PHOTOVOLTAICS IN THE SMART GRID

Tamás Kerekes PhD

Department of Energy Technology
Aalborg University
Overview

Renewable energy 2011
PhotoVoltaics 2011
PV systems
Technical challenges
Conclusion
European power capacity

**EU POWER CAPACITY MIX 2000**

- Peat: 1,868 MW (0%)
- Fuel oil: 66,518 MW (12%)
- Large hydro: 105,552 MW (18%)
- Gas: 89,801 MW (16%)
- Nuclear: 128,471 MW (22%)
- Coal: 159,482 MW (28%)
- Biomass: 2,790 MW (1%)
- Waste: 2,054 MW (0%)
- Geothermal: 604 MW (0%)

**EU POWER CAPACITY MIX 2011**

- Peat: 2,030 MW (0%)
- Fuel oil: 53,745 MW (6%)
- Large hydro: 121,243 MW (10%)
- Gas: 209,953 MW (23%)
- Nuclear: 121,444 MW (14%)
- Coal: 230,253 MW (26%)
- Wind: 93,957 MW (10%)
- PV: 46,300 MW (5%)
- Biomass: 6,019 MW (1%)
- Small hydro: 4,845 MW (1%)
- Waste: 3,804 MW (0%)
- Geothermal: 924 MW (0%)
- Ocean: 254 MW (0%)
- CSP: 1107 MW (0%)

New electricity installations in 2011

• In Europe 45GW of new electricity generating capacity has been installed
• Solar PV installed 21,000 MW (46.7% of total installed capacity in 2011)
• Gas installations have a share of 21.6%
• Wind installations 21.4%

In Europe 32GW of renewable has been installed in 2011
- New PV installations represent 66%

PV capacity worldwide

According to EPIA:

- Worldwide 29GW of PV installed in 2011
- Total capacity up to almost 70GW of PV in the world at the end of 2011

Ref: EPIA and IEA-PVPS, 2012
Grid-Connected PV systems

Distributed Generation

- Residential Houses
- Energy Storage
- PV Inverter
- PV Array
- Power Quality Device
- Industry
- Low Voltage Grid
- Commercial Buildings
- Wind Power Plant
- Residential Houses
- Central Power Plants

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Grid-Connected PV systems

PV Generator

Electrical Power

Sun → Power Converter → Grid

Residential systems:
• up to 30kW
• connected to LV grid (400V)

Photovoltaic plants:
• several MW
• connected to MV grid (20kV)

Source: PoweOne Ultra 1400; tomorrowisgreener.com; danfoss.com
PV inverter structures

1. Central inverter
2. String inverters
3. Multi-string inverters

PV Strings
AC bus

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Slide 9
PV inverter structures: Central Inverters

- High Performance for Large PV Plant, High Level Monitoring, High Level Intelligence, Reliability
- High Efficiency (up 97%), Competitive prize/performance ratio.
- Typical structure – String inverter, 3-phase FB proven technology (more parallel) with transformer to MV
- Manufacturers:

ABB – PVS800
- Multi-level achieved by dual inverter configuration
- 100-500 kW
- 450-750Vdc input
- 400Vac out
- Efficiency > 97.5%
- Modular design, Long life-time, PF Comp
690VAC is standard in the wind industry
- Standard-components for up to 3MW + are cost-effective and reliable
- Inverter cost (approx.) proportional to AC current
- Up to 1500VDC is enabled for PV components by DIN VDE0100
- Reduces installation time
- Reduces copper costs and cabling losses

Nominal power: 333kW @ 3AC690V+N
- Max. efficiency: >98.5% with UltraEta®-topology
- MPP voltage range: 600-1200VDC
- Max. DC Voltage: 1400V
- Weight: approx. 400kg (1,20kg/kW)
- Outdoor-qualified housing
Structures: Central Inverters

SUNNY CENTRAL up to 1250MV (2x Sunny Central 630HE)

**Efficient**
- Without low voltage transformer → Higher system efficiency due to direct connection to the medium voltage Grid

**Turnkey Delivery**
- With medium-voltage transformer and concrete substation for outdoor installation

**Optional**
- Grid management
- Control of reactive power
- Medium-voltage switching stations for a flexible structure of large solar parks
- AC transfer station with measurement
- Medium-voltage transformers for other grid voltages (deviating from 20 kV)
Structures: Central Inverters

**SUNNY CENTRAL 800CP (up to 800kVA)**

**Economic**
- Direct deployment in the field due to outdoor enclosure
- Simplified shipping without concrete substation

**Efficient**
- Full nominal power at ambient temperatures up to 50 °C
- 10 % additional power for constant operation at ambient temperatures up to 25 °C
- Max. efficiency: 98.6 % (w/o internal power supply)
- Euro ETA: 98.4 %

**Flexible**
- Powerful grid management functions (including LVRT)
  - Remote controlled power reduction in case of grid overload
  - Frequency-dependent control of active power
  - Static voltage support based on reactive power
  - Dynamic Grid Support
- DC voltage range configurable

**Reliable**
- Easy and safe installation due to a separate connection area
- Optional: extended input voltage range up to 1,100 V
1. What constraints are more influential on LV networks?
2. What is the most effective solution?

