Geothermal power in the reality of the electricity market

Session III: Plant operation, energy supply and grid integration

GEOELEC training course Pisa
9. October 2013
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   - c. Support Systems for RES in Europe

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   - d. Control of the European electricity grid

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   - a. Demand for geothermal power
   - b. Lessons learned
Brief portrait
EnBW Energie Baden-Württemberg AG

› One of the largest energy companies in Germany and Europe
› Business segments:
  electricity generation and trading, electricity grid and sales, gas, energy and environmental services
› Annual revenue 2012: in excess of € 19 billion
› Customers: some 5.5 million
› employees: some 20,000
› Installed capacity: 13 042 MW thereof 2 527 MW renewable
› 2 geothermal power plants
Geothermal power plant in Soultz-sous-Forêts, France
Upper Rhine Valley

Source: E.G.E.E, 2010
### Geothermal power plant – Soultz-sous-Forêts
French-German consortium (federal agencies, research agencies; industry)

<table>
<thead>
<tr>
<th>Thermal capacity</th>
<th>Power plant</th>
<th>boreholes</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-35 l/s</td>
<td>ORC power plant</td>
<td>EGS-power plant</td>
</tr>
<tr>
<td>Flow rate</td>
<td>~ 19 bar</td>
<td>4</td>
</tr>
<tr>
<td>175 °C</td>
<td>Pressure</td>
<td>Number of boreholes</td>
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<tr>
<td>Flow temperature</td>
<td>Isobutan</td>
<td>3600 m / 5100 m / 5100 m / 5260 m</td>
</tr>
<tr>
<td>70 °C</td>
<td>Working fluid</td>
<td>Depth of GPK1/GPK2/GPK3/GPK4</td>
</tr>
<tr>
<td>Return flow temperature</td>
<td>Air cooling tower</td>
<td>Electric submersible pump/ lineshaft pump</td>
</tr>
<tr>
<td>~ 14 MW</td>
<td>~ 2,1 MW</td>
<td></td>
</tr>
<tr>
<td>Thermal capacity</td>
<td>Gross electrical output</td>
<td></td>
</tr>
</tbody>
</table>
Geothermal power plant Bruchsal - Kalina pilot plant

- Machinery hall
- Water treatment
- Building of the control system
- Salt silo
- Wet cooling tower
- Pump station
- Preheater
- Evaporator 1
- Evaporator 2
- Generator
- Gear unit
- Turbine
# Geothermal power plant – Bruchsal

**Consortium between ewb & EnBW**

<table>
<thead>
<tr>
<th>Thermal water</th>
<th>Power plant</th>
<th>boreholes</th>
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<tbody>
<tr>
<td>24 l/s Flow rate</td>
<td>Kalina power plant</td>
<td>Hydrothermal</td>
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<tr>
<td>120 °C Flow temperature</td>
<td>~ 22 bar pressure</td>
<td>2 Number of boreholes</td>
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<tr>
<td>60 °C Return flow temperature</td>
<td>Water-ammonia Working fluid</td>
<td>- 1874 m / - 2542 m Depth of GBI/GBII</td>
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<tr>
<td>~ 5.5 MW Thermal capacity</td>
<td>Wet cooling tower</td>
<td>Electric Submersible pump</td>
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<tr>
<td>~ 0.55 MW Gross electrical output</td>
<td></td>
<td></td>
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</table>
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   b. Lessons learned
96/92/EC – Liberalization of electricity and gas markets

- Free Choice of electricity supplier
- Unbundling of production; transport; distribution; sales/trade
- Discrimination free grid access
- Network fees are regulated

Customer friendly, Environment friendly, secure, efficient, inexpensive, Adapting optimization, security, reliability, Adapted development, Adapting enforcement.
Electricity trade in the liberalised market

Exchange trading
Standardized products, lower transaction costs, anonym, lower default risk

Bilateral-/OTC-trade
Individual negotiated contracts, not regulated, only few market participants, higher transaction costs, higher default risk

Spotmarket
Conclusion of the contract and its fulfilment are close together
Physical $\rightarrow$ electricity delivery

Electricity exchange
standardized products
base-products
peak-products
hours-products

OTC-trade

Derivates market
Between conclusion and fulfilment is at least one weak
Hedging transactions

Options
Caps
Floors

Buyer has an exercise right; Seller is obligated to fulfilment

Buyer and Seller are obligated to fulfilment

Forwards
Futures
Swaps

Exchang e trade (Options)
OTC-trade (all trade products)
Exchang e trade (Futures)
OTC-trade (all trade products)

Source: Konstantin, 2007, S. 42
Electricity trade in the liberalised market

Development of the electricity price - theoretical

- Electricity prices develop through the equilibrium of
  - Offered power plant capacity (Merit-Order)
  - Load demand.
- Amount offered, price and demand are influenced by different circumstances.
- Typically there are hourly price equilibriums identified
  → This means 8760 different markets with different influencing factors
- The last power plant sets the price
Spotmarket Germany 07.10.2013

