Regenerative Energy Conversion in Germany

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Overview

- Motivation
- Electrical energy situation in Germany
- Regenerative energy conversion
- Integration of large wind power plants
- Summary
- Impact of the use of energy on climatic change:

- Here the impact of electric energy conversion is considered.

- A reduction of carbon dioxide production is necessary.

- Germany can contribute.

- The influence of regenerative energy conversion is discussed.
Asia and America will determine mainly the world energy growth in the next 20 … 30 years!

**Increase of electrical energy in the world**

**Electrical Energy Generation (TWh)**

- W-Europe
- E-Europe
- N-America
- C-/S-America
- Near East
- Asia
- Africa

<table>
<thead>
<tr>
<th>Year</th>
<th>W-Europe</th>
<th>E-Europe</th>
<th>N-America</th>
<th>C-/S-America</th>
<th>Near East</th>
<th>Asia</th>
<th>Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>
World wide trend: Increase of **regenerative energy** contribution to power supply, especially solar, bio mass, but also wind and hydro.
Overview

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- Electric energy conversion in Germany:

- Per year need for electric energy of ca. 510 TWh, with a 1 ... 2% annual increase.

- For these 510 TWh (100%) we need 175 % of primary energy (coal, nuclear power, natural gas) in order to compensate the losses in the power plants and transmission.

- About 75% of primary energy is imported.

- The primary energy for electrical energy conversion is 38 % of total primary energy in Germany (which is 14 440 PJ).

- Electric energy conversion in power plants causes ca. 30 % of the total German CO₂-emission.
Electrical energy conversion – Energy mix (Germany 2006)

- Natural gas 10%
- Nuclear 24.1%
- Black coal 27%
- Brown coal 27%
- Regenerativ 11.9%
- Wind 5%
- Hydro 3.5%
- Bio mass 3.1%
- PV 0.3%
- Brown coal 27%
- Nuclear 24.1%
- Black coal 27%
- Regenerativ 11.9%
- Wind 5%
- Hydro 3.5%
- Bio mass 3.1%
- PV 0.3%
CO\textsubscript{2}–Emissions in different types of power plants

<table>
<thead>
<tr>
<th>Type</th>
<th>kg CO\textsubscript{2} per kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite</td>
<td>0.96</td>
</tr>
<tr>
<td>Black coal</td>
<td>0.78</td>
</tr>
<tr>
<td>Oil</td>
<td>0.76</td>
</tr>
<tr>
<td>Gas</td>
<td>0.35</td>
</tr>
<tr>
<td>Solar (Photovoltaic)</td>
<td>0.2</td>
</tr>
<tr>
<td>Wind</td>
<td>0.020</td>
</tr>
<tr>
<td>Hydro</td>
<td>0.004</td>
</tr>
<tr>
<td>Uranium</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Emissions in kg CO\textsubscript{2}/kWh
- Operation
- Fuel supply
- Construction

Source: Siemens

Prof. Dr.-Ing. habil. Andreas Binder, Institute for Electrical Energy Conversion
Electrical power generation from natural gas and renewables (wind, biomass) will increase. Nuclear power will be stopped (political will).
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Alternative energy conversion for reduction of CO₂

- **Wind energy „off-shore“**: Efficiency ca. 45%, ca. 2500 full load hours
- **Hydro power**: Efficiency ca. 80%, ca. 6500 full load hours
  - Upgrading, refurbishment
  - Additional pump storage plants in neighbor countries
- **Bio mass**: Efficiency 30%, Organic fuel burning is neutral in CO₂
- **Photo voltaic**: Efficiency 10%, ca. 800 full load hours
- **Geothermal energy**: Aim: 3 ... 5 km deep bore holes
- **Still mainly research**:
  - **Fuel cell power plants**: Gas turbine combined with fuel cell
    - Aimed efficiency: 70% (Prototype ca. 300 kW)
    - Solid oxide fuel cell (SOFC) uses hydrogen from reformed natural gas, waste gas is afterwards burnt in gas turbine
  - **Fusion energy**: Heavy water protons (Deuterium) are fusioned to Helium, thus producing fast neutrons (= kinetic energy)
    - Test facility 500 MW ITER under construction in **Cadarache/France**
    - 10 Billion Euros budget: Germany contributes!
### Regenerative electrical power generation (Germany 2006)

