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Electrical Power Systems

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Improved grid integration of wind energy

3rd April 2009, Zielona Gora

Content

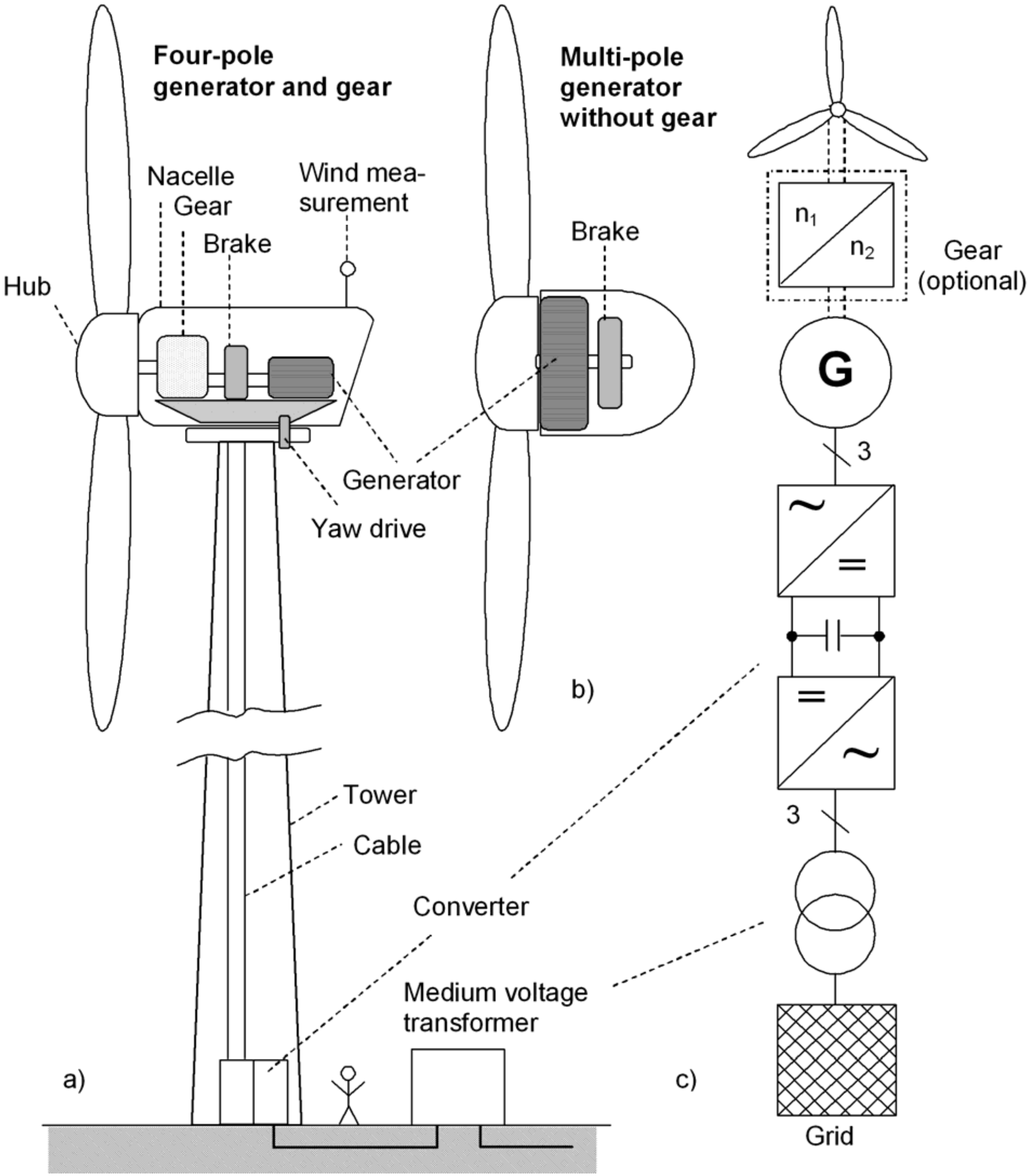
- ⇒ **Renewable energies in Germany**
- ⇒ **WT technology**
- ⇒ **Grid integration**
- ⇒ **Renewable Energy Law 2009**
- ⇒ **Future Demands**
- ⇒ **Virtual power plants**
- ⇒ **Grid impedance**
- ⇒ **Energy storage**
- ⇒ **Capacity analysis of mining lakes**
- ⇒ **Storage capacity**
- ⇒ **Summary**

Renewable energies in Germany

Share on the electrical consumption 2008, Source: BEE

Energy source	Share in %
Wind energy	6.4
Biomass	4.6
Hydropower	3.5
Photovoltaic	0.7
Geothermal	0.1
Total	**15.3**

2009: 23.9 GW installed wind energy power



Grid connected Wind Turbine

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a) Four-pole generator with gear

b) Multi-pole generator without gear

c) Schematic drawing

Drive train concepts

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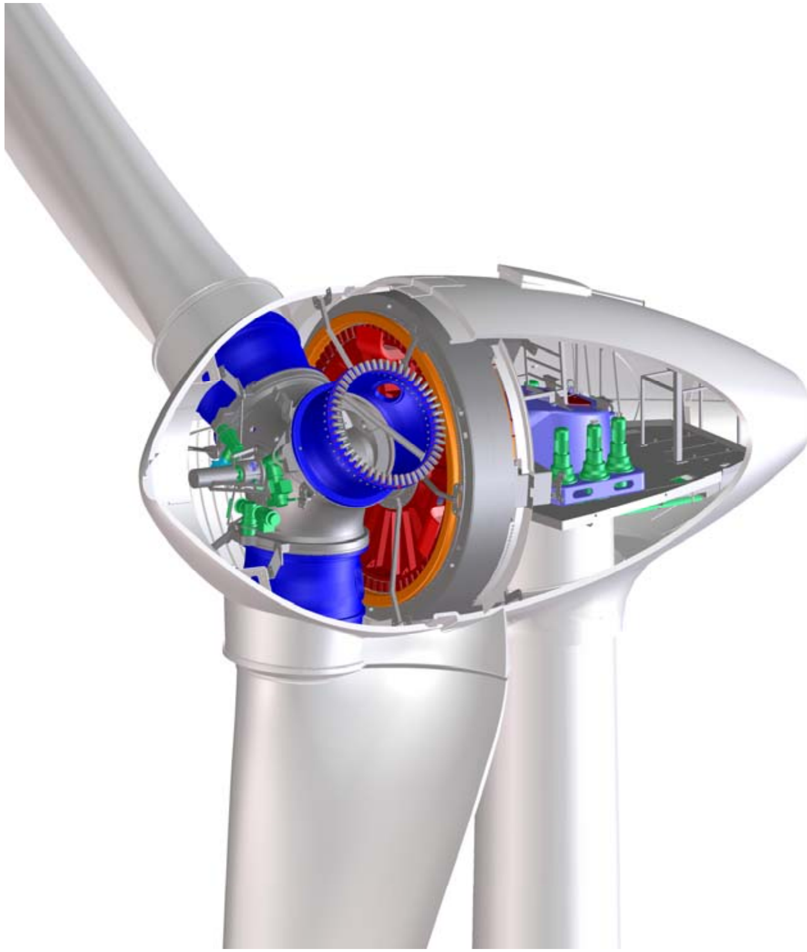
Generator and gear

Picture: Nordex

Gearless, multi pole generator



Picture: Enercon

Grid coupling: generator types

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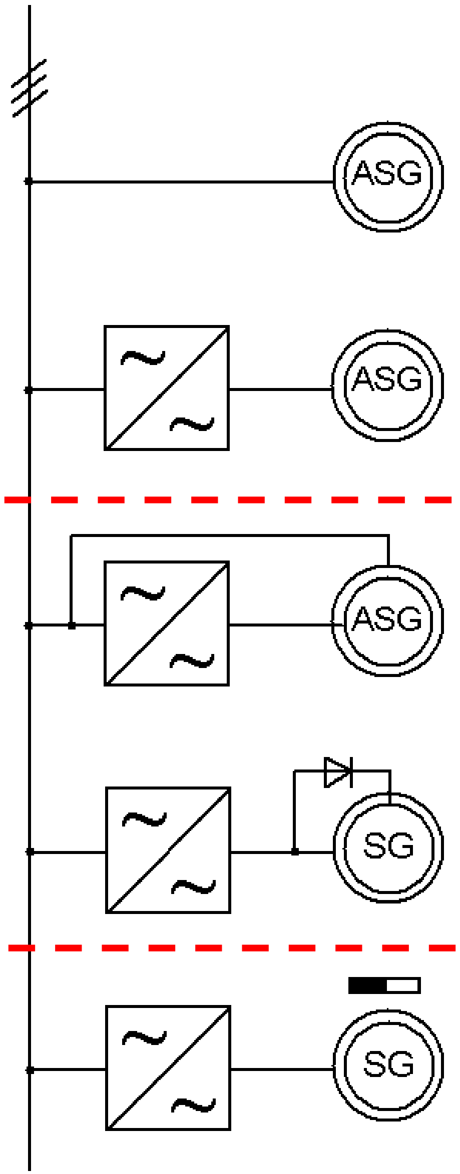

a) Direct coupled asynchronous generator (induction machine)

b) Converter coupled asynchronous generator (induction machine)

