Modellierung zukünftiger auf Erneuerbaren Energien basierender Stromversorgungssysteme

Stefan Weitemeyer, David Kleinhans, Thomas Vogt, Carsten Agert
Herbstsitzung des AK Energie der DPG, Bad Honnef
15. November 2013
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- Founded in 2007 as an independent Research Institute at the University of Oldenburg (D)
- About 100 employees in R&D and admin.
- Research in the fields of Fuel Cells, Energy Storage, Thin-film PV and Energy Systems

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Having energy available at all times is taken for granted these days.

How will the future power supply look like?
Today’s major sources of electricity are nuclear and fossil resources.

How will the mix change in the future?
The Future is ...

Coal is cheap & sufficiently available
But: CO$_2$ emitting
The Future is ...

Nuclear power is cheap and CO₂-free
But: increasing safety requirements & waste-problem unsolved
The Future is ...

Renewable Energy is CO₂-free and might be even cheaper
But: depends on weather
Renewable Energy Sources

What is the potential for integration of Renewable Energy Sources?

- 100% by 2050:
  - RE-thinking (EREC)
  - 100% renewable electricity (PWC)
  - Pathways towards a 100% renewable electricity system (SRU)

- 41% by 2040:
  - The Outlook for Energy - A View to 2040 (ExxonMobil)

- 85% by 2050:
  - Long-term scenarios and strategies ... (DLR/IWES)

- 23% by 2030:
  - EU energy trends (EC, 07)

- 32% by 2030:
  - EU energy trends (EC, 09)
Renewable Energy Sources

- High share of RES: Power production depends on weather

- Upcoming issues with large-scale integration of RES
  - Technological issues, e.g.
    - Voltage stability, balancing power
    - Reactive Power
    - Black-start capability
  - Economic issues, e.g.
    - Current increase in electricity prices
    - Large-scale investments in grids needed to connect RES

- Numerous tools available to study different aspects of RES integration
Renewable Energy Sources

Transformation of the European Power System

- Significant changes in the way we produce and consume energy
- Production by RES is driven not any more by consumer but by the weather
- Many energy-producing consumers (*prosumers*)
Renewable Energy Sources

Conceptual issues:

- How should our future power supply system look like to guarantee a stable, reliable and cheap supply of electricity for everyone?

- How can we study our prospective energy system?
Renewable Energy Sources

- Energy balance
- EU scenarios
- Electricity demand
- RE portfolio

Long-term meteorological data

Source: T. Feck, Presentation in Bosch Forschungskolloquium, 17.03.11
Renewable Energy Sources

Renewable Energy Sources

11.7 GW (6pm)

-0.1 GW (0am)

Hydro storage capacity (Germany)
7 GW / 40 GWh

Storage

Days of calm and “darkness” need to be bridged

Europe

- 500 million people
- 215 million households
- Power consumption: 3500 TWh per year today (+50%? in 2050)
Pumped hydro: 15 TWh (no dams) mainly in Norway, Alps region, Spain

Pumped hydro storage plant in Goldisthal (Germany): 8.5 GWh
One electric car (85kWh) per household: 19 TWh
Storage – Chemical storage can provide seasonal storage

Salt caverns in Europe: 32 TWh (hydrogen)
Storage – and Alternatives

Alternatives

- Storage
- Grid Expansion
- DSM (Smart Grids)
- Optimized Mix
- (Over-) Capacities

Interactions between different system components & reliability analysis → Modelling / Simulations

Source: Vattenfall, Pitopia, Siemens
Grid Expansion

Alternatives

- Storage
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Source: Vattenfall, Pitopia, Siemens
Grid Expansion

Grid expansion allows for balancing production and load over larger distances.
Grid Expansion: reduces need for storage / backup devices

Grid Expansion: No interconnectors

Scenario: national; Day: 1; Hour: 8

Surplus
Deficit
Grid Expansion: Today’s interconnection capacities

Scenario: TodaysGrid; Day: 1; Hour: 8

Surplus
Deficit
Grid Expansion: Extended interconnection capacities
15% of the total EU-27 electricity demand by 2050 can be covered by imports of solar electricity from the MENA region (DLR2009)
DSM (Smart Grids)

