An overview of different tools for smart grid studies
Experiences from several European projects

Serdar Kadam
Outline

- Introduction

- Tools and methods in research projects

- Synthetic networks and probabilistic tools

- Large-scale network data analysis

- Conclusion
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Centralized and Decentralized Energy System

Centralized extremity:
Centralized Energy System
(generation in large Power Plants)

More large Power Plants
Increased efficiency and reliability

Enlarged distribution networks
and frequency control increase reliability

Small generation units lead (again)
to a more decentralized system

Level of
decentralization
of a Smart Grid;
respectively of
several parts of
the Smart Grid,
that have to work
together in one
EU Smart Grid
System

Decentralized extremity:
Decentralized Energy System
(generation in a very big number of distributed small
and midsize generation units, all units are
interconnected; large Power Plants did not exist)

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Growing need for network support from DER

Distributed Energy Resources and LVRT

- E.g. Germany: BDEW Guideline “Generating Plants Connected to the Medium-Voltage Networks
- Key documents FGW TR3 (Measurement), TR4 (Model validation) TR8 (Certification procedure)
- Test specification IEC 61400-21 Measurement and assessment of power quality characteristics of grid connected wind turbines SDLWindV
  Additional requirements and amendments
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Q1: Which networks to use?

- Literature (IEEE...)
- Synthetic networks
- Complete data set
- “Typical”
- Example

Network study
Q2: Which DRES scenario to consider?

- Generation at the beginning: (high HC)

- Generation at the end: (low HC)
morePV2grid – local voltage control through PV inverters

- >800m LV-feeder
- 5 single-phase installations, 4 controllable (15kWp) on same line
- Simulation, Lab tests, Field tests
- 2010-2013
Functional validation in the field

\[ \cos \varphi(P) \quad \text{Q&P(U)-control} \]
Assessment of smart grid schemes
MetaPV in a Nutshell – Large scale demonstration of network support through PV inverters

- October 2009 - March 2015
- Budget:
  - € 5.5 million funding from the EC € 9.5 million total eligible budget
- Partners: 3E, AIT, Infrax, LRM, SMA, UoL
- Large scale demonstration
  - Residential: 85 installations, ~400 kW
  - Industrial (MV): 9 installations, ~2500 kW
- Approach:
  - Development and simulations
  - Lab tests
  - Field tests and validation
Challenges of demonstration projects (MetaPV experience)

- **Results very positive:**
  - no equipment failure, no malfunction.
  - functionality demonstrated: control behaves as intended!

- **Demo projects** as a key step towards the large-scale deployment (functional validation)

- **What a demo can do:**
  - Foster a better understanding from all parties (DSO, equipment manufacturer, R&D)
  - **Demonstrate the functionality**

- **What a demo usually does not do:**
  - Study the potential for scalability and replicability (beyond the particular conditions of the demo)
  - Provide guidance on **how to replicate** the solution
  - Provide “general results”
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Generic Feeder study

- Continuous feeder with slack
- Punctual or continuous load (100 loads)
- Balanced and unbalanced load flow
- Type of cable / length
- Allowed voltage rise:
  - Currently: 3 % (AT, DE)
  - Sensitivity study: 1-10 % (e.g. through distribution transformer with OLTC)

<table>
<thead>
<tr>
<th>Cross-section (mm²)</th>
<th>Overhead Line (OL)</th>
<th>Cable (CBL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>OL_A1_4x50</td>
<td>CBL_4x50</td>
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<tr>
<td>70</td>
<td>OL_A1_4x70</td>
<td>CBL_4x70</td>
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<td>95</td>
<td>OL_A1_4x95</td>
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<tr>
<td>120</td>
<td>OL_A1_4x120</td>
<td>CBL_4x120</td>
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<tr>
<td>150</td>
<td></td>
<td>CBL_4x150</td>
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<tr>
<td>240</td>
<td></td>
<td>CBL_4x240</td>
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</table>
Hosting Capacity in LV network \((U_N = 0.4\text{kV})\)

- Hosting Capacity study for typical cable
- No loads considered
Parametric Q&P(U)-study

Sensitivity of curtailment and network losses (over-head line network)

<table>
<thead>
<tr>
<th>VVI (p.u.)</th>
<th>P_L (%)</th>
<th>P_C (%)</th>
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</thead>
<tbody>
<tr>
<td>0.19</td>
<td>0.25</td>
<td>0.31</td>
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<tr>
<td>0.38</td>
<td>0.44</td>
<td>0.5</td>
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<tr>
<td>0.63</td>
<td>0.69</td>
<td>0.75</td>
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<tr>
<td>0.81</td>
<td>0.88</td>
<td>0.94</td>
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</table>

Network losses
Curtailment
Could several inverters with a Q(U)-control become instable?