c) Double-fed asynchronous generator

standard MW power class

d) Converter coupled synchronous generator

e) Converter coupled synchronous generator with permanent excitation

Principle grid connection of wind parks

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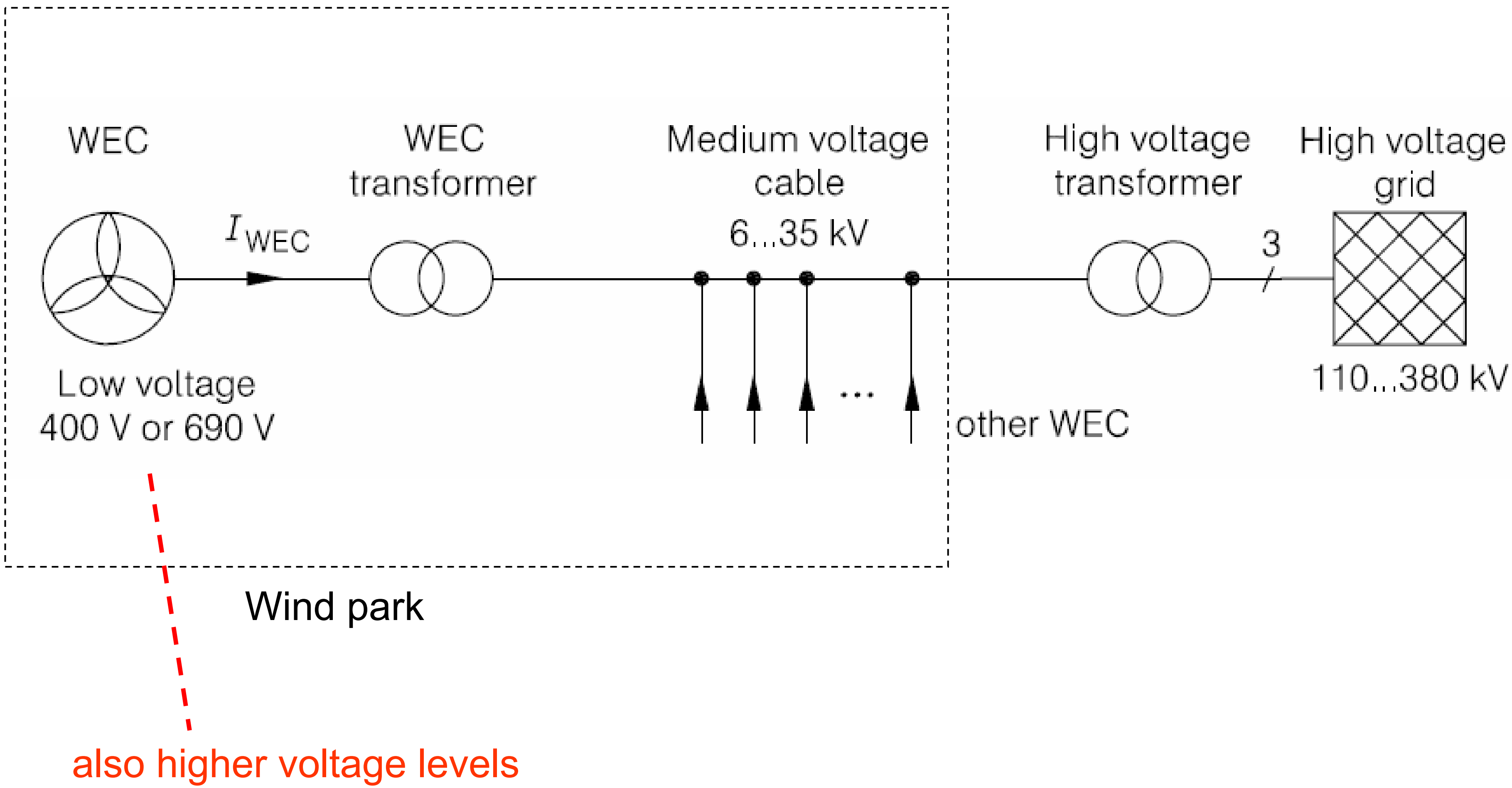

Typical wind park structure

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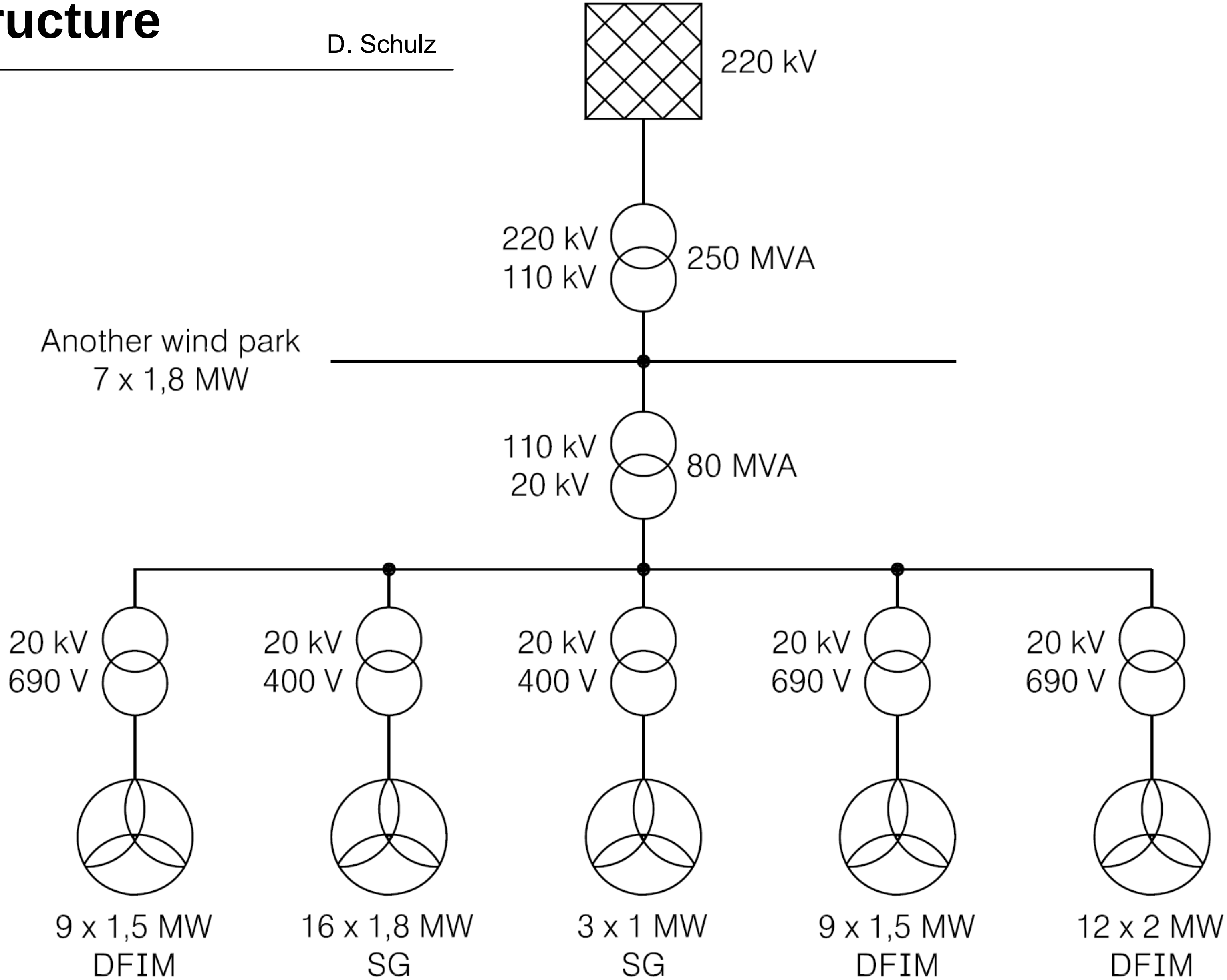

WT with 5 MW power in offshore design

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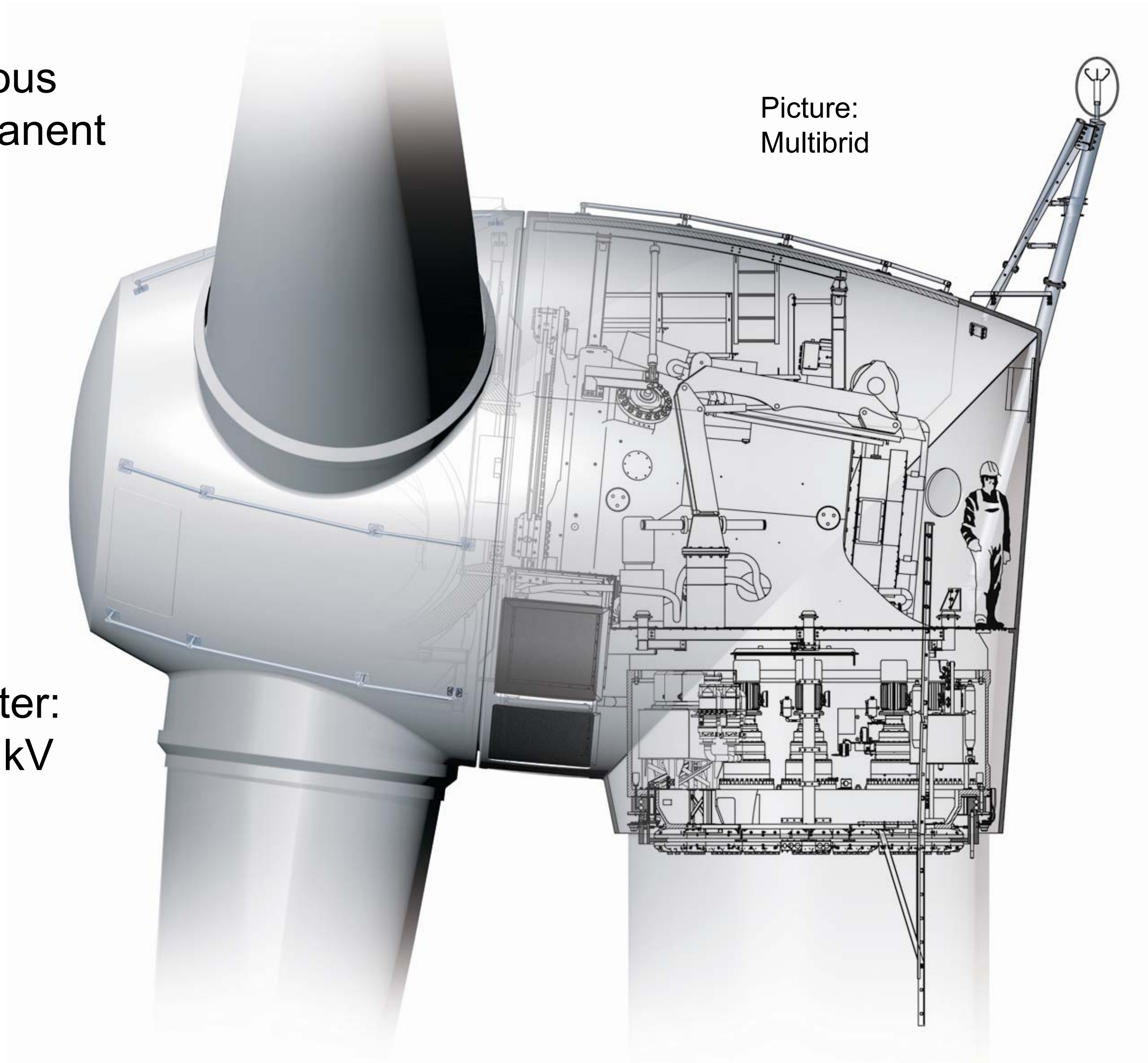
Multi-pole synchronous generator with permanent magnet excitation, slow-speed gear

