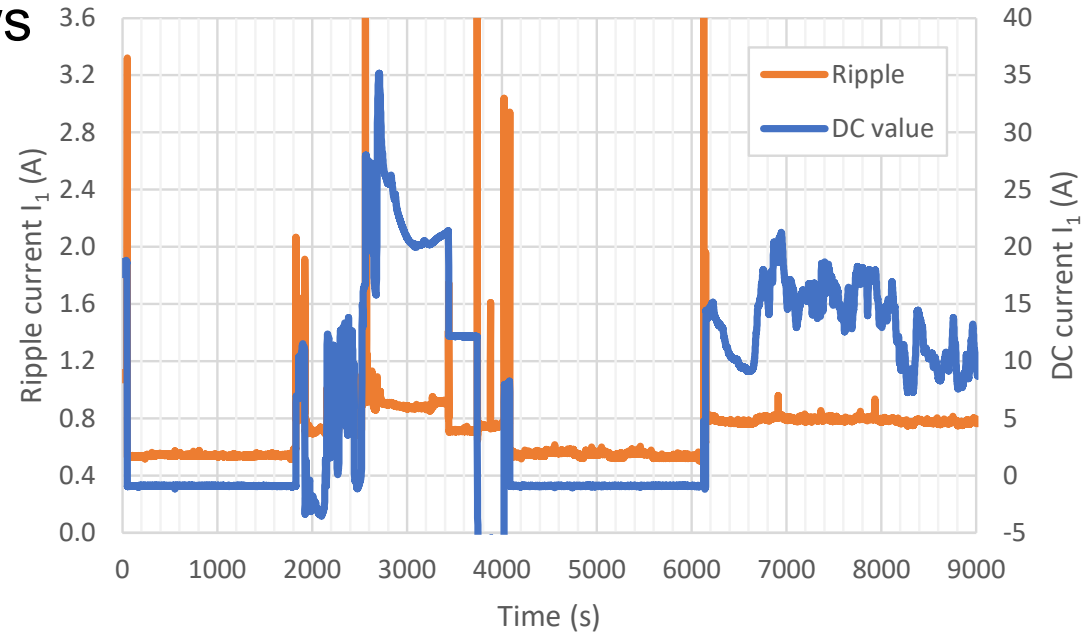


H.E. van den Brom, R. van Leeuwen, J.M. Warmerdam, and R. Schaacke, “Power Quality Measurements in a Low-Voltage DC Microgrid in an Open Parking Garage,” I2MTC, Glasgow, UK, 20-23 May 2024

ASR building: voltage and current

- Voltage/current averaged over 1 s windows
- Ripple voltage ~ 0.6 to 0.8 V





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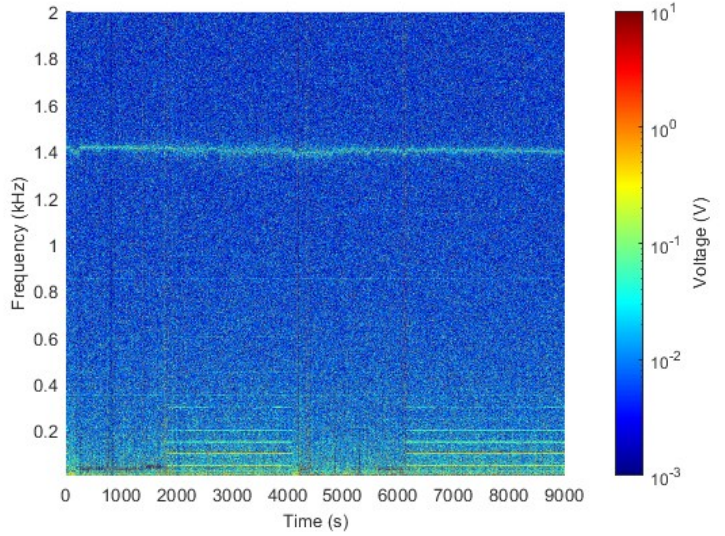
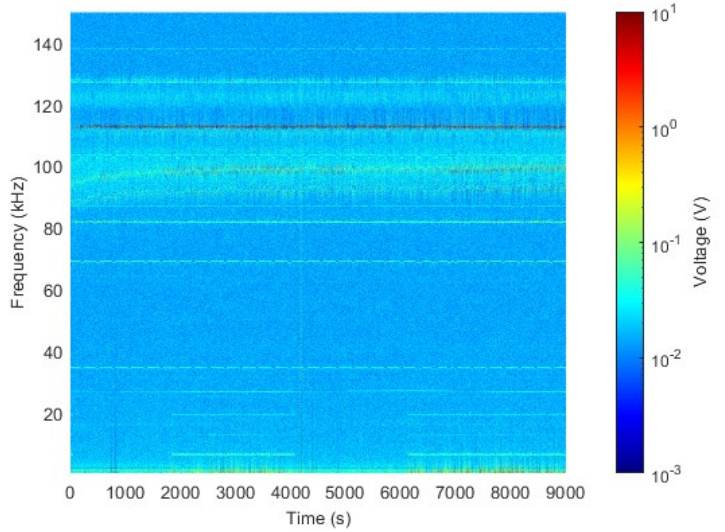
ASR building: Fourier transforms