Stability criterion:

\[ \frac{T}{\tau} \leq \frac{1}{a_\zeta \cdot \frac{\Delta U_{PV}}{\Delta U_{droop}} \cdot \tan \varphi + b_\zeta \cdot \frac{R}{X}} \]

Delay shall be lower than half of the desired response time

\( \Rightarrow \) Relevant for systems relying on communication

Hosting Capacity Feeder Screening (MV network)

<table>
<thead>
<tr>
<th></th>
<th>F01</th>
<th>F02</th>
<th>F03</th>
<th>F04</th>
<th>F05</th>
<th>F06</th>
<th>F07</th>
<th>F08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (km)</td>
<td>11.9</td>
<td>6.2</td>
<td>38.5</td>
<td>14.2</td>
<td>4.6</td>
<td>5.8</td>
<td>15.1</td>
<td>10.5</td>
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<tr>
<td>DER number</td>
<td>24</td>
<td>18</td>
<td>87</td>
<td>43</td>
<td>8</td>
<td>19</td>
<td>50</td>
<td>24</td>
</tr>
</tbody>
</table>

CDF of every feeder

Hosting Capacity (MW)
Pareto optimal distribution of Single-phase DER

Pareto-optimal reassignment of single phase installations

- Easy to use tool
- Network data from GIS (GIS-DGS - PowerFactory)
- PV/Load data from GIS and metering data-base (AMI-PowerFactory/Python)
- User-defined balancing tool
- Result: report & diagrams
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IGREENGrid

Challenge

- IGREENGrid project focuses on identifying the most promising solutions for increasing the hosting capacity for Distributed Renewable Energy Sources (DRES) in power distribution grids without compromising the reliability or jeopardizing the quality of supply.

Set of guidelines:

- Most promising solutions.
- Recommendations for the integration of DRES in distribution grids, Methodologies and tools.
- Criteria to establish hosting capacity and to manage curtailment procedures.
- Technical requirements to DRES, equipment manufacturers & technology providers.
- Assessment of the scalability and replicability at EU level (from technical, regulatory and economic point of view).
iGreenGrid Key facts

- > 15 smart grids solutions (MV&LV)

- Data:
  - Network data from GIS/NIS/SCADA
  - Load data (metering / SCADA)
  - PV (& Wind) data per country

- From 8 DSOs:
  - 149 MV feeders (27 networks)
  - 55 LV feeders (16 networks)

- From 2 DSOs:
  - >11,000 LV networks
  - >37,000 LV feeders
Feeder characterization
(\sim 11,000 \text{ LV networks and 37,000 LV feeders})

DSO1

DSO2
Reactive Power and Hosting Capacity

DSO1 ~25,000 LV-feeders

DSO2 ~12,000 LV-feeders

- HC increase >30% for 15% of the feeders
- HC increase by 20-30% for 25% of the feeders
- HC decrease for 12% of the feeders
- HC increase < 20% for 48% of the feeders

- HC decrease for 28% of the feeders
- HC increase by 20-30% for 30% of the feeders
- HC increase >30% for <10% of the feeders
- HC increase < 20% for 32% of the feeders
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Conclusion and Outlook

- Different tools for different tasks…
  - Simulations, laboratory and field tests
  - Load flow, Probabilistic LF, OPF, Quasi-Dynamic, RMS-simulations…
  - Proof of concept (e.g. Q(U)-Stability)
  - Parametric studies (e.g. Q(U)-control)
  - Probabilistic assessment (e.g. HC-screening, Pareto-optimal switching)
  - Scalability & Replicability (Grid data needed)
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