Impact of renewable energy expansion on national grids – Challenges and viable solutions

Christoph Müller, RWTH Aachen - Institute for High Voltage Technology (IFHT)
mueller@ifht.rwth-aachen.de

www.german-energy-solutions.de/
Agenda

1. Introduction
2. Basics – System Overview
3. Challenges and Solutions for Grid Integration of Renewable Energy Sources
   a. Market Perspective
   b. Transmission Grid Perspective
   c. Distribution Grid Perspective
4. Summary
1. Introduction
2. Basics – System Overview
3. Challenges and Solutions for Grid Integration of Renewable Energy Sources
   a. Market Perspective
   b. Transmission Grid Perspective
   c. Distribution Grid Perspective
4. Summary
Introduction

- Geographic concentration of PV expansion in southern regions with high solar radiation and large roof surface
- Ratio of installed capacities of roof-top and open space PV units: ~75:25

Installed capacity: roof-top & open space

Reference: German TSO, https://www.netztransparenz.de

© IFHT
Introduction

- Geographic concentration of onshore wind energy expansion
- Expansion mostly offshore and in northern regions with high wind velocities
- Development of wind turbines with hub heights of >150 m and rotor diameters of >120 m
  - More efficient use of wind power in low wind regions
  - In future: expansion of onshore wind turbines in high wind (north) and low wind regions
  - Utilization of total potential surface
1. Introduction
2. Basics – System Overview
3. Challenges and Solutions for Grid Integration of Renewable Energy Sources
   a. Market Perspective
   b. Transmission Grid Perspective
   c. Distribution Grid Perspective
4. Summary
Basics – System Overview

Transmission Grid

Horizontal load flow

Very High Voltage
380 /220kV

High Voltage
110kV

Medium Voltage
5-30kV

Low Voltage
400V

Transmission

Distribution

Vertical load flow

© IFHT
Basics – System Overview

- Grid characteristics of renewable energies:

<table>
<thead>
<tr>
<th></th>
<th>Wind</th>
<th>Photovoltaics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage level</strong></td>
<td>Low voltage (approx. 0%)</td>
<td>Low voltage (approx. 69%)</td>
</tr>
<tr>
<td></td>
<td>Medium voltage (approx. 48%)</td>
<td>Medium voltage (approx. 26%)</td>
</tr>
<tr>
<td></td>
<td>High voltage (approx. 42%)</td>
<td>High voltage (approx. 5%)</td>
</tr>
<tr>
<td></td>
<td>Very high voltage (approx. 10%, Offshore)</td>
<td></td>
</tr>
<tr>
<td><strong>Number of Units</strong></td>
<td>approx. 25.000</td>
<td>approx. 1.500.000</td>
</tr>
<tr>
<td><strong>Geographic concentration</strong></td>
<td>North &amp; Offshore (regions with high wind velocities)</td>
<td>South (regions with high solar radiation)</td>
</tr>
<tr>
<td><strong>Seasonal generation</strong></td>
<td>Autumn -&gt; <strong>Winter</strong> -&gt; Spring</td>
<td>Spring -&gt; <strong>Summer</strong> -&gt; Autumn</td>
</tr>
<tr>
<td><strong>Intraday generation</strong></td>
<td>volatile generation at 24 hours a day</td>
<td>generation just at daylight</td>
</tr>
<tr>
<td><strong>Network connection point</strong></td>
<td>directly to medium and high voltage</td>
<td>mostly low voltage (house connection point)</td>
</tr>
<tr>
<td><strong>Congestions</strong></td>
<td>Transmission grid -&gt; thermal overload</td>
<td>Distribution grid -&gt; voltage limit violation</td>
</tr>
</tbody>
</table>
1. Introduction
2. Basics – System Overview
3. Challenges and Solutions for Grid Integration of Renewable Energy Sources
   a. Market Perspective
   b. Transmission Grid Perspective
   c. Distribution Grid Perspective
4. Summary
Challenges and Solutions – *Market Perspective*

- Increasing volatile feed-in of renewable energies
  - Wind Onshore
  - Wind Offshore
  - Photovoltaics

- Rising flexibility requirements for the energy system to guarantee security of supply

- Balancing of generation and load by different flexibility options
  - Electrical storages
  - International electricity exchange
  - More flexible conventional power plants (higher power gradients, shorter downtimes etc.)
  - Flexible loads/demand side management (e.g. Power2X)
Challenges and Solutions – Market Perspective

- Imbalances of generation and load can occur due to:
  - Power plant failures
  - Forecast errors of REN
  - Forecast errors of load
  - Grid losses
- Undersupply: frequency lower than rated frequency
- Oversupply: frequency higher than rated frequency
- Requirement for **control reserve**
  - Goal: adherence of power balance and to guarantee frequency stability (50 Hz)
  - Deviation control of frequency deviations due to imbalances in load and generation (active power control)
  - Positive control reserve: provision of power by power plants
  - Negative control reserve: curtailment of power or switching on of additional loads (e.g. Power2Heat)
Challenges and Solutions – Market Perspective

- The Transmission System Operators (TSO) are responsible for power balancing.
- There are three qualities of control reserve.
  - **Primary control reserve:** Automated and fast balancing of frequency deviations and stabilization of the grid within 30 seconds.
  - **Secondary control reserve:** Balancing of imbalances in a control area of a TSO within 5 minutes (activation already after 30 seconds).
  - **Minute reserve:** Replacement of secondary control reserve for power balancing. Balancing for at least 15 minutes on a constant level.