Special design for offshore-installation

Low weight of the generator

Generator and inverter: medium voltage 3.3 kV

Two prototypes, six offshore WTs next year



Picture: Multibrid

Grid integration:

a) Grid compliance

b) Stability of energy supply

Active and reactive power delivery

Grid services

Germanys Renewable Energy Law 2009

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Before 2009: renewable energies have always grid connection priority

2009: wind energy has to fulfil “minimum” technical requirements to get priority in grid connection:

- behaviour during grid failure events
- voltage control and reactive power supply
- frequency control
- proof of the required properties (certificate)
- power system reconstruction after blackout
- extension of existing wind parks

Different rules for new and old devices,

system service bonus of 0,5 Cent/kWh.

Active power output during voltage drops

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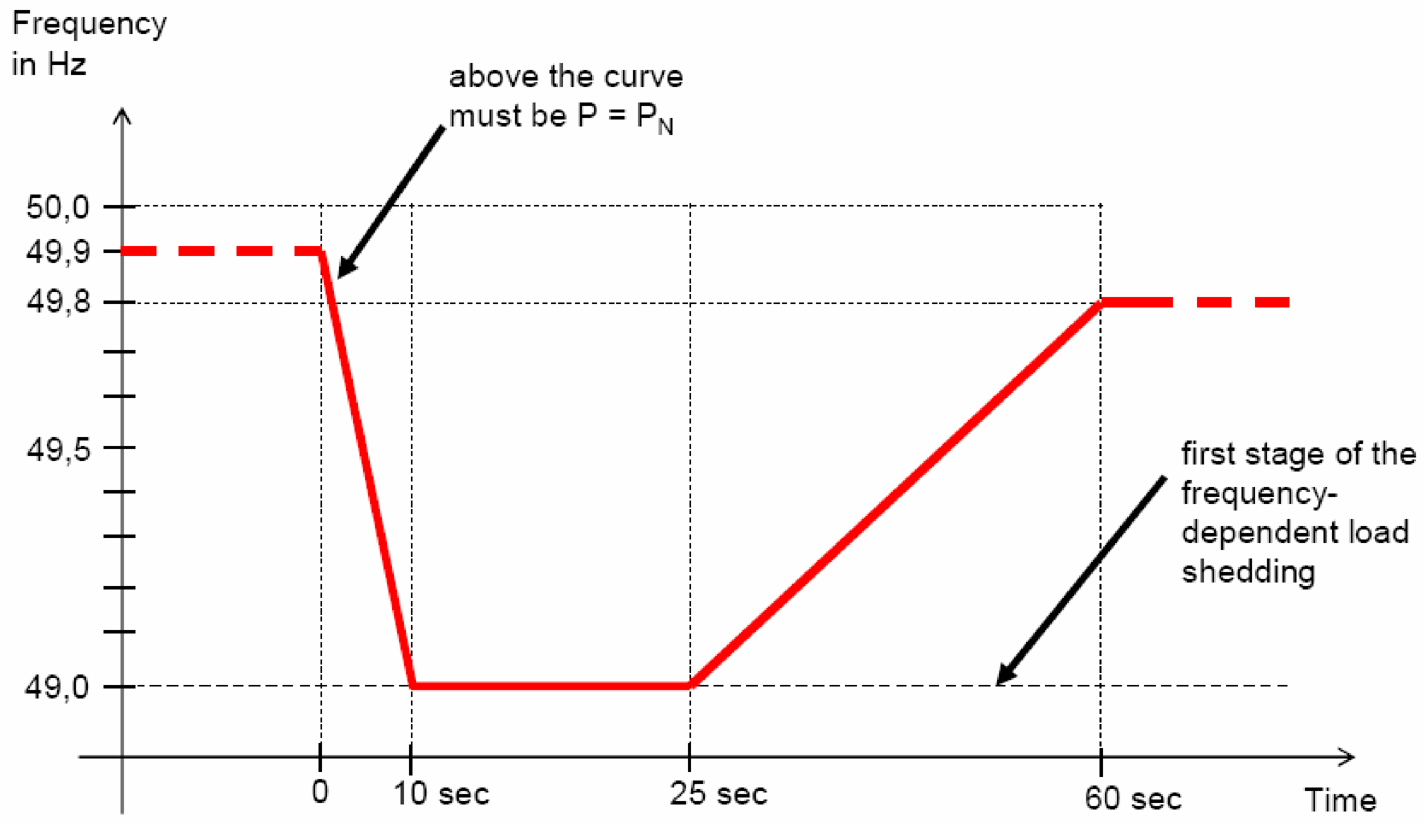
(E.ON Grid Code. High and extra high voltage, 1. April 2006, p. 11)



→ New adjustment of the frequency relays in the WEC control was necessary

Figure 2 Frequency envelope for frequency drops in which there may be no limitation of the active power output

Active power output over frequency

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(E.ON Grid Code. High and extra high voltage, 1. April 2006, p. 11)

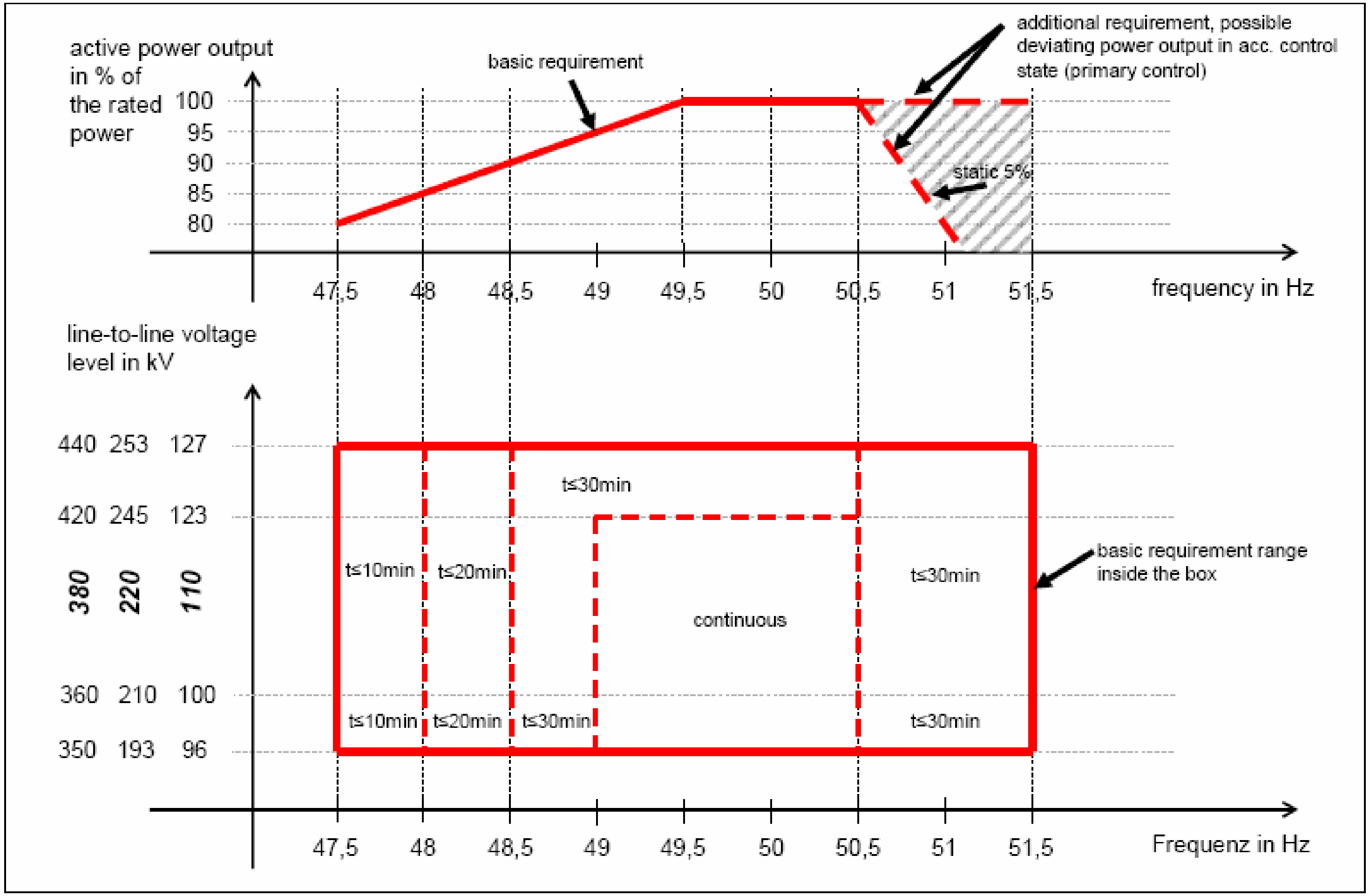

Figure 3 Requirements placed on the output power of a generating plant to the grid for certain periods, as a function of grid frequency and grid voltage (quasi-stationary observation, i.e. frequency gradient < 0.5% / min., voltage gradient 5% / min.)

