Optimal operation management of energy distribution grids considering stationary and mobile energy storages

Research meets Industry
Hannover, 20. April 2010
Steffen Nicolai, Fraunhofer Application Centre Systems Technology IOSB-AST
Outline

• Motivation
• Classification of Energy storages
• Application of stationary Energy Storage Systems
• Hierarchical concept for optimal management
• E-Mobility
• Summary and Outlook
Motivation

- Massive development of renewable energy in Europe - political intention and ecological necessity

- Relation fluctuating vs. controllable power
  - 2007: 1 to 6 (26 GW Wind + PV)
  - 2030: 1 to 1.3 (62 GW Wind + PV)
  - 2050: 1 to 0.5 (90 GW Wind + PV)

- Additional need for control / reserve power*
  - positive 3.5 – 7 GW (2015)
  - negative 2.8 – 5.5 GW (2015)

- Generation with stochastic characterisation could causes variability in the grid
  - Grid overload
  - Undersupply
  - Local stability problems

- Grid stability requires the match between consumption and generation at any time
  - need for control / reserve power (positive /negative ) (up to 20 % control / reserve power of installed wind power)*
  - massive grid expansion/ reinforcement
  - Smart Grid approaches
  - Energy storage

* Source: dena Grid study I (2005)

Steffen Nicolai, Fraunhofer IOSB-AST, 20.04.2010
Structure of the energy system - Past

- Tight hierarchical energy system
- Central generation
- Load in the distribution grids
- Unidirectional load flows
Structure of the energy system - Present

- Hierarchical energy system
- Additional distributed generation
- Stochastic infeed characteristic
- Temporal mismatch of local generation and load
- Bidirectional load flows possible
Structure of the energy system – Future?

- Decentralized system
- Distributed generation and storage
- Local usage of energy based on energy storage systems
- Local stability with smart grid concepts
Storage Technologies Classification

Classification based on stored energy

Classification based on power rates, capacity and discharge time
• decision of Energy Storages for specific application
Application of stationary ESS: Combination with renewables

- possible objective e.g. direct marketing of wind energy
- need for observance of a production schedule
- energy storage task of balancing forecast error
- create stock market products (1 – 24h)

Steffen Nicolai, Fraunhofer IOSB-AST, 20.04.2010
Application of stationary ESS: Distribution Grid

Energy storage 1

Wind park

110 kV / 10 kV

10 kV / 0.4 kV

Commercial

Residential

PV

Energy storage 2

Grid losses – Optimization Energy Storage 1

<table>
<thead>
<tr>
<th>Time [min]</th>
<th>P [p.u.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>w/o Storage</td>
<td>w Storage</td>
</tr>
</tbody>
</table>

Grid losses – Optimization Energy Storage 2

<table>
<thead>
<tr>
<th>Time [min]</th>
<th>P [p.u.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>w/o Storage</td>
<td>w Storage</td>
</tr>
</tbody>
</table>
Hierarchical Approach for optimal operation

Integrated optimization

- Level 1:
  - Interface to conventional energy management systems, control systems
  - Schedule planning (e.g. day ahead)

- Level 2:
  - Shadow prices as input
  - Short term optimization
  - Storage systems included
  - Set point optimization

- Level 3:
  - Set point control
  - Feedback terms of energy
  - Device level

Forecast Data
- Renewable infeed
- Load shape

Storage Scheduling (Long term)

Storage Dispatch (Short term)

ESS 1
Control System

... ESS n_s
Control System
Optimal dimensioning of ESS

Example: Redox-Flow-Batterie

- Optimization model with a specific model of the energy conversion system via characteristic diagram for charging and discharging
- Modular representation of the Energy Storage System (Stack, Tank)
- Optimization regarding the technical and economical conditions
### E-Mobility: Development trend for Germany