- **Rural networks**
  - Available space for PV installation
  - Low load density
  - Higher areas for PV installation

- **Suburban networks**
  - Available space for PV installation
  - High load density
  - Limited and common areas for PV installation
  - Short distances to the substation

- **Urban networks**
  - Available space for PV installation
  - Low load density
  - Higher areas for PV installation
  - Longer distances to the substation

- **Critical networks**
Simulation Study

Low voltage (230/400V) Radial Feeder Model

Grid resistance \( R_g \) 0.034 ohm
Grid inductance \( L_g \) 0.5 mH
Transf. Primary and secondary resistance \( R_p, R_s \) 0.5 ohm
Transf. primary and secondary leak. inductance \( L_p, L_s \) 1 mH
Line resistance \( R \) 0.025 ohm
Line inductance \( L \) 0.04 mH
Line resistance \( R_1 \) 0.25 ohm
Line inductance \( L_1 \) 0.4 mH

- 11 inverters
- Average inverter model
- SOGI PLL
- Fixed DC voltage at 700 V
- Stationary-frame proportional-resonant digital current controller
TABLE I
Summary of The Grid Characteristic

<table>
<thead>
<tr>
<th>Grid characteristics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of network</td>
<td>suburban</td>
</tr>
<tr>
<td>Type of settlement</td>
<td>residential</td>
</tr>
<tr>
<td>Number of houses</td>
<td>60</td>
</tr>
<tr>
<td>Type of houses</td>
<td>Detached, single- or two-family</td>
</tr>
<tr>
<td>Transformer rated power</td>
<td>400 kVA</td>
</tr>
<tr>
<td>Grid topology</td>
<td>radial for the simulation, meshed in real</td>
</tr>
<tr>
<td>Average distance between transformer and houses</td>
<td>415.5 m</td>
</tr>
<tr>
<td>Feeder cable types</td>
<td>Al 3x240, Al 3x150, Al 3x95 mm² (simulation), underground</td>
</tr>
<tr>
<td>Service cable types (between houses and feeder connection points)</td>
<td>Al 50 mm² underground</td>
</tr>
</tbody>
</table>
Braedstrup Grid Model

Ref: Erhan Demirok, AAU

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The possible solutions to voltage rise problem

1. Adapting tap positions of OLTC transformers (110/20kV)

2. Network expansion

3. Output power curtailment by PVs

4. Reactive power control by PVs

5. PV + storage system

Ref: Erhan Demirok, AAU
Main drawbacks of \textbf{P dependent Q control} methods:

- Absorbing unnecessary reactive power when the produced real power is consumed locally and the grid voltage is in the admissible range.
- Voltage sensitivities are not taken into consideration. The inverters with the least voltage sensitivity and with the highest voltage sensitivity may utilize the same amount of Q.

Drawback of \textbf{U dependent Q control} methods:

- The inverters closer to the transformer may not react to the overvoltage emergency condition that occurred at the end of feeders.

Following modifications are proposed:

- Power factor level of the nearest inverters to the transformer is increased at certain amounts for \textit{fixed cosφ} and \textit{cosφ(\textit{P})} methods.
- Reactive power amount of the inverters nearest to the transformer is forced to be higher for \textit{Q(U)} method.
Grid Interface Requirements - LV

Voltage Deviations

<table>
<thead>
<tr>
<th>Voltage Deviation</th>
<th>IEEE 1574</th>
<th>IEC 61727</th>
<th>VDE 0126-1-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage range (%)</td>
<td>Disconnection time (sec)</td>
<td>Voltage range (%)</td>
<td>Disconnection time (sec)</td>
</tr>
<tr>
<td>V &lt; 50</td>
<td>0.16</td>
<td>V &lt; 50</td>
<td>0.10</td>
</tr>
<tr>
<td>50 ≤ V &lt; 88</td>
<td>2.00</td>
<td>50 ≤ V &lt; 85</td>
<td>2.00</td>
</tr>
<tr>
<td>110 &lt; V &lt; 120</td>
<td>1.00</td>
<td>110 &lt; V &lt; 135</td>
<td>2.00</td>
</tr>
<tr>
<td>V ≥ 120</td>
<td>0.16</td>
<td>V ≥ 135</td>
<td>0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency range [Hz]</th>
<th>Disconnection time [s]</th>
<th>VDE 0126-1-1</th>
<th>VDE-AR-N 4105</th>
</tr>
</thead>
<tbody>
<tr>
<td>47.5 &lt; f &lt; 50.2</td>
<td>0.20</td>
<td></td>
<td>0.10</td>
</tr>
</tbody>
</table>

Obs. The purpose of the allowed time delay is to ride through short-term disturbances to avoid excessive nuisance tripping (LVRT)
LVRT for PV inverters
The objective of the laboratory setup was to establish a real time bi-directional data communication between the interconnected three-phase inverters and the master controller (Client) and show that the communication concept can be successfully applied in power substations.

Ref: MSc project, Ana maria Man and Vlad Muresan, AAU
Conclusion

• PV systems have had a significant increase in the last years

• Around 70GW of PV installed worldwide

• High PV penetration can become a challenge for LV grid operators, but solutions are there to overcome these limitations

• Grid support from PV inverters (Q and LVRT)

• Communication between inverters is a requirement in case of a Smart Grid
Laboratory Facilities

- Grid connected converter setups controlled by dSpace®
- PV inverter test setup 32kW (EN 50530, EN 61000)
- Residential microgrid setup (3 kVA)
- Linear PV simulator Regatron (32kW)
- California Instruments grid simulator (32kVA)
- Linear grid simulator (21kVA) with RTDS
- Class AAA Flash Sun simulator for PV modules - Spi Sun 4600 SLP from Spire
- SWIR Imaging (EL, PL) - Photonic Science InGaAs camera (640x512)
PhD/Industrial Courses - 2013

- Power Electronics for Renewable Energy Systems - in Theory and Practice (3 days)
- Photovoltaic Power Systems - in Theory and Practice (3 days)
- AC Microgrids - in Theory and Practice (2 days)
- DC Microgrids - in Theory and Practice (2 days)
- Power Quality in Microgrids - in Theory and Practice (2 days)
- Communications for Microgrids - in Theory and Practice (2 days)