Dynamic voltage drops, type 2 plants

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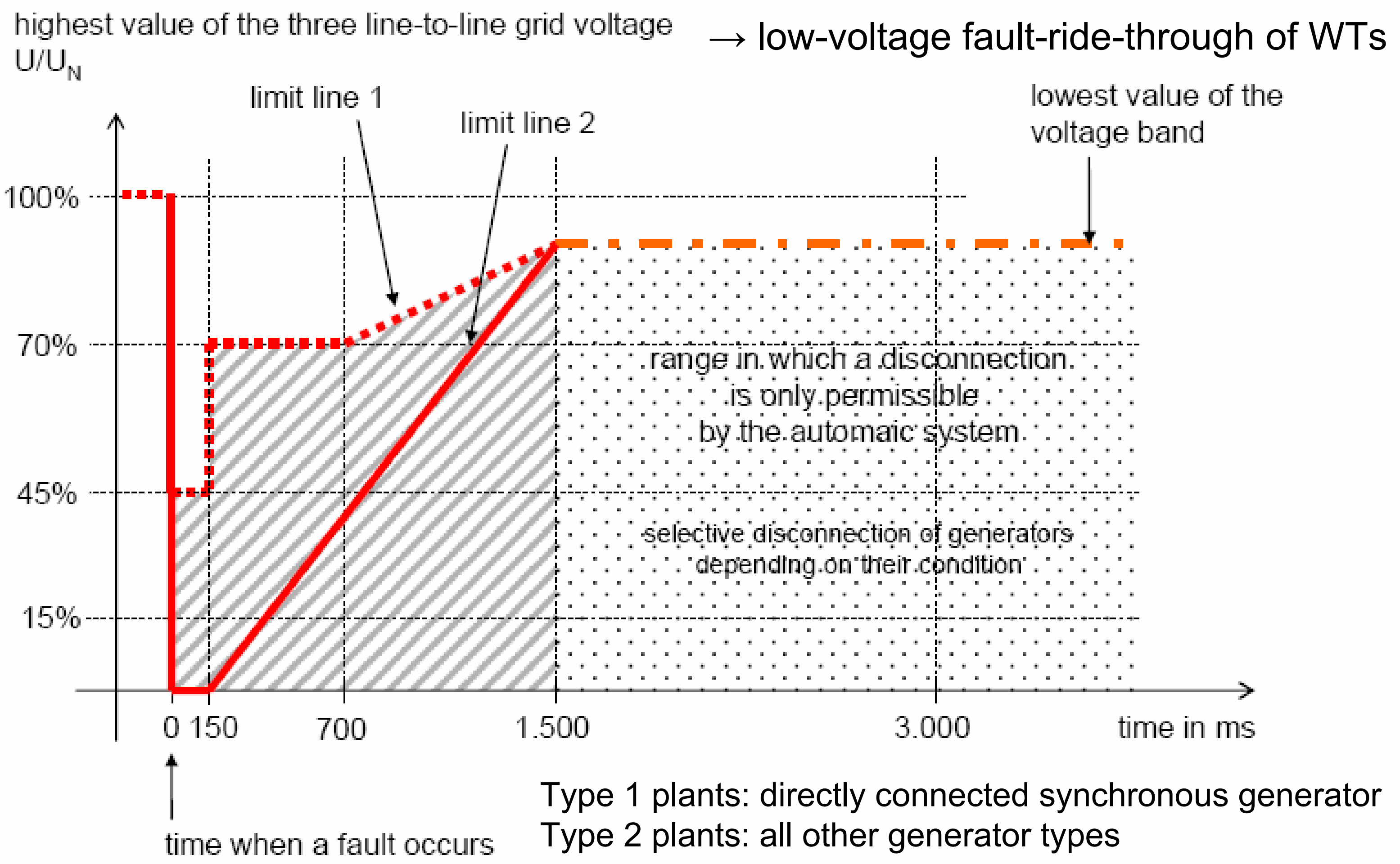

Type 1 plants: directly connected synchronous generator
Type 2 plants: all other generator types

(E.ON Grid Code. High and extra high voltage, 1. April 2006, p. 17)

Figure 6 Limit curves for the voltage pattern at the grid connection for Type 2 generating plants in the event of a fault in the grid

Wind energy 2009 and future demands

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End of 2008: 23.9 GW (40 TWh)

Wind energy: 6.4 % share on the electrical energy consumption in Germany

all renewable energies have 15.3 %

By 2020: increase of the renewable share **up to 25 or 30 %**

Essential: Stability of energy delivery

- **Energy transport**
  - **a) Grid retrofitting**
  - **b) Grid construction**
  - **c) Capacity utilisation of the PCC**
- **Grid control**
- **Energy storage (offshore wind farms and local power hot spots)**

Principle of an overhead transmission line

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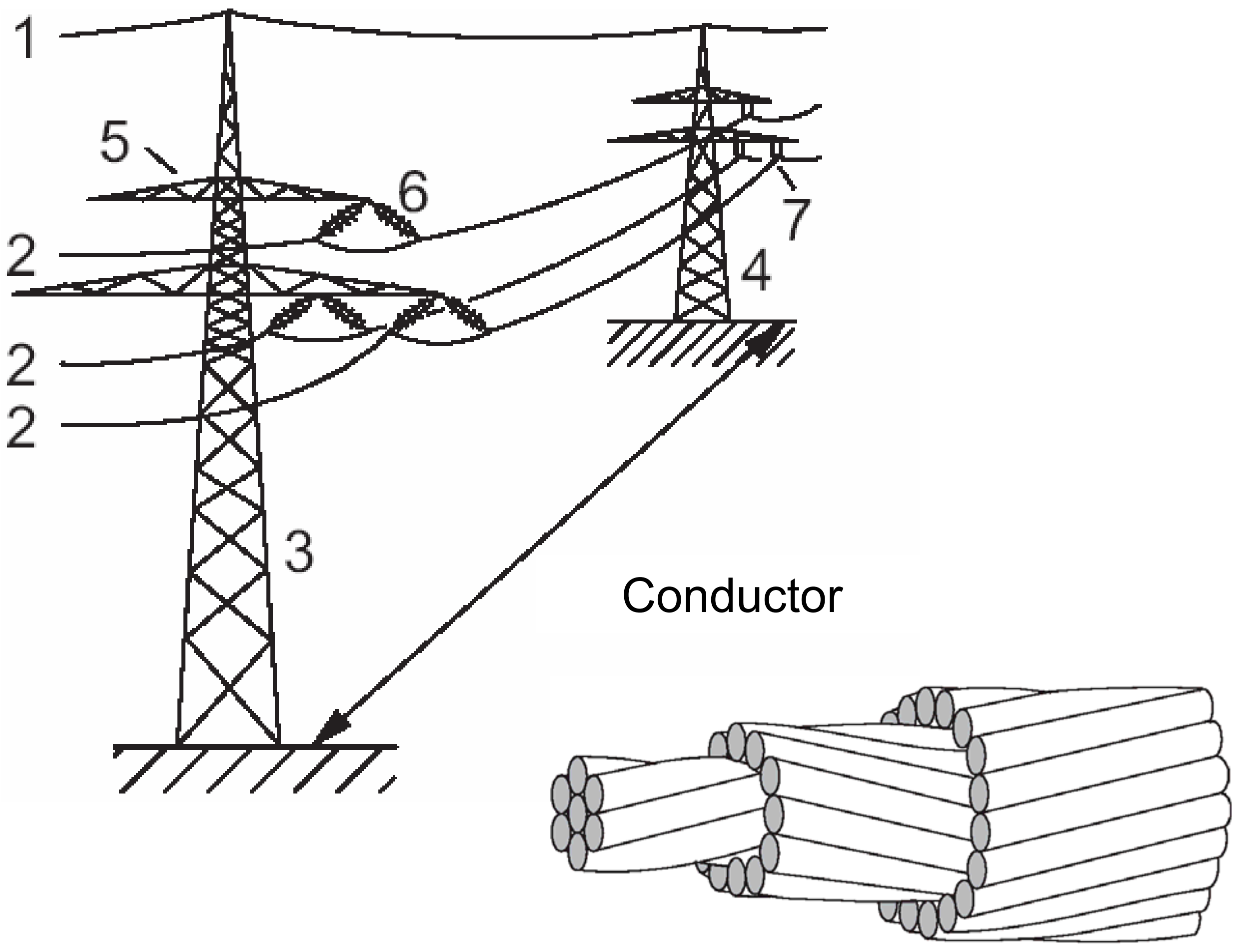