Alternatives

- Storage
- Grid Expansion
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Source: Vattenfall, Pitopia, Siemens
Load management / Demand side management (DSM)
   » Actively manipulate demand (by the supplier)

Two classes:
1. Curtailment (energy demand is decreased temporarily)
   Generally high impact on consumers
2. Load shifting (energy demand is conserved)
   Formal analogy to energy storage

→ Quantitative characterisation required!
DSM (Smart Grids) – used for short-term “storage”

- Estimate storage-equivalent potential from scheduled loads (no individual devices are considered)
  - Storage-equivalent of heating devices is up to 100 GWh / 30 GW for Germany in winter
  - Potential to replace short-time storage
  - Usage on local level to overcome technical issues

Source: D. Kleinhans, Towards a systematic characterization of the potential of demand side management, 2013 (submitted)
Optimized Mix

Alternatives

Storage

Grid Expansion

DSM (Smart Grids)

Optimized Mix

(Over-) Capacities

Source: Vattenfall, Pitopia, Siemens
Optimized Mix to better match load curve

Combination of solar and wind resources to match demand

Left: Normalised power production from wind (blue), solar (orange) and demand (red) over a period of 8 years in Europe. Right: Combination of power production from wind and solar with a ratio of 60%/40% (green).

(Over-)Capacities

Alternatives

- Storage
- Grid Expansion
- DSM (Smart Grids)
- Optimized Mix
- (Over-)Capacities

Source: Vattenfall, Pitopia, Siemens
(Over-)Capacities

How soon do we need more storage capacities?

Integration of renewable energy sources into the system

(Over-)Capacities

- Hourly power generation time series (8 years, Germany)
  - Wind $W(t)$
  - Solar $S(t)$
  - Load $L(t)$

- $\gamma$: average renewable energy power generation factor [“installed capacity”]
- $\alpha$: share of wind power generation [(1-$\alpha$) share of solar power generation]

- Mismatch (cf. Heide et al 2010):

$$\Delta(t) = \gamma (\alpha W(t) + (1 - \alpha)S(t)) - L(t)$$

[fixed $\alpha$ and $\gamma$]

(Over-)Capacities

- Decreasing slope means curtailment (lower capacity factor)
- BUT: today already large “over-capacities”

- Power capacities in Europe: 920 GW (non-RES: 600 GW, hydro: 200 GW)
  peak demand: 520 GW

- Capacity factors for current power plants (2005):
  - Nuclear: 0.80
  - Thermal conventional: 0.49

- Limited “over-capacities” needed for large-scale integration of RES

- Controllable RES (biomass, hydro) might fill the top percentages
Limited, highly efficient storage capacities are good to start with.

Results will soon be published – preprint available upon request.

Energy System Modelling

Alternatives

- Storage
- Grid Expansion
- DSM (Smart Grids)
- Optimized Mix
- (Over-) Capacities

Interactions between different system components & reliability analysis
→ Modelling / Simulations

Source: Vattenfall, Pitopia, Siemens
Energy System Modelling

- EU scenarios
- Electricity demand
- Grid model
- RE portfolio
- Long-term meteorological data

Source: T. Feck, Presentation in Bosch-Forschungs-Kolloquium, 17.03.11
Outlook & Discussion

Open questions:

- What is the optimum mix of RES to reduce backup capacities?
- Can the expansion of the European transmission grid significantly reduce the demand for storage capacities?
- Over-capacities vs backup capacities: where is the optimum?
- To what extent can intelligent methods like demand-side management contribute to a reduction of storage capacities?
- Which share of the energy could be imported from the MENA region?

RESTORE2050: research project, coordinated by NEXT ENERGY
Outlook & Discussion

What do we need? DATA

- Load data with higher temporal and spatial resolution
- Detailed, standardized grid model
- Reference data set
  - Physical data (e.g. radiation, wind speed)
  - Technological data (e.g. learning curves)
  - Economical data (e.g. costs for CO₂, prices)
Summary

- A stable and reliable European Power System is possible with a system based mainly on Renewable Energy Sources

- Fluctuations of wind and solar power generation: Need for large storage capacities with high share of RES

- High cost and limited capacities of storage: Need to reduce storage or backup capacities by use of alternative options

- Small storage capacities lead to significant increase of share of RES

- Limited overcapacities needed for large-scale integration of RES
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Fragen? Anmerkungen?

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Appendix