Green Industrial Hydrogen via Reversible High-Temperature Electrolysis

25-07-2017  Konstantin Schwarze / SOFC XV
Introduction
Solid Oxide Cells convert...

... electricity into **hydrogen**

![Diagram of Electrolysis Mode]

- **Steam** ($+\text{CO}_2$) → **Hydrogen** ($+\text{CO}$) → **Heat** → **Electricity**
- **Electricity** → **Oxygen** ($\text{O}_2$) → **Heat** → **Electricity**

**Electrolysis Mode**

... chemical energy into **electricity** and **heat**

![Diagram of Power & Heat Mode]

- **Fuel** ($-\text{CH}_2$) → **Oxygen** ($\text{O}_2$) → **CO$_2$** & **H$_2$O**
- **Heat** → **Electricity**
One Core - Multiple Products

- Heat and Power for Households
- Power and Heat for Commercial Buildings
- Power for Remote Locations
- Fuels and Gases for Mobility + Industry
RSOC State of the Art
RSOC Cooperation Sunfire / Boeing

**Electrolysis Mode** – $\text{H}_2\text{O} \rightarrow \text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow$ Produce and Store H2

**Fuel Cell Mode** – $\text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O} \rightarrow$ Use H2 to Produce Power

- **H2 Storage**
  - H2 Compression
  - Potable/Sea Water Inlet
  - Desalination/Deionizer Unit
  - Process Water Storage Tank
  - Sunfire Reversible SOFC Stack

- **Facility Grid**
  - Wind
  - Solar

- **Power in from the Grid During Electrolysis Mode**
  - H2
  - H2O

- **Power Out to the Grid During Fuel Cell Mode**
  - H2
  - H2O

- **RSOFC System**
System Highlights

- Electricity storage for autonomous electricity supply during day and night (PV connected)
- Application: Autonomous power supplies (e.g. islands), smart grids
- 2 x 80 kW SOEC power input and 2x 20 kW SOFC power output (H₂ based)
- Roundtrip efficiency ca. 45%
- Highlights:
  - Worlds first thermally self-sustained SOEC system at representative scale
  - First demonstration of RSOC technology at system level
  - Automatically controlled electricity storage and release → filling level of H₂ vessel
The GrInHy Concept
GrInHy Project

EU funded project (04/2016 - 03/2019)

Objectives:

- Overall electrical efficiency of at least 80 %\(_{\text{LHV}}\)
- Scaling-up the SOEC unit up to 150 kW\(_{\text{el}}\)
- Operation > 7,000 h while meeting hydrogen quality standards of the steel industry
- Integration of a reversible operation mode (fuel cell mode) with natural gas as feedstock
- Integration in a relevant industrial environment
RSOC Integration in an Iron and Steel Work
GrInHy System Layout
RSOC System Layout

- System consists of RSOC Unit and Hydrogen Processing Unit
- RSOC Layout:
RSOC Layout

1440 SOCs
## Technical Data RSOC Unit

<table>
<thead>
<tr>
<th>Operation Mode</th>
<th>EL Mode</th>
<th>H2-FC Mode</th>
<th>NG-FC Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Power Input</td>
<td>142.9 kW ± 8 %</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>AC Power Output</td>
<td>-</td>
<td>30 kW ± 10 %</td>
<td>25 kW ± 10 %</td>
</tr>
<tr>
<td>H2 Production</td>
<td>40 Nm³/h ± 5 %</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Steam Consumption</td>
<td>45 kg/h ± 2.5 kg/h</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>H2 Consumption</td>
<td>-</td>
<td>21.3 Nm³/h ± 15 %</td>
<td>-</td>
</tr>
<tr>
<td>NG Consumption</td>
<td>-</td>
<td>-</td>
<td>5.3 Nm³/h ± 15 %</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>50...125 %</td>
<td>30...100 %</td>
<td>30...100 %</td>
</tr>
<tr>
<td>Gross Efficiency AC</td>
<td>84 % ± 2 % points</td>
<td>47 % ± 2 % points</td>
<td>50 % ± 2 % points</td>
</tr>
</tbody>
</table>
Technical Hydrogen Processing Unit

The HPU by BR&T-E compresses and dries the Hydrogen to feed it to the onsite pipeline.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Pressure</td>
<td>20 mbar(g)</td>
</tr>
<tr>
<td>Output Pressure</td>
<td>8 bar(g)</td>
</tr>
<tr>
<td>H2 Output</td>
<td>54 Nm³/h</td>
</tr>
<tr>
<td>H2 Purity</td>
<td>Dew Point: -60 °C</td>
</tr>
<tr>
<td></td>
<td>N₂: &lt; 200 ppmv</td>
</tr>
<tr>
<td></td>
<td>O₂: &lt; 1 ppmv</td>
</tr>
<tr>
<td>AC Nominal Power</td>
<td>20 kW</td>
</tr>
</tbody>
</table>
RSOC Test Results
Lab testing

- Tested Units: GrInHy RSOC + 2 identical commercial prototypes
- Lab tested w/o HPU or integration in other processes
- About 1000 hours testing each
- Relevant load points were established in fully automated operation

→ Very good repeatability has been found
H2-FC Results

+ Power target reached: 30 kW_{AC} @ > 0.7 V/cell, 0.27 A/cm²
+ Gross AC Efficiency 45 %_{LHV} @ full load, 50 %_{LHV} maximum @ part load
+ High fuel utilization > 95%
+ Part load ability achieved
NG-FC Results

+ Power target reached: $25 \text{ kw}_{\text{AC}} @ > 0.7 \text{ V/cell}, 0.23 \text{ A/cm}^2$
+ Gross AC Efficiency $50 \%_{\text{LHV}}$ @ full load, $52 \%_{\text{LHV}}$ maximum @ part load
+ High fuel utilization of $> 85 \%$
+ Part load ability achieved, but at relatively low efficiencies at deep part load
Electrolysis Results

- Hydrogen output targets reached: 40 Nm³/h, including overload (50 Nm³/h) and peak load 200 kW_{AC}
- Gross AC Efficiency 80 %_{LHV} @ full load, > 75 %_{LHV} minimum @ part load and overload
- Systems shows very good operability and dynamics
Conclusion & Acknowledgement
Conclusion

+ High consistency between specification and test results was reached
+ Reaching the typically higher efficiencies in part load seems difficult
+ In Electrolysis mode efficiency is 2 % points lower than predicted

+ Reason for deviation between specs and test results
  1. Thermal losses higher than predicted
     → Next generation hotbox will be more compact an comes with enhanced thermal insulation
  2. Power electronics efficiency only 90 %
     → Bidirectional power electronics with a high dynamic/voltage range operate in suboptimal load points: use of different unidirectional power electronics
  3. Systematic error in power measurement
     → Deviations between high-end lab measurements and more cost efficient online measurement: possibly recalibration needed
Conclusion

+ The prototypes were successfully operated as Electrolyser and Fuel Cell with Hydrogen and Natural Gas

→ It is the world's largest High-Temperature Electrolyser Unit

+ Possible further enhancements elaborated
+ Next step: Long term testing, operation in industrial environment
Acknowledgement

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THANK YOU!

ENERGY EVERYWHERE

Konstantin Schwarze
Project Engineer
Large Systems

E: konstantin.schwarze@sunfire.de

sunfire GmbH
Gasanstaltstraße 2
01237 Dresden
Germany

W: www.sunfire.de