Energy transport: conductor design

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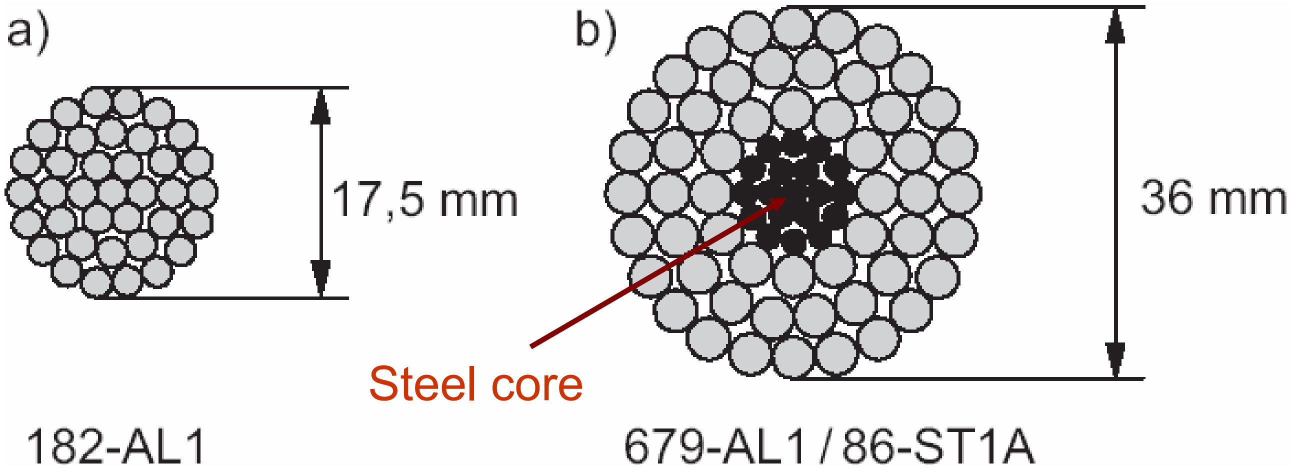
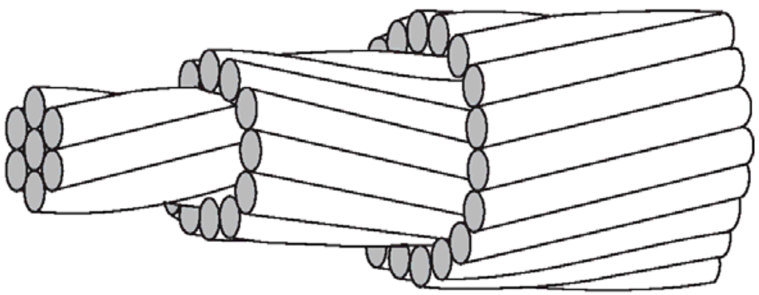


Low power conductor

Compound conductor



Limit temperature: 80°C

DIN EN 50182:

ambient temperature of 35°C

wind speed of 0.6 m/s

100 % sun insolation

→ higher capacity utilisation by temperature monitoring

Grid retrofitting: High temperature conductors

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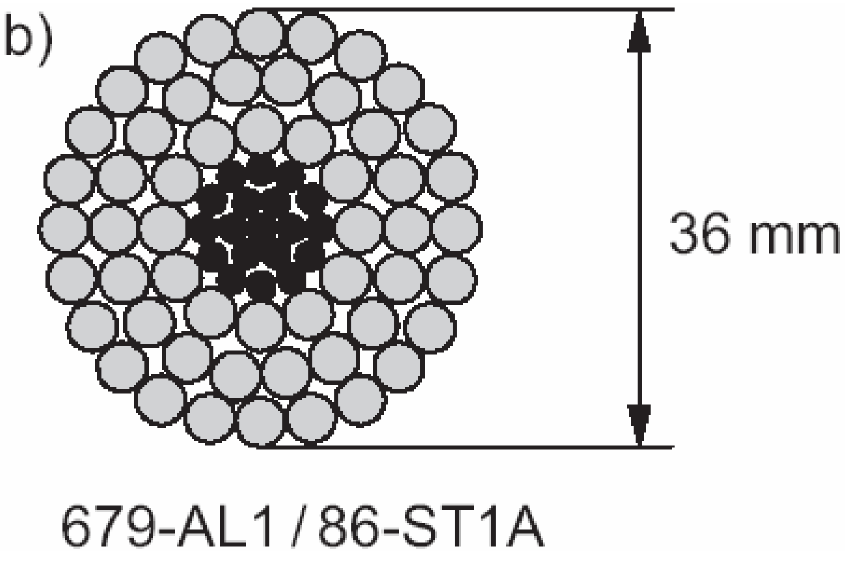

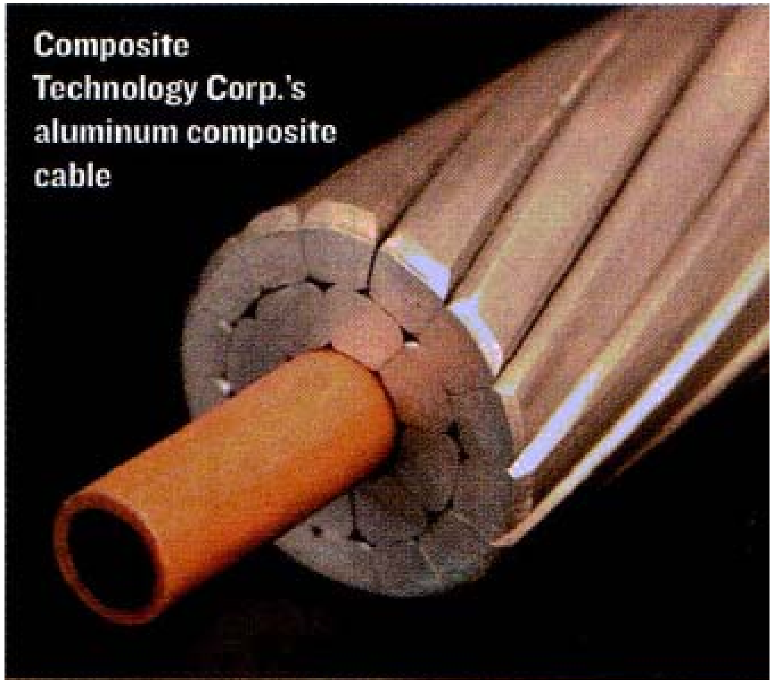

Composite core = plastic compound: no eddy current losses

Temperature limit is 150°C instead of 80°C

Transmitted power: doubled, but higher transmission losses

Virtual power plants

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- distributed power plants work together → hybrid power plant
- combination of fluctuating and continuously working energy sources
- Example 1: 120 MW wind power and 500 kW biomass (Prenzlau)
- Example 2: 80 MW wind park (Dardesheim) and 80 MW pump storage
- Example 3: Hydrogen production (Prenzlau)

- Level 1: Consideration of different single power plants as one power plant, realisation of an agreed output power
- Level 2: Coordinated control of the loads flows in the transmission system: SmartGrids → power electronic load flow control, sophisticated grid operation