- Fourier Transforms of voltage samples
  - 5 Hz resolution up to 2 kHz
  - 200 Hz resolution up to 150 kHz
- Background noise does not change with configuration
- Spectral components grid-connected mode:
  - Multiples of 50 Hz
  - Single tones at 7 kHz and 30 kHz
- Persistent components:
  - Tones at 1.4 kHz and several above 30 kHz
  - Major tone at 113 kHz
  - Tone below 100 kHz shows frequency drift





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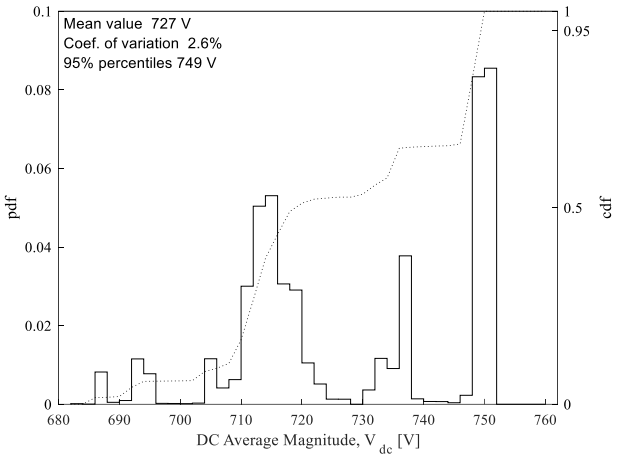
ASR building: further analysis

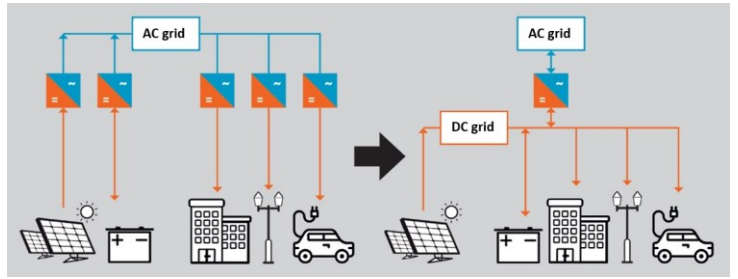
- Further analysis performed at Campania University – see later presentation
  - Flagging and detection of events (dips/swells, transients)
  - Ripple with compensation for slow amplitude variation
  - Proposed frequency groups up to 9 kHz and 150 kHz
  - Statistical analysis (probability density, 95 % percentile, …)
  - Influence of reducing sampling rate on statistics and ripple



- Further analysis performed at EDF – see later presentation
  - Quasi-peak detection (Digital-CISPR) for 9 kHz to 150 kHz

PQ Measurements in LV DC Grids

- How to measure PQ in DC grids?
  - Initial DC PQ definitions and considerations
  - Onsite measurement equipment
  - Onsite PQ measurement results:
    - Lelystad Airport, Lelystad
    - The Green Village, Delft
    - Parking Garage, Utrecht
  - Further analysis methods
- Future:
  - Improved standardization of DC PQ
  - Utilities: DC PQ planning levels
  - Surveillance authorities: DC PQ compatibility



Contact details

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- 20NRM03 DC grids project, www.dc-grids.nl