RESULTS FOR A MV-HYBRID-MICROGRID TEST CAMPAIGN IN THE MW-RANGE

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AGENDA

- Project „Zukunfts­kraftwerk PV“
- Categories of Inverter Control
- Grid-Sustaining Control
  - Implementation
- Laboratory Microgrid Setup
- Measurement Results
  - Single Inverter: On-Grid Behavior
  - Micro-Grid with 2 Inverters and Diesel Genset
- Summary and Outlook
Project Presentation
Zukunftskraftwerk PV

- Partners:
  - BELECTRIC Solarkraftwerke GmbH
  - GE Energy Power Conversion GmbH
  - MTU Friedrichshafen GmbH
- Nov. 2014 to Dez. 2018
- Funded by the Federal Ministry of Economic Affairs and Energy of Germany (BMBF)

Diesel-PV-Hybrid Power Station including storage system

(©Belectric)
Categories of Inverter Control
Control Strategies for Grid-Connected Inverters

- **current controlling**
  - **grid feeding**
    - application: power injection into the grid
  - **grid supporting**
    - application: power injection into the grid & additional system services (e.g. LVRT)

- **voltage controlling**
  - **grid forming**
    - application: single voltage source in island grid
  - **grid sustaining**
    - application: parallel operating voltage sources in National Grids or Micro Grids
# Categories of Inverter Control

## Control Strategies for Grid-Connected Inverters

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Grid-Feeding</th>
<th>Grid-Supporting</th>
<th>Grid-Forming</th>
<th>Grid-Sustaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Impedance</td>
<td>Z = ∞</td>
<td>Z = ∞</td>
<td>Z = 0</td>
<td>finite, ≠ 0</td>
</tr>
<tr>
<td>Output Frequency</td>
<td>Synchronous to the Grid Freq.</td>
<td>Synchronous to the Grid Freq.</td>
<td>Fixed Frequency</td>
<td>Defined by Droop</td>
</tr>
<tr>
<td>Scope of Application</td>
<td>On-Grid</td>
<td>On-Grid</td>
<td>Off-Grid</td>
<td>On-Grid and Off-Grid</td>
</tr>
<tr>
<td>Inertia</td>
<td>No</td>
<td>No</td>
<td>Infinite</td>
<td>finite, ≠ 0</td>
</tr>
</tbody>
</table>
Grid-Sustaining Control
Implementation of Droop-Control

- Droop Control
- Highly Dynamic Voltage Controller
- Current Limiting required
  - Alternating Current-Limiting Functionality
Laboratory Microgrid Setup

Equipment

- **Sources**
  - 2 Inverters with changeable Control (Grid-Supporting or Grid-Sustaining)
    - 1000 kVA and 725 kVA
  - 1 Diesel Genset
    - 275 kVA, 220 kW

- **Load**
  - Ohmic-Inductiv Load Bank
    - 2280 kVA, ohmic 1820 kW, inductiv 1370 kVar

- **Measurement Devices**
  - On Medium Voltage and Low Voltage side (46 channels in total)
  - Highly Dynamic, Sampling Rate up to 50 kHz
Laboratory Microgrid Setup

Single-Line Diagram

- **Grid**
  - $V = 0...1500$ V
  - $I_{\text{Max}} = 960$ A

- **DC-Source**
  - $V = 0...1500$ V
  - $I_{\text{Max}} = 960$ A

- **DUT 1**
  - $V_N = 550$ V
  - $I_N = 1050$ A
  - $S_N = 1$ MVA

- **DUT 2**
  - $V_N = 400$ V
  - $I_N = 1050$ A
  - $S_N = 727$ kVA

- **Grid-Sim. as DC-Source**
  - $V = 0...750$ V
  - $P_{\text{Max}} = 600$ kW

- **Loadbank**
  - $P_{\text{N}} = 0...1.36$ MW
  - $Q_{\text{N}} = 0...1.02$ MVAR

- **Diesel Genset**
  - $V_N = 400$ V
  - $P_{\text{N}} = 220$ kW
  - $S_N = 275$ kVA
Measurement Results
Single Inverter: On-Grid Behavior

Setpoint Change Active Power
Setpoint 100 kW 700 kW
Voltage
Current
Active, Reactive, Apparent Power
Actual Value 150 kW 750 kW

Setpoint Change Reactive Power
Setpoint 100 kVar ind. 100 kvar cap.
Voltage
Current
Active, Reactive, Apparent Power
Actual Value 84 kVar ind. 129 kVar cap
Measurement Results
Falling into Island - MV

Loss of Mains

Grid

DUT 1

\[ \sim \]

200 kW

DUT 2

\[ \sim \]

0 kW

Genset

SG

Loadbank

220 kW

500 kW

Mains Voltage

8.739 8.801 8.864 8.926 8.988

Mains Current

8.739 8.801 8.864 8.926 8.988

Island Voltage

8.739 8.801 8.864 8.926 8.988
Measurement Results
Falling to Island - LV

Grid

DUT 1

DUT 2

Genset

SG

Loadbank

Loss of Mains
Measurement Results

Black Start

Voltage

Current

2 s

400 kW
Measurement Results

Island Situation – Load Step

- DUT 1 and DUT 2
  - Grid-Sustaining
- Diesel Genset
  - Power set point of 220 kW (fixed Active Power)
- Load
  - 500 kW → 1000 kW
- Grid Control solely by Inverters
Measurement Results
Island Situation – Load Step

![Diagram of grid connection with DUT 1 and DUT 2, Genset, and Loadbank]
Measurement Results
Island Situation – Load Step

- DUT 1
  - Grid-feeding (PV)
  - Power Reduction 800 → 200 kW

- DUT 2
  - Grid-Sustaining (Droop)

- Diesel Genset
  - Frequency Control with Droop

- Load
  - 800 kW

- Grid Control by DUT 2 and the Genset
Measurement Results
Island Situation – Load Step

Grid

DUT 1

DUT 2

Genset

SG

Loadbank

Voltage Current

02:01.189 02:01.677

Rec

Voltage Current

02:01.189 02:01.677

Rec

Voltage Current

02:01.189 02:01.677

Rec

Voltage Current

02:01.189 02:01.677

Rec
Measurement Results
Island Situation – Current Limiting

- **DUT 1**
  - Grid-Feeding (PV)
  - 785 kW → 0 kW (shut down)

- **DUT 2**
  - Grid-Sustaining (Droop)

- Diesel Genset
  - Frequency Control with Droop

- **Load**
  - 800 kW

- Slow reaction of Genset → DUT 2 sees an overload during the first cycles and needs to limit the current
Measurement Results

Island – Current Limiting

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Current</th>
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</thead>
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<td></td>
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Diagram of electrical system with grid, DUT 1, DUT 2, genset, loadbank, and voltage/current waveforms for different time intervals.
Summary and Outlook

Summary

- Grid-Sustaining Droop Control implemented on 2 inverters with 1 MVA / 725 kVA

- The Control has been tested successfully in a MV-Micro-Grid laboratory setup, regarding the following aspects:
  - Parallel Operation with the mains grid
  - Power Sharing with other Sources as there are...
    - Diesel Genset with Droop Control
    - Other Grid-sustaining Inverters
  - Current Limiting in Over-Load-Situation
  - Parallel Operation with other non grid-sustaining power sources (e.g. CHP, PV-inverters, ...)
  - Black Start capability
In future Measurement Campaigns the following should be tested:

- Inverter under asymmetric load
- Grid Connected LVRT
- Resynchronization of the Micro-Grid to the mains grid
- Tests with additional secondary control
Thank you for your attention

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