#### Plug-In Hybrid (PHEV)

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market share (forecast NEE)</td>
<td>250,000 Mio.</td>
<td>1,0 Mio.</td>
<td>2,5 Mio.</td>
<td>5,0 Mio.</td>
</tr>
<tr>
<td>Market share (target RWE/Daimler)</td>
<td>1,25 Mio.</td>
<td>3,7 Mio.</td>
<td>8,6 Mio.</td>
<td>15 Mio.</td>
</tr>
<tr>
<td>Passenger cars inventory (BMU Lead study 2008)</td>
<td>47,8 Mio.</td>
<td>48 Mio.</td>
<td>47,7 Mio.</td>
<td><em>(48 Mio.)</em></td>
</tr>
</tbody>
</table>

#### Full Electric Vehicle (FEV)

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market share (forecast NEE)</td>
<td>0,5 %</td>
<td>2,1 %</td>
<td>5,2 %</td>
<td>10,4 %</td>
</tr>
<tr>
<td>Market share (target RWE/Daimler)</td>
<td>2,6 %</td>
<td>7,7 %</td>
<td>18,0 %</td>
<td>31,3 %</td>
</tr>
</tbody>
</table>

*assumption
E-Mobility: Requirements concerning the distribution grid

- Electric Vehicle (EV) are additional consumers in the grid
- The consumption is in time and location volatile
- Supply of negative control / reserve power possible
- Supply of positive control / reserve power (Vehicle to Grid – V2G)

Challenges

- Types of charging
  - Fast charging (<= 15 Min)
  - normal charging (several hours)
  - battery placement (better place)
- Charging stations
  - Charging stations in public domain
  - Private domain
  - Standardizing of plugs
- Supply of control / reserve power
  - high requirements on ICT

<table>
<thead>
<tr>
<th>Charging Type</th>
<th>Capacity (kWh)</th>
<th>Power (kW)</th>
<th>Charging Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toyota Prius</td>
<td>10</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Daimler Smart</td>
<td>30</td>
<td>4-8</td>
<td></td>
</tr>
<tr>
<td>Tesla Roadster</td>
<td>55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chevy Volt</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMW Mini</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEGA eCity</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Steffen Nicolai, Fraunhofer IOSB-AST, 20.04.2010
• Analyze the change of the load factor in parts of a distribution grid with EV penetration ratio of 25%, 50%, 75% and 100% to each household

• Customer load is represented via standardized load profiles scaled to the total power of the households

• E-Mobility load is represented via self developed EV load profiles, which are also scaled to the sum power at the grid point
  – The EV load profiles are linked to each household in the selected distribution grid
  – Reference loading data for 2 scenarios
    • Fast charging 43 kW in 90 min
    • Slower charging “over night” 11h
E-Mobility: Simulation results

**Scenario 1 ("fast loading")**
Load profile for charging EV in 1½ h without any charging concept

**Scenario 2 ("EV loading concept")**
Load profile for charging EV from 4:30 pm to 03:30 am ("over night") with constant charge power

**Result scenario 1: load factor of the selected distribution grid**

Huge load factor (70%) of the distribution grid in case of 100% EV penetration

**Result scenario 2: load factor at the selected distribution grid**

Charging concept could reduce the load factor of the grid to 8% in case of 100% EV penetration

*Steffen Nicolai, Fraunhofer IOSB-AST, 20.04.2010*
Summary and Outlook

Summary

• Future energy systems with high quota of renewable stochastic generation
• Energy storage could play a role beside other instruments, e.g. grid reinforcement or smart grid technologies
• Optimal operation management of distribution grids needs approaches for the optimal integration for energy storage systems in the grid
• E-mobility as additional load and energy storage has to regard in future system

Outlook

• Optimal dimensioning and placement of stationary energy storage systems is an important research field
• The forecast of additional load from E-mobility
• The combination of the distributed generation and the local demand utilizing energy storages and smart grid technologies is mandatory for future power supply
Thank You!
Questions?

Fraunhofer Application Center System Technology
Am Vogelherd 50
98693 Ilmenau

Business field “Power Systems”
Energy Storage: Dipl.-Ing. Steffen Nicolai
Tel.: +49 (0)3677 461 - 112
E-Mail: steffen.nicolai@iosb-ast.fraunhofer.de