Cryogenics in high-current busbars and multistage cooled current leads

2ND INTERNATIONAL WORKSHOP ON COOLING SYSTEMS FOR HTS APPLICATIONS, KARLSRUHE, GERMANY
Outline

1. Motivation
2. 20 kA/1 kV/20 m demonstrator
3. Multistage cooled current lead
4. Busbar
5. Conclusion
Busbars for 20 kA

Comparison of Copper, Aluminium and Superconductor

- **Copper busbar 20 kA**
  - Cross section: 16,000 mm²

- **Aluminium busbar 20 kA**
  - Cross section: 27,000 mm²

- **HTS stack 20 kA**
  - Cross section: 320 mm²
Busbar systems in high-current applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Typical Current</th>
<th>Length</th>
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</thead>
<tbody>
<tr>
<td>Chlorine Plants</td>
<td>approx. 20 kA</td>
<td>30 - 300 m</td>
</tr>
<tr>
<td>Data Centers</td>
<td>15 - 40 kA</td>
<td>40 - 500 m</td>
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<tr>
<td>Copper Electrolysis</td>
<td>40 - 80 kA</td>
<td>200 - 400 m</td>
</tr>
<tr>
<td>Zinc Electrolysis</td>
<td>120 - 200 kA</td>
<td>100 - 300 m</td>
</tr>
<tr>
<td>Aluminium Plants</td>
<td>200 - 350 (500) kA</td>
<td>100 - 1200 m</td>
</tr>
</tbody>
</table>

Power losses and operation costs of superconducting busbars are lower above 10 kA / 25 m than those of normal-conducting Cu- or Al-busbars.
Applications for busbars

Chlorine electrolysis, 20 kA

Aluminium plant, 200 kA
Conventional busbars

space limitation

cellar situation ➔
20 kA/1 kV/20 m demonstrator in chlorine electrolysis

- Closed-loop operation
- Busbar operated between 65 and 70 K to increase current density
- Superconductor: YBCO
- Conventional positive busbar bypassed
- Demonstrator in real industry
- Installation in chlorine plant at BASF, Ludwigshafen in 2017
Current lead “ICE®Link”, 20 kA

- Efficient due to cooling on different stages
- Closed-loop operation “zero boil-off”
- Reduced losses in comparison to conduction cooled and gas cooled current leads
- Standardized components for reasonable production costs

In cooperation with
Test of current lead

- Copper lamellas in open bath cryostat for return line
- Cool down with mixed-refrigerant machine to save liquid nitrogen
- Test at 0, 10 and 20 kA
- Zero boil-off operation at all tested currents

\[
P_{el} = 1.3 \text{ kW} \\
P_{el} = 5.6 \text{ kW} \\
P_{el} = 10.7 \text{ kW} \\
P_{el, \text{ges}} = 17.6 \text{ kW} \\
\approx 0.88 \text{ kW/kA}
\]
Busbar: cross section

- Two spreaded HTS stacks instead of one compact stack
- Lower impact by magnetic field
- 50% less HTS tapes
- Higher cryostat costs more than compensated by lower HTS costs
- Small pressure drop for liquid nitrogen transport
- Good cooling and wetting for each single HTS tape
- Smooth support of the tapes
Test of busbar subscale

- Busbar in open bath cryostat at 77 K
- Subscale consists of three HTS parts with two low-resistance couplings and two inputs
- 46 HTS tapes in parallel
- Test up to 20 kA
- No relevant voltage above $I_c$-criteria at 20 kA

Test set-up at KIT Campus North
Busbar “ICE® Bar” cooling

- Busbar cooling independent of current lead cooling
- Pulse-tube cryocooler provides about 400 W cooling power at 65 K
- Cryogenic pump circulates sub-cooled liquid nitrogen (65 – 70 K) in busbar

For details see poster P-19 this afternoon: Moritz Kuhn et al. (ILK Dresden, Germany) Cooling system for a superconducting DC-rail
Conclusion

• Novel multistage current lead successfully tested at 20 kA
• Current lead achieves zero-boil-off
• Busbar cooling also designed as closed loop
• Lack of evaporating nitrogen advantageous in industrial applications
• Busbar subscale successfully tested at 20 kA
• Installation and test of 20 m demonstrator at BASF starts in October 2017
Thank you very much for your attention

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