Grid impedance over time and frequency

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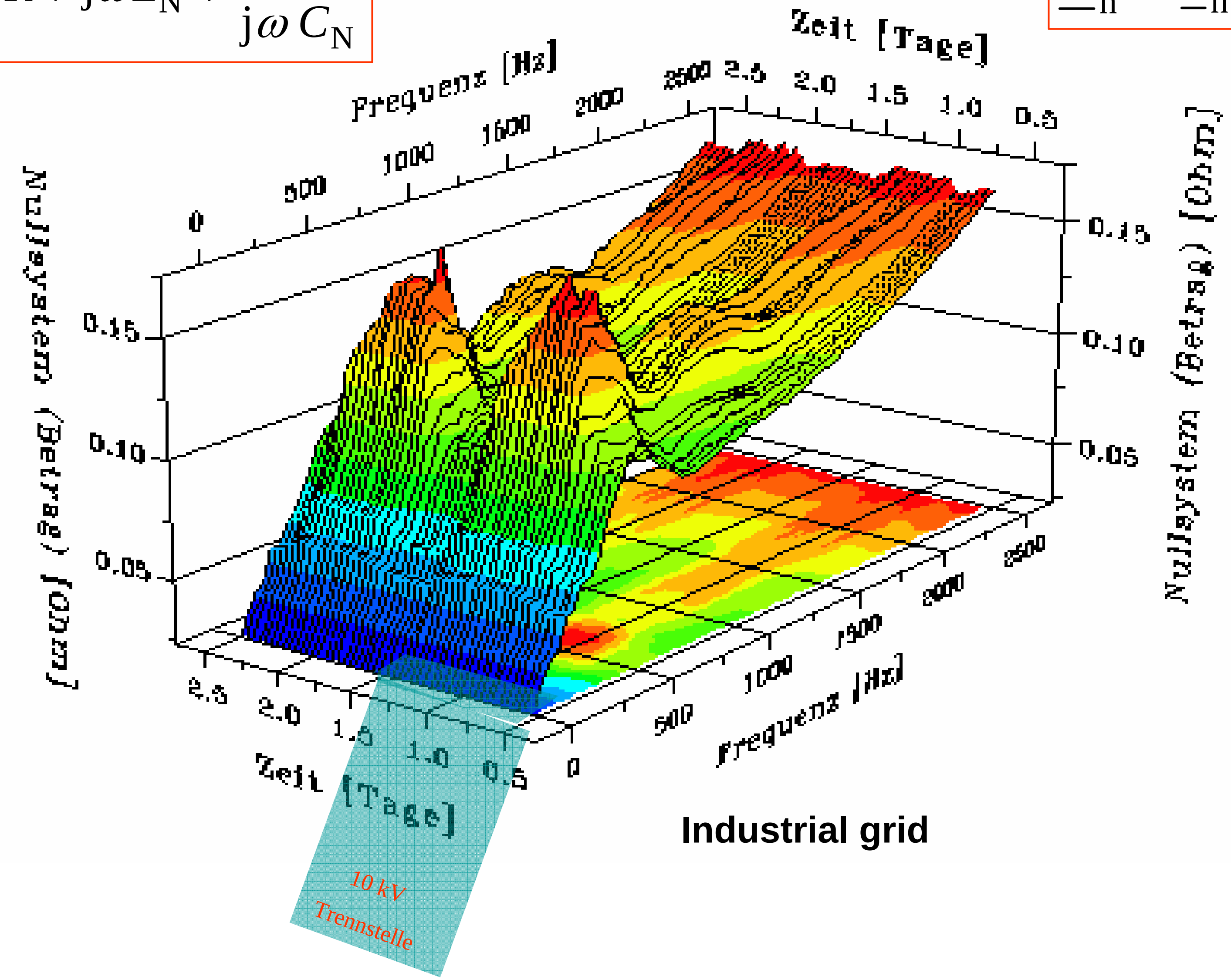
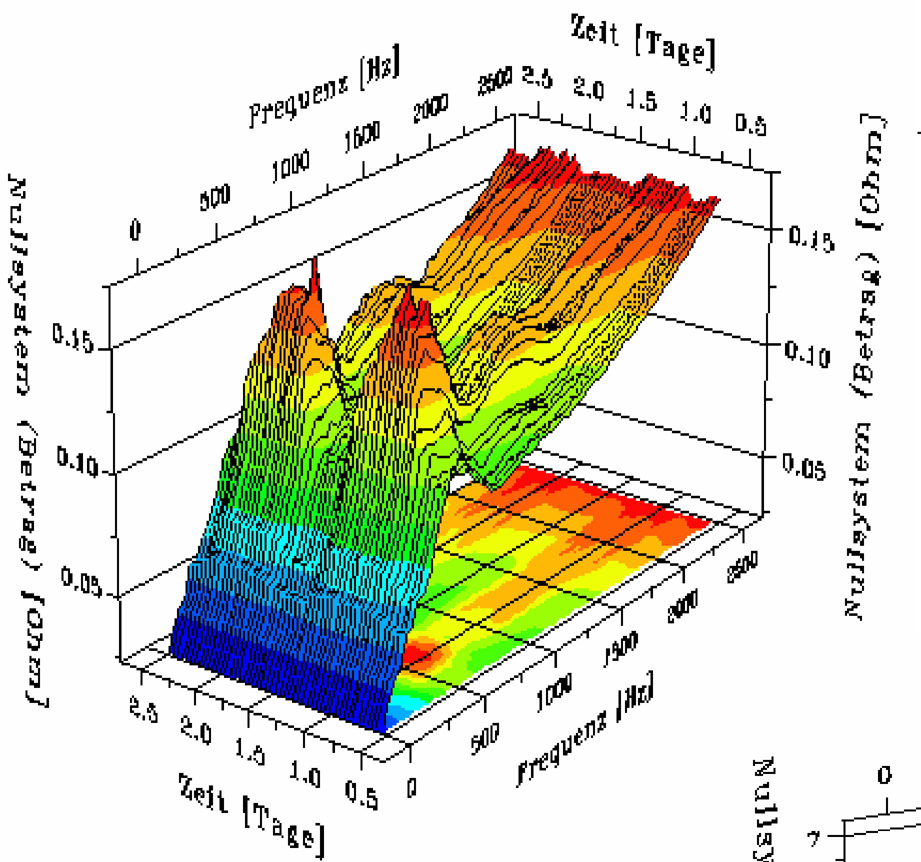
$$\underline{Z}_{\mathrm{N}} = R + \mathrm{j}\omega L_{\mathrm{N}} + \frac{1}{\mathrm{j}\omega\, C_{\mathrm{N}}}$$

$$\underline{V}_{\mathrm{h}} = \underline{I}_{\mathrm{h}} \cdot \underline{Z}_{\mathrm{N}}$$



Industrial grid

Impedance measurement

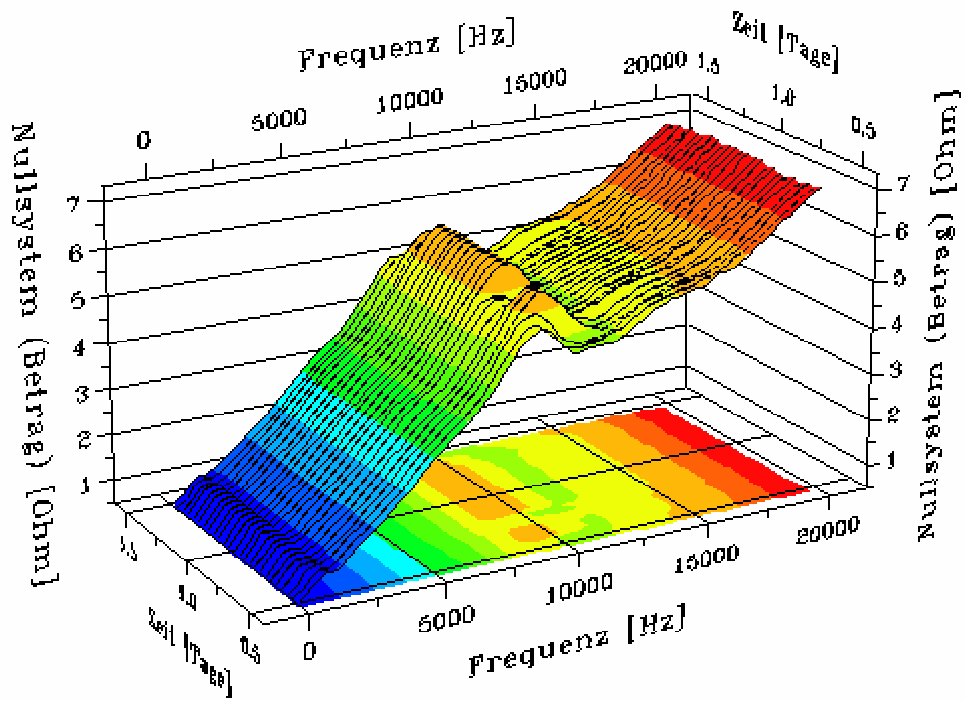


$$\underline{Z}_{\mathrm{N}} = R + \mathrm{j}\omega L_{\mathrm{N}} + \frac{1}{\mathrm{j}\omega C_{\mathrm{N}}}$$

Laboratory grid:
1.5 Ohm at 2.5 kHz

Industrial grid structure with low impedance:
0.15 Ohm at 2.5 kHz

$$\underline{V}_{\mathrm{h}} = \underline{I}_{\mathrm{h}} \cdot \underline{Z}_{\mathrm{N}}$$



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Measurement of the grid impedance

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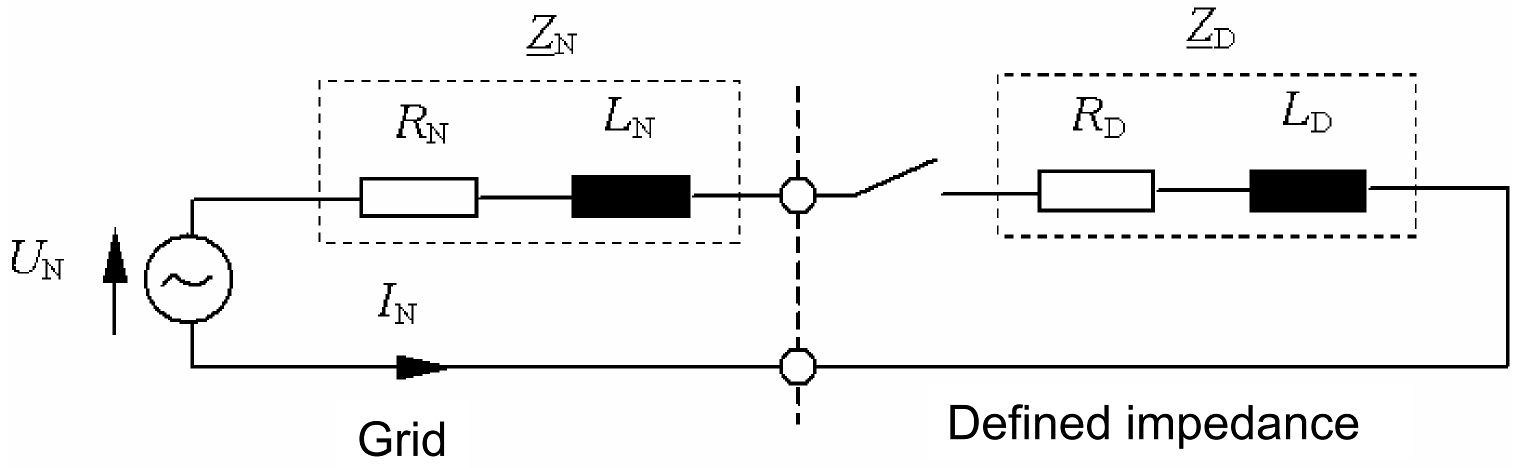

$$\underline{Z} = R + jX = \frac{\underline{U}}{\underline{I}} = \frac{U \cdot e^{j\varphi_u}}{I \cdot e^{j\varphi_i}} = \frac{U}{I} \cdot e^{j(\varphi_u - \varphi_i)}$$

$$\underline{Z} = R + jX = \frac{\Delta \underline{U}}{-\Delta \underline{I}} = \frac{\underline{U}_1 - \underline{U}_2}{\underline{I}_2 - \underline{I}_1}$$

If only the absolute value is of interest, contributes the no-load measurement one calculation point :

$$\left|\underline{Z}\right| = \frac{\left|\underline{U}_N - U \cdot e^{j(\varphi_u - \varphi_i)}\right|}{\left|\underline{I}\right|}$$