Preis

€/MWh

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<td>2</td>
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Volumen

GWh

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<td>24</td>
<td>10,0</td>
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Gesamt: 649,110 GWh
Support Systems for renewable energy in Europe
Directive 2009/28/EC

Goals

- Reduction of CO₂ – emissions
- Reduction of the dependence on fossil energies
- Fulfilment of the individual goals from directive 2009/28/EC

Directive 2009/28/EC guaranties a priority feed-in for Renewables

Feed-in tariffs
- Legal determined feed-in tariff
- Customers are charged for the extra costs

Quota systems
- Legally determined quota for RES in the elec. production
- Projects are financed through energy price and certificate price

Tender models
- Tendering for a fixed amount for renewable capacity
- Cheapest project is done

Tax reduction
- Tax reduction for renewable energy
- Widely used
Support Systems for renewable energy in Europe

Feed-in tariffs in Europe for geothermal electricity

Source: Ragwitz et al.; 2012; Recent developments of feed-in systems in the EU
Source: Gipe; 2011; Geothermal Feed-in Tariffs Worldwide
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   a. Demand for geothermal power
   b. Lessons learned
Load distribution in the network

Quelle: M. Beer, CO2-Vermeidung in DE, Teil II „Umwandlung & Ind.“, S. 17, FfE München, 2009,
The electricity network

Fundamentals of electricity distribution:

\[ P = U \times I \times \sqrt{3} \times \cos \varphi \]

\[ P_V = n \times R' \times d \times I^2 \]

- Different losses occur through electricity transport
  - Losses of the alternating current (AC)
  - Losses of the overhead lines
  - Losses of the wire
- Losses of the wire
  - Ohmic resistance
  - Limited heat resistance
Load and demand in Europe
Country analyses under normal & severe conditions

- no imports required to maintain demand & reserve
- imports required to maintain demand & reserve on at least one week
- imports required to maintain demand & reserve every week

ENTSO-E 2011
Physical power flows in Central - Europe 17.10.2012;

**Export vs. Import**

Source: entso-e
Physical power flows between Germany and Switzerland 17.10.2012

Source: entso-e; EEX
Transport capacity – a more and more scare good

Challenges for the network operation in Europe

Example: TenneT-control zone

› Currently there is a high burden through wind energy and trade flows from Scandinavia
› 6.200 MW transport capacity/ 3.500 MW min. demand

Example:

› Central Europe at the 22.12.04, 17:30 h, phys. Load flows
› Wind feed-in: 11,461 MW
› Export balance: ca. 6200 MW

Result:

› With a growing wind feed-in the electricity is pushed in the neighbouring countries
› Growing stress on the cross-border transfer capacity
› Overloading of the neighbouring networks
Wind energy feed-in in the TenneT-network, Aug. 2010
prognosis and real feed-in

0 1000 2000 3000 4000 5000 6000 7000 8000

Prognose
Einspeisung

-2000 -1000 0 1000 2000 3000 4000 5000

Abweichung
prognosis
feed-in
deviation

Tage

Power [MW]

1 3 5 7 9 11 14 16 18 20 22 25 27 29 31
days

Power [MW]

1 3 5 7 9 11 14 16 18 20 22 25 27 29 31
days

EnBW
Market reaction strong wind situation 25./26.12.2009:

- Wind capacity:
  - approx. 20 GW wind at 23:00

- Load (Sum EHV of all 4 network operators)
  - approx. 20 GW

- EEX-Spotprice:
  - "disposal premium" for ca. 17 GW in 10 h
  - approx. 22 Mio €

- KW-feed-in EEX-notification Germany:
  - Reduction compared to 23.12.:
    - 6.5 GW or 8.5 GW nuclear/lignite

September 2013:
- 31.8 GW installed wind capacity in Germany
The Challenge

*Difference between electricity demand and operating wind capacity*

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**German pump storage capacity (~40 GWh)**

**Pump storage Goldisthal (~8.6 GWh)**
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European directives and goals concerning renewable/geothermal energy sources

› European directive 2009/28/EC

› Article 2a: “energy from renewable sources’ means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, … “

› Article 2c: “geothermal energy’ means energy stored in the form of heat beneath the surface of solid earth;”

![Graph showing European RES Goals](source: EREC 2011)
Geothermal power plants in Germany

- Neustadt-Glewe
- Landau
- Bruchsal
- Soultz-sous-Forêts
- Simbach-Braunau
- Unterhaching
- Insheim
- Sauerlach
- Kirchstockach
- Kirchweidach, Traunreuth

*existing *planned
Capacity factors for electricity production
Availability of power plants

Source: (Tidball, Bluestein, Rodriguez, & Knoke, 2010)
Future demand for controllable renewable power

Source: Nitsch et. al 2012
Renewable heat production – the sleeping giant of climate protection