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>TWh</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>30.5</td>
<td>5.0%</td>
</tr>
<tr>
<td>Hydro</td>
<td>21.6</td>
<td>3.5% without pump storage</td>
</tr>
<tr>
<td>Bio mass</td>
<td>19.1</td>
<td>3.1% incl. waste gases</td>
</tr>
<tr>
<td>Solar power</td>
<td>2.0</td>
<td>0.3%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>73.2</td>
<td>11.9%</td>
</tr>
</tbody>
</table>

**Brutto-Consumption of electrical power 2006: 615.8 TWh (100%)**

- Consumption + Power station supply + pump storage operation
  - 92% 6.5% 1.5%

**Electrical power generation 2006: 635.8 TWh**

- Utilities + Private + Industry
  - 539.5 45.1 51.2 TWh
Wind power in Germany

30.5 TWh  5.0%
- Rotor blades are pitched to adjust wind power.
- Variable speed operation to extract maximum wind power at variable wind velocity.
- “Pitch 90°” at storm.

### Wind Turbines - Ratings

<table>
<thead>
<tr>
<th>Rated Power $P$</th>
<th>Rotor Diameter $D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 MW</td>
<td>77 m</td>
</tr>
<tr>
<td>2.0 MW</td>
<td>80 m</td>
</tr>
<tr>
<td>2.7 MW</td>
<td>84 m</td>
</tr>
<tr>
<td>3.0 MW</td>
<td>90 m</td>
</tr>
<tr>
<td>3.6 MW</td>
<td>104 m</td>
</tr>
<tr>
<td>4.5 MW</td>
<td>125 m</td>
</tr>
<tr>
<td>5.0 MW</td>
<td>125 m</td>
</tr>
</tbody>
</table>

**Prof. Dr.-Ing. habil. Andreas Binder, Institute for Electrical Energy Conversion**
- Three-blade rotors, pitching for optimum power operation at variable wind speed, full load operation 1500 … 2500 h/y, 40 … 45 % efficiency

**- 5 MW rating** is developed as standard size for the next years!

<table>
<thead>
<tr>
<th>$P$ / MW</th>
<th>$D_R$ / m</th>
<th>$n_R$ / min$^{-1}$</th>
<th>Generator</th>
<th>$v_{Rmax}$ / km/h</th>
<th>$v_n$ / m/s</th>
<th>Gear $i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>77</td>
<td>9...17</td>
<td>DS-ASM</td>
<td>247</td>
<td>3...20, 11.1</td>
<td>104</td>
</tr>
<tr>
<td>2.0</td>
<td>80</td>
<td>9...19</td>
<td>DS-ASM</td>
<td>287</td>
<td>4...25, 15</td>
<td>ca. 100</td>
</tr>
<tr>
<td>2.7</td>
<td>84</td>
<td>6.5...18</td>
<td>DS-ASM</td>
<td>285</td>
<td>4...25, 14</td>
<td>70.65</td>
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<tr>
<td>3.0</td>
<td>90</td>
<td>10...20</td>
<td>PM-Syn</td>
<td>339</td>
<td>3 ... 20</td>
<td>Gearless</td>
</tr>
<tr>
<td>3.6</td>
<td>104</td>
<td>8.5...15.3</td>
<td>DS-ASM</td>
<td>300</td>
<td>3.5...25, 14</td>
<td>ca. 100</td>
</tr>
<tr>
<td>4.5</td>
<td>104</td>
<td>ca. 7 ... 13</td>
<td>Syn-G SL</td>
<td>ca. 300</td>
<td>3 ... 25</td>
<td>Gearless</td>
</tr>
<tr>
<td>5.0</td>
<td>125</td>
<td>7...13</td>
<td>DS-ASM</td>
<td>306</td>
<td>4...30, 12</td>
<td>98.3</td>
</tr>
</tbody>
</table>