Project: Measurement of the frequency-depending grid impedance of the medium voltage grid, funded by German Ministry of Environment and Reactor Security (BMU)

Renewable energies in Germany

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- in 2009: over 15 percent of the German energy supply was delivered by renewable energies, 6.4 % by wind energy
- now over 24 GW wind power is installed in Germany
- in future this trend will continue with offshore wind installations
- offshore planning at the German coast lines includes over 30 wind parks with a total power of 27 GW
- these parks will have only some MW in the first project stage, in the second stage powers of 1000 MW and more per wind park
- their grid integration will require also **new storage approaches**

Power hot spots: Per capita wind energy feed-in

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federal states of
- Saxony-Anhalt (39%)
- Mecklenburg-Western Pomerania (36.5%)
- Schleswig-Holstein (35.98%)
- Brandenburg (30%)

- over proportional concentration in the eastern and northern part of Germany:
  local solutions are required for power spots
- possibility: in the federal states of Brandenburg, Saxony and Saxony-Anhalt exist remaining coal-mines of the open cast mining


www.lausitzer-braunkohle.de

Open cast mining in Germany

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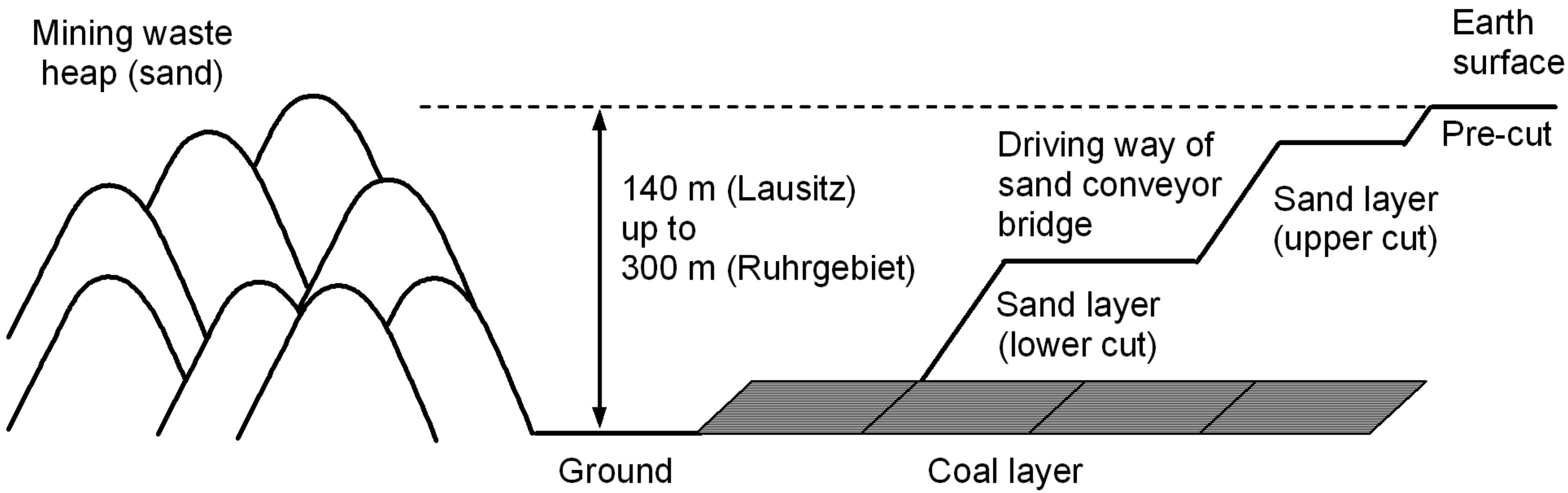

Pumped water storage plant in open cast mining

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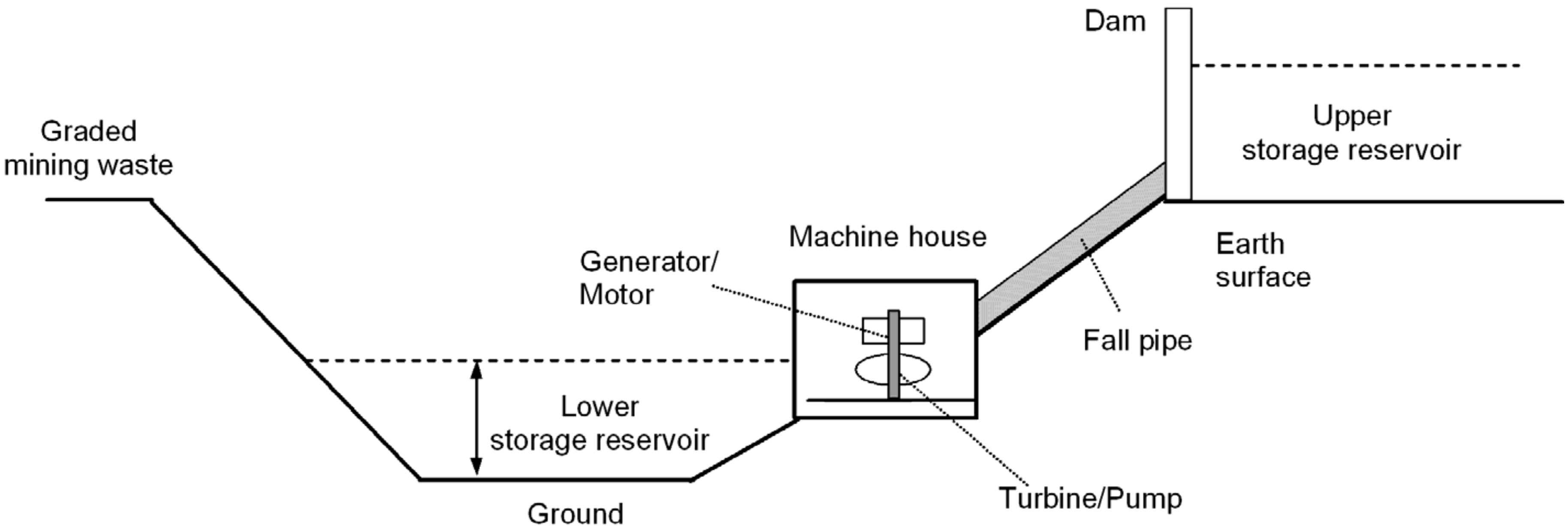
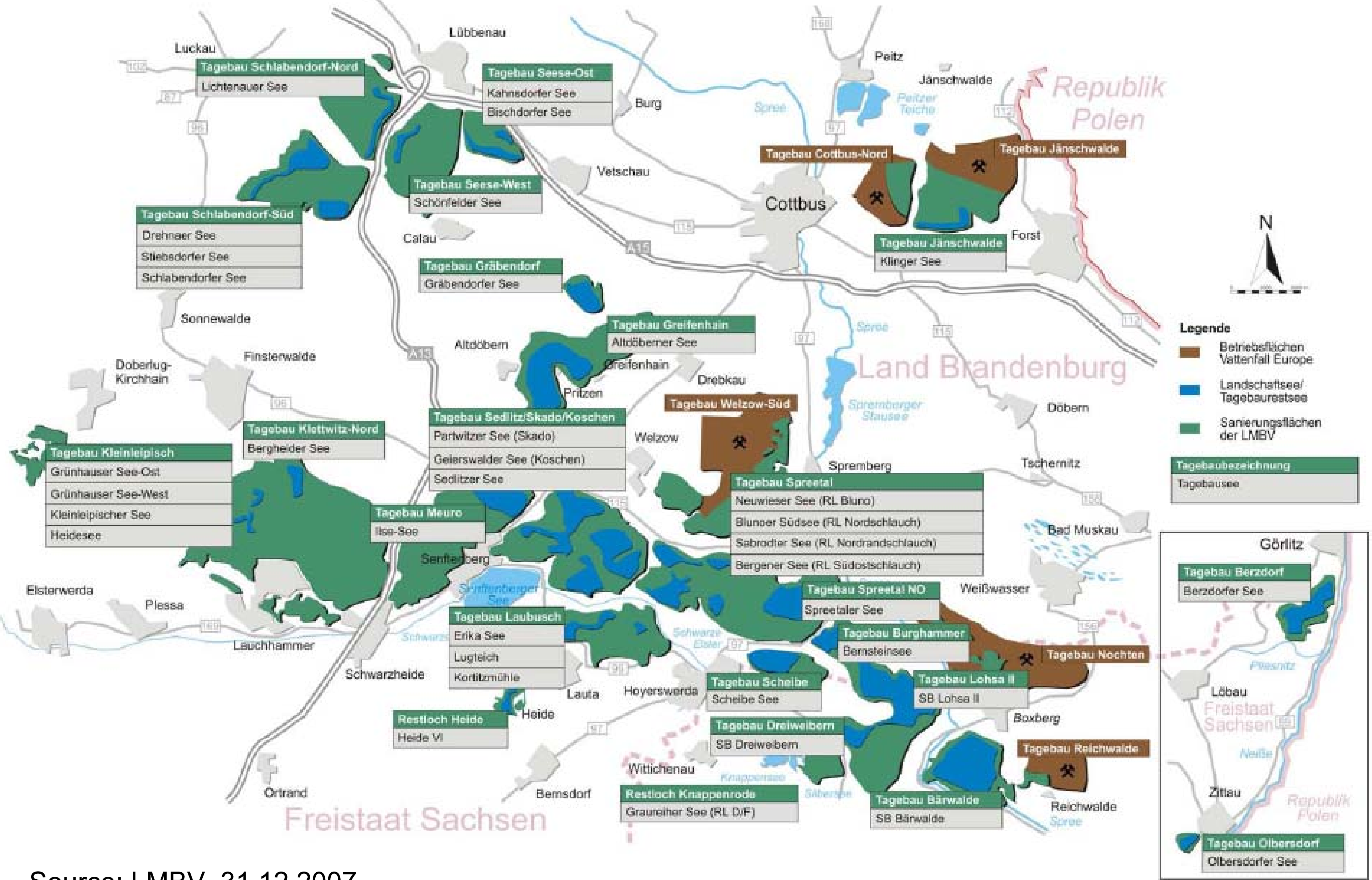