Christoph Müller, RWTH Aachen - Institute for High Voltage Technology (IFHT)
1. Introduction

2. Basics – System Overview

3. Challenges and Solutions for Grid Integration of Renewable Energy Sources
   a. Market Perspective
   b. Transmission Grid Perspective
   c. Distribution Grid Perspective

4. Summary
Challenges and Solutions – *Transmission Grid Perspective*

- Generation concentrates in the north
  - Main drivers: Wind Onshore and Offshore
- Load centers are near big cities and industry regions
- Less generation capacity in the south due to nuclear phase-out in Germany
- Transit of electricity from Scandinavia through Germany to southern Europe
  - Flow of electricity from the north to the south of Germany
  - Generation and demand pattern show an energy transport problem
  - Need for transmission grid expansion
German Grid Development Plan (GDP)

- The German TSO’s create the GDP every second year
- Goal: In the GDP the future transmission grid is planned to guarantee an efficient electricity transport
- NDP contains several scenarios that describe possible future developments for different simulation years (e.g. NDP 2016: 2030 & 2035)
- Minimization of transmission grid expansion / GORE-principle

- Grid Optimization prior Reinforcement prior Expansion

Reference: German TSO, https://www.netzentwicklungsplan.de
Challenges and Solutions – Transmission Grid Perspective

- **Grid Optimization**
  - Power flow control -> HVDC-control, phase shifting transformers (PST)
  - Overhead line monitoring

- **Reinforcement**
  - Voltage upgrade (220 kV -> 380 kV)
  - Increase of transmission capacity

- **Expansion**
  - New HVAC (380 kV) lines
  - New electrical switchgear
  - Overlay-grid (HVDC)

Reference: German TSO, https://www.netzentwicklungsplan.de
Temporary solutions until grid expansion proceeds

Short-term remedial actions for elimination of network congestions and to guarantee system security, e.g. (n-1)-security

- Redispatch: *Intervention of the TSO in the power plant dispatch in order to guarantee system security*
- REN feed-in management / Peak shaving
- HVDC-adjustment
- Reserve power plants (system services)
- Power2Gas in the north & transport of gas by gas pipelines to power plants in the south

No alternative for required grid expansion in the long run!
1. Introduction
2. Basics – System Overview
3. Challenges and Solutions for Grid Integration of Renewable Energy Sources
   a. Market Perspective
   b. Transmission Grid Perspective
   c. Distribution Grid Perspective
4. Summary
Challenges and Solutions – Distribution Grid Perspective

Changing conditions in distribution grids

- Generation / Storage / Loads

- Different powerflows & new technologies

- New marketing concepts

- Increasing ICT infrastructure

Changing conditions in transmission grids

- Decreasing number of rotating masses/inertia

- Spatial divergence generation <-> load

- Providing ancillary services increasingly critical

Changing demands on DSO

1. Local services and operational requirements

2. Implications for normal and faulty operation

3. Services / requirements of the overlayed grid

Share of IIDG for LV and MV in a distribution system with >180,000 distributed generators [1]
Challenges and Solutions – *Distribution Grid Perspective*

- **Future smart grid**
  - Smart components monitor the state of the electrical grid and keep balance between generation and load
  - Goal: Efficient use of regional infrastructure through smart operation/control (optimized grid operation)
  - Controllable loads (e.g. e-mob, white goods) , storage (grid- and home storage), new equipment (voltage regulated transformer, switch)

- **Further Challenges**
  - High complexity in possible operation points and options in action
  - Control in „real time“ with limited resources (Hardware)

- Need for an intelligent control system with an online-self-learning algorithm (smart operator)
Challenges and Solutions – *Distribution Grid Perspective*

- Smart Operator: Process of development
  1. Simulation based conceptual design
  2. Implementation on used hardware
  3. Validation with real grid components in the test center / laboratory
  4. Collecting operating experience in field tests

![Graph of Min-Max-voltage limit](image)

© IFHT
Control options in distribution grids:
- Feed-in management
- Reactive power control
- On-load tap-changer
- Flexibilities from private households

Central intelligence controls low-voltage grid
- Self-learning algorithm
- Learning from information from measurements and meteorological data
- State estimation for determination of current grid state

Day-ahead forecast for efficient battery usage
Use of powerflow calculations for validation of switching action

Field tests show the successful operation
- Day-ahead forecast is preventing invalid grid states in over 90% of cases
Challenges and Solutions – Distribution Grid Perspective

- Input / output activities of a smart operator – real time control

1 second
10 seconds
20 seconds
30 seconds
38 seconds
42 seconds
52 seconds
1 minute

© IFHT
1. Introduction
2. Basics – System Overview
3. Challenges and Solutions for Grid Integration of Renewable Energy Sources
   a. Market Perspective
   b. Transmission Grid Perspective
   c. Distribution Grid Perspective
4. Summary
1. REN installed capacities and REN feed-in have been increased significantly and further expansion is expected in the next years

2. Spatial divergence generation <-> load: no regional balance
   - Energy transport problem in the transmission grid
   - Need for **transmission grid expansion** (Grid Development Plan)
   - Principle: Grid Optimization prior Reinforcement prior Expansion
   - Temporary solutions: Short-term remedial actions for elimination of network congestions

3. Volatile feed-in of renewable energies requires the **expansion of smart distribution grids** (smart grids)
   - Rising number of Prosumers (Producers and Consumers)
   - Need for flexibility and control options in distribution grids
   - Need for good state estimations & forecasts and smart operation (software)
Thank you for your attention!

Christoph Müller
RWTH Aachen
Institute for High Voltage Technology (IFHT)
mueller@ifht.rwth-aachen.de