Harmonic interaction of LED lamps in islanded microgrids
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4. Summary of findings
Motivation

Trends regarding electric power systems:
- Increasing importance of harmonic interactions due to power-electronic based sources and loads
- New architectures for electricity networks gain importance, e.g. microgrids (MGs)

Problem regarding these trends:
- Publications on harmonic interactions concentrate on „traditional“ interconnected electric networks
- Conditions in MGs based on 100% PE generation are different, previous findings might not be applicable

→ Goal of this paper:
- Analyse harmonic interactions in a microgrid compared to interconnected mode of operation
- Identify differences, i.e. check if present harmonic emission standards are applicable to MGs
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Laboratory setup: Test cases

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<th>source</th>
<th>Load</th>
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<td>Islanded mode (ISM)</td>
<td>Battery converter</td>
<td>Variation: number of LEDs n = [1, 2, 3, 4, 5, 10, 15, 20, 25, 30, 38]</td>
<td>LED A (aPFC)</td>
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<td>Grid simulator</td>
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Current waveform:

- LED A
  - Current vs. time graph

- LED B
  - Current vs. time graph
Laboratory setup: Different grid structures

- Clear resonance with capacitive characteristic above 700 Hz

- Impedance in interconnected mode about 15-20 times lower than in islanded mode
Measurement procedure

General comments
- All measurements performed at thermal steady state
- Measurement position: PoC

Impedance Measurement
- Injection of current with given frequency
- Measurement of resulting voltage change

Measurement of voltage and current harmonics
- Measurement over time (10 s) with 1 MS/s with transient recorder dewetron 2600 with HIS-HV and HIS-LV modules
- Division of measurement into 10 intervals of 1 s each
- Calculation of harmonic magnitudes and phase angles using FFT up to 40th harmonic for each interval
- Arithmetic averaging of magnitudes, calculation of prevailing phase angles
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Measurement results (1/3) – Network Impedances

**Interconnected mode** (grid simulator)

- Small influence of load on network impedance
- Influence for LED B higher due to higher load (less impedance)

**Islanded mode** (battery converter)

- Small influence of nPFC load on network impedance
- High influence of aPFC load on network impedance including shift in resonance frequency
Measurement results (2/3) – Harmonic currents as function of LED number
Active PFC load (LED A)

**Interconnected mode** (grid simulator)

- Harmonic currents increase linearly with number of lamps

**Islanded mode** (battery converter)

- Harmonic currents of third order increases linearly, some slopes increase ($h=5, 7$) and some ($h=9, 11, \ldots$) decrease
  
  ➢ Can be explained by resonance shift
Measurement results (2/3) – Harmonic currents as function of LED number
No PFC load (LED B)

Interconnected mode (grid simulator)

Islanded mode (battery converter)

- 3rd to 7th harmonic increase linearly, slope for higher order harmonics decreases
- Can be explained by change of network impedance, cancellation effects between lamps and change of voltage distortion

- 3rd harmonic increases linearly, slope for 5th to 9th harmonic decreases, above 11th harmonic behavior varies
Measurement results (3/3) – Voltages as function of LED number

**Interconnected mode** (grid simulator)

- **Active PFC (LED A)**
  - Voltage distortion almost independent from load

- **No PFC (LED B)**
  - Stronger load dependency compared to LED A due to higher load current of LED B

**Islanded mode** (battery converter)

- **Active PFC (LED A)**
  - Strong load dependent increase due to high impedance
  - Significant nonlinear behavior due to resonance shift

- **No PFC (LED B)**
  - Strongest load dependent increase due to high impedance and higher load current of LED B
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### Summary of findings

#### Load influence on harmonic parameters:

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<th>Islanded mode</th>
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<tbody>
<tr>
<td></td>
<td>aPFC (LED A)</td>
<td>nPFC (LED B)</td>
</tr>
<tr>
<td>Network impedance characteristic</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>THD$_{i}$</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>THD$_{u}$</td>
<td>low</td>
<td>medium</td>
</tr>
</tbody>
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### Indications:

- Harmonic current emission in MGs will be less compared to traditional grids
- Harmonic voltages will be significantly greater in islanded MGs compared to interconnected grid configurations
- Compatibility levels are complied with in this study but could easily be exceeded with higher nPFC load
- Harmonic iterations are more complex in islanded MGs, which makes estimating calculations and modeling more complicated
Thank you for your attention