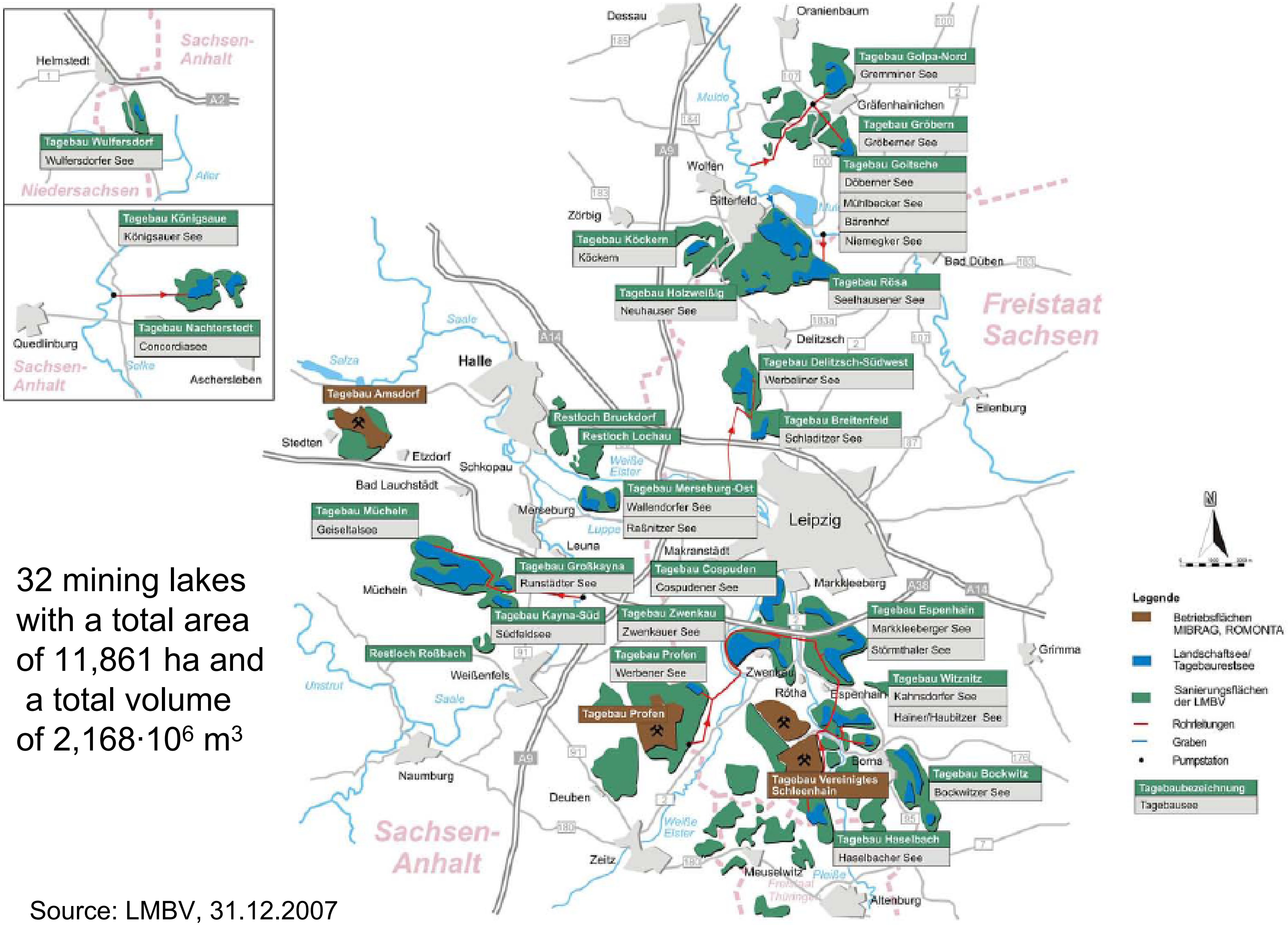
36 mining lakes with a total area of 14,657 ha, the total volume is $2{,}343 \cdot 10^6$ m^3

Water planning concept of the area Lausitz



Source: LMBV, 31.12.2007

Wasserwirtschaftliches Planungskonzept Mitteldeutschland



32 mining lakes with a total area of 11,861 ha and a total volume of $2{,}168 \cdot 10^6$ m^3

Source: LMBV, 31.12.2007

Total capacity of the mining lakes of the two areas

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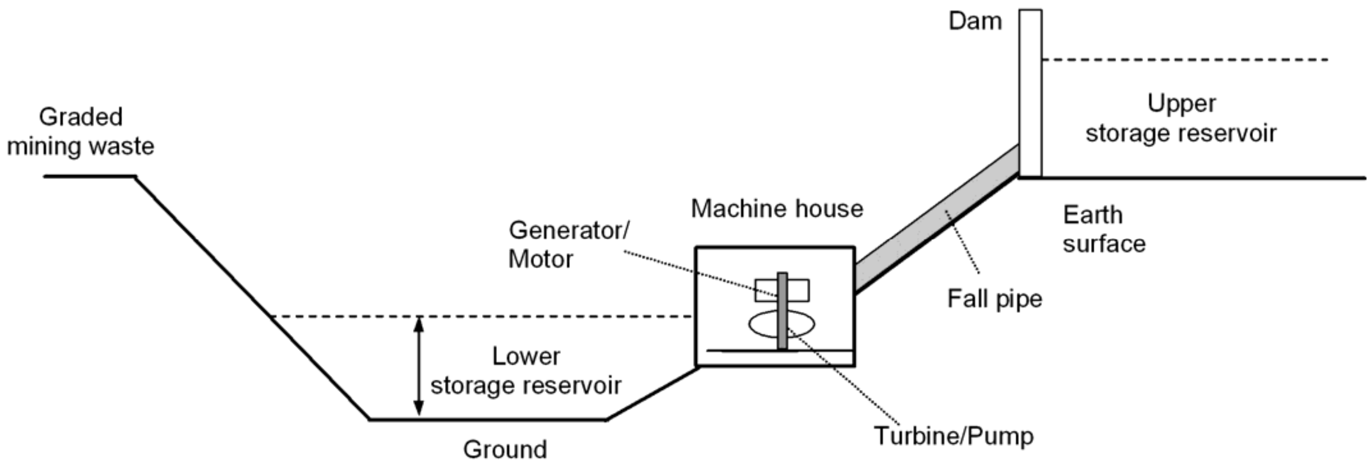
Both areas together have 68 mining lakes
with a total area of 26,518 ha
and a total volume of $4{,}511 \cdot 10^6$ m^3

Not all lakes are suited for the installation of pumped-water storage plants, some properties are required:

- high volume
- stable geological conditions
- possibilities for the grid connection of some GW power



Storage capacity of a tenth of the mining lakes

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Stored energy: $$E_\mathrm{p} = m \cdot g \cdot h_\mathrm{p} \qquad (1)$$

$$E_\mathrm{p} = \rho \cdot V \cdot g \cdot h_\mathrm{p}$$

$$E_\mathrm{p} = \frac{1}{3.6 \cdot 10^6} \cdot \rho \cdot V \cdot g \cdot h_\mathrm{p} \qquad (2) \quad [\mathrm{kWh}]$$

Assuming that

a) only a tenth of the lakes are suitable for pumped water storage plants

b) a mean fall height of 80 m:

$$E_\mathrm{p} = \frac{1}{3.6 \cdot 10^6} \cdot 10^3 \frac{\mathrm{kg}}{\mathrm{m}^3} \cdot 450 \cdot 10^6 \,\mathrm{m}^3 \cdot 9{,}81 \frac{\mathrm{m}}{\mathrm{s}^2} \cdot 80\,\mathrm{m}$$
$$= 98.1\,\mathrm{GWh}$$

Comparison: 24 GW wind power in 2009

Customer control versus energy storage

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First tests in the 1970 years with ripple frequency control: low effects

Switch-off and switch-on of non-critical processes:

- electrical storage heating, electrical water heating
- cooling and heating devices, air conditioning devices
- circular pumps, exhausters, air compressing pumps
- power plants with combined power and heating

Energy consumption of industrial cooling in Germany (Stadler 2006):

165,000 GWh/a, thereof

can participate 46,000 GWh/a on the customer control

Energy feed-in from renewable energies in 2006: 48,000 GWh

ca. 90,000 GWh are expected for the year 2012

Also the primary and secondary control can be realized by the customer control: there would be no need for a control reserve in power plants

Power system design with renewable energies

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Power balance requires the grid integration of renewable energies with:

- Energy storage: balance between generated and consumed power
- High power quality: power electronic grid connection
- Grid development: temperature monitoring of transmission lines,

  high temperature transmission lines
- Grid extension: retrofitting of transmission lines, new transport lines
- Virtual power plants
- SmartGrids: „intelligent“ control of power flows
- Customer control: switching of non-sensitive industrial customer loads

  = interim solution until new storage systems are build

Summary

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⇒ **Renewable energies in Germany**

⇒ **WT technology**

⇒ **Grid integration**

⇒ **Renewable Energy Law 2009**

⇒ **Future Demands**

⇒ **Virtual power plants**

⇒ **Grid impedance**

⇒ **Energy storage**

⇒ **Capacity analysis of mining lakes**

⇒ **Storage capacity**

⇒ **Summary**


D. Schulz
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Thank you for your attention!