**DS-ASM**: Doubly fed induction generator: Rotor fed via slip ring set from inverter (inverter rating 30%)

**PM-Syn / Syn-G SL**: Synchronous generators: Permanent magnet & electrical excitation, gearless or low transfer ratio < 10, 100% inverter rating
Geared wind turbines - Example: 5 MW

- Wind rotor: 110 t
  - Rotor blade
  - Rotor spider
  - Turbine shaft
- Generator-Cable to the grid, three-phase 690 V
- Nacelle: 240 t
- Three-stage gear 1:100
- Generator shaft + Coupling
- Doubly-fed induction generator, needs slip rings
- Rotor feeding inverter, 1/3 of generator rating
- Transformer for increase of voltage 690V/20 kV
- Mast

Source: Winergy, Germany
Hydro power in Germany

21.6 TWh  3.5%
Large Hydro Power

- Equivalent full load hours typically 6000 … 7000 h/y, efficiency ~ 80%
- In Germany: Limited potential for new plants
- Focus on: - Refurbishment – Increase of efficiency
  - Increase of power rating in existing pump storage plants in neighboring countries
Needed a) to equalize wind power, b) grid stabilization in a liberal market

Examples:
- Kopswerk (Austria): + 500 MW (= + 100%), co-financed by EnBW
- Vianden/Luxembourg (additional 10th generator)
Innovation: Speed variable pump storage operation:

Two of 4 turbines operate at variable speed with data:
2 x 340 MVA, 300 ... 346/min, 18 poles, 50 Hz

Asynchronous doubly-fed generators, rotor fed via cyclo-converter

- Improved efficiency
- Enhanced operation

Source: VA Tech Hydro
Bio mass in Germany

19.1 TWh  3.1%
**Bio mass power plants**

- **Bio mass:** Burning of organic material
  - wood, - gas from garbage deposits
  Produced CO\(_2\) equals consumed CO\(_2\) during growth of the plants
- **CO\(_2\)-neutral**
- **Problems:** Deposits and corrosion in the burning chamber

**Examples:**

*Landesbergen (D) (2003):* 20 MW el. power, 31% efficiency, wood

*Düsseldorf (D):* (08/2007): 25 GWh/a el. Power, 78 GWh/a heating

- **Research:** Wood gasification, burnt in combined cycle power plants:
  expected efficiency: 40%
  mixed with natural gas: 60%
Solar power in Germany
(Photo voltaic)

2.0 TWh  0.3%
Solar power - Photovoltaic

Basic principle of photo diode as electric DC voltage source

Vision of future large array photo-voltaic power plant in southern regions

**Germany: 2006:**
- 750 MW new installed photovoltaic power (private & utilities)
- Totally installed power: 2.6 GW; delivered energy to the grid: 2 TWh
- Island-use (e.g. traffic systems): totally 32 MW installed power!
Photovoltaic power plants (D)

Germany: 2006:

Over 30% thin layer solar cells in use in new solar parks!

Examples:
- Solar park Gut Erlasee: (Arnstein/Bavaria): 12 MW peak power
- Solar park Pocking (Bavaria): 10 MW peak
- Solar park Leipziger Land (Saxonia): 5 MW peak
- BGZ Solarpark Passauer Land (Bavaria): 3.3 MW
- Bürgersolarpark Fünfstetten: 1.7 MW peak
- Under construction: till 2009
  Solar park Waldpolenz (Leipzig): 40 MW pk
  550000 solar modules
  covered area: 220 hektar
  40 Million kWh/a
  20000 tons CO₂ saved per year
Photovoltaic power generation (D)