Ambitious goals for renewable heating in Europe

- 10.4 % of German heat demand (heating; warm water) comes from RES (2012)
- In Germany around 90 % of a household's energy demand is used for heating
- Only 3 renewable Sources

Source: Nitsch et. al 2012
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Mineralisation of the brine (Bruchsal)

123.4 g/l  32.5 g/l  2.4 g/l
Scaling - Bruchsal

Source: ewb Bruchsal
Gas Composition - Bruchsal

Carbon Dioxide 89,99%

Nitrogen 8,90%

Helium 0,01%

Hydrogen 0,08%

Methane 1,00%

Argon 0,02%

Others 1,11%
Two Phase Flow: CO$_2$ and Aqueous Phase
Two Phase Flow: CO₂ and Aqueous Phase

› Technical measures to prevent precipitations and low efficiency of heat exchange:
  › Pressure maintenance
  › Acidifying
  › Application of inhibitors

Diagram:
- CO₂ & Aqueous Phase to Injection Well
- CO₂ & Aqueous Phase from Production Well
- Aqueous Phase from Power Plant
- Gas Bypass
- Gas Re-Feed
- Shut-off valve
- Ascending Gas Bubbles
- Gas Bypass
- Sight Glas
- Aqueous Phase to Power Plant
Three different kinds of pumps are used in the geothermal loop:

- **Line Shaft Pump (LSP):**
  - The hydraulic pump is down-hole, the motor drive is at surface, connection being done through a line shaft
  - ⇒ mechanical risk

- **Electric Submersible Pump (ESP):**
  - Both electrical motor and pump are down-hole, the motor drive is fed by a cable
  - ⇒ electrical risk

- **Injection pumps:**
  - Horizontal, multistage high pressure pump (surface equipment)
Working principle and general configuration of LSP

Ref: IGE Ldt.

Shaft
Lub string
Exhaust pipe

Well casing
Centralizer
Teflon bearing
Working principle and general configuration of LSP

- riser, enclosing tube, shaft
- Teflon bearings
- hydraulic part, 17 stages
- installation
- motor/shaft coupling
- view at well head/motor
The LSP pump has been installed/removed 5 times at different depth

- ~23 month of operation, ~15 to 20 start ups
- All installations have been carried out by the GEIE team.
Dismantling due to lubrication problems

- Failure mode
  - Shaft wedged in enclosing tube and broke
  - Caused by bad quality of lubricant (demineralized tap water)

- Problem solving
  - Re-engineer of water treatment plant
Dismantling due to hydraulic problems

› Failure mode
› Damage of impellers (all stages), bearings, centralizers and enclosing tube
› Caused by abrasion, corrosion
› Problem solving
› Material selection, adapted operation conditions
Design and operation improvements done for the restart in March 2012

› Test of new bearing material (lub string): Bronze
› Increase the number of stages in order to decrease the rotation speed of the pump ⇒ avoid vibration problems
› Replacement of damaged parts (hydraulic part, piping)
› Adjustment of shaft diameter ⇒ reduce sleeve diameter from 47,5 to 47mm
› Renew surface connection (shaft/motor coupling)
Working principle and general configuration of ESP
The ESP was installed from November 2008 to December 2011

- 10 month of operation, 12 start ups
- Operation outside operating range, as GPK4 is no good producer
Injection pumps

- Injection pumps were used in 2008, 2009 and beginning of 2010 to re-inject the brine into GPK3
- Since 2010, trial of a new strategy without reinjection pump
- Today brine is re-injected in GPK3 (deep reservoir) and GPK1 (upper reservoir) without pumps
  - System is working
  - Temperature decrease of ~7 °C due to new concept
## Comparison ORC and Kalina

<table>
<thead>
<tr>
<th>ORC</th>
<th>Kalina</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial available</td>
<td>Currently only few power plants</td>
</tr>
<tr>
<td>Organic, pure fluid as working fluid</td>
<td>Zeotropic mixture of Ammonia/water as working fluid</td>
</tr>
<tr>
<td>Isotherm evaporation and condensation</td>
<td>non.- isotherm evaporation and condensation</td>
</tr>
<tr>
<td>Higher exergetic loss</td>
<td>Better adaption of the cycle to the heat source</td>
</tr>
<tr>
<td>Less complex, no separators</td>
<td>Separators necessary</td>
</tr>
<tr>
<td>Experience: operation is manageable</td>
<td>Experience: operation is manageable</td>
</tr>
<tr>
<td>Engineering and design seems to be challenging</td>
<td>Engineering and design seems to be challenging</td>
</tr>
</tbody>
</table>

Source: G.E.I.E, 2010
Outlook: Research in the field of deep geothermal energy

Environmental influences
› noise
› Natural radioactivity
› Optical influences
› etc.

Power plant technology
› corrosion
› scaling
› Aqueous chemistry
› Plant operation
› etc.

Reservoir
› Reservoir management
› seismicity
› Hydraulic behaviour of bore holes
› etc.

Quelle: AGW am KIT
Thanks for your kind attention!