Solar park Leipziger Land (Saxonia): 5 MW peak
Source: GEOSOL

Germany:

Since 2006: Largest installed photovoltaic peak power in the world (2.6 GW) – Second: Japan

- Installed photovoltaic power per capita: 150% of Japan
Geothermal power in Germany

First projects
Geothermal potential in Germany

Per 100 m depth plus 3°C rock temperature

1000 m depth
- 120°C
- 22°C
- 174°C

3000 m depth
- 54°C

Prof. Dr.-Ing. habil. Andreas Binder, Institute for Electrical Energy Conversion
Electrical energy conversion with geothermal power plants

- 3 km deep bore hole: ca. 120°C hot water – evaporates at the surface: but steam pressure too low for turbine operation

- **Kalina-cycle**: Heat exchanger: Water-Ammoniac-mixture (low boiling point: ammoniac: -33°C): high steam pressure sufficient for turbine

- Closed cycle between heat exchanger and cooling tower

- **Project Munich-Unterhaching** (2007): 3300 m, 122°C, 150 l/s, 3.3 MW electrical power

- In addition:
  - Cogeneration of heat
  - central heating for 10 000 persons, 25 l/s
  - 12000 tons CO₂ are avoided per year

*Source: Siemens*
STILL IN RESEARCH:
Hot Dry Rock - Cycle

- When no hydrothermal rock bed is found: **Hot Dry Rock-Cycle**: Injection of surface water to produce steam

- Between injection hole and extraction hole an **artificial hydro circulation** is installed

- Via **hydraulic stimulation** (= high pressure water injection) cavities are produced in the rock bed. Here the water can circulate.

- 4 … 6 km deep holes are needed. Test drillings have been done (e.g. near **Speyer** in the **Rhine** valley)
  **Deep drilling is expensive!**

*Source: TU Darmstadt, Prof. Katzenbach*
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• Summary
3-phase, AC:
380 kV
220 kV

Single phase, HV DC

Connection sub-sea to the Baltic
Regenerative and small power energy sources – decentralized grid

Integration of
- Wind farms
- Fuel cell plants
- Photo-voltaic
- Small bio mass

Partially dual directed energy flow!
Integration of big wind power flow

Installed wind power, Europe, 2004: 34.2 GW

- Germany:
  - installed wind power: 16.6 GW (22% of peak load)
  - produced wind energy: 26 TWh (5% of consumed energy)
Wind power: Daily availability

Energy of 5400 wind turbines at 28.10.2001

Load curve of the grid

Source: ISET

Prof. Dr.-Ing. habil. Andreas Binder, Institute for Electrical Energy Conversion
Wind power: Monthly availability

Energy of 5400 wind turbines during October 2001

Wind Generation [MW]

Days
Wind power availability – Additional storage necessary

- Additional storage: pump storage magnetic storage
- Better wind prediction

Source: Komarek, FSZ Karlsruhe
Future: Large magnetic storage device?

- **Superconducting ring coils**
  - 269°C (Liquid Helium)
  - 360 coils!
  - 5000 MWh

- **Energy storage in the magnetic field**
  - 150 kA
  - 9 T

- Source: Max Planck Gesellschaft

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Coil current: 150 kA
Magnetic flux density: 9 T

520 m
26 m
Wind energy
Flow across the country

Northern Germany: many wind farms, but low consumer density

Consumer centers, where the power is needed

Main power flow directions

- Liberalized market and
- Increased size of wind farms

The high voltage grid needs
a) to be enlarged
b) thermal monitoring
c) FACTS to avoid reactive power.
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• **Germany** is world leader in installed wind power and photo voltaic

• Regenerative energy **shall increase from 11% to about 25%** in electric energy production in Germany

• Electrical power generation: **NOT revolution, BUT Evolution**

• Find the right **Energy-Mix with a co-existence of conventional and – with increasing part – of regenerative energy sources**

• Increased need of new storage devices and new power transmission lines
Thank you for your attention!

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