AC-Loss Measurements and Detailed Loss Analysis on a 1 MVA – Class Superconducting Fault Current Limiting Transformer

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Transformer Specifications

- Transformer primarily designed for current limitation
- Conventional transformer parts except superconducting secondary winding and surrounding cryostat
- Primary winding and iron core are operated at room temperature
- Secondary winding cooled with LN₂ at 77.3 K in open pool boiling cryostat
- Secondary winding is composed of 12 parallel, 4 mm wide YBCO-tapes

### Transformer Specifications

<table>
<thead>
<tr>
<th>Name</th>
<th>Unit symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>nominal power (single phase)</td>
<td>Pₙom</td>
<td>577</td>
<td>kVA</td>
</tr>
<tr>
<td>prim. voltage / sec. voltage</td>
<td>Uₚrim / Uₚsec</td>
<td>20 / 1</td>
<td>kV</td>
</tr>
<tr>
<td>prim. current / sec. current</td>
<td>Iₚrim / Iₚsec</td>
<td>28.9 / 577.4</td>
<td>A</td>
</tr>
<tr>
<td>prim. tums / sec. tums</td>
<td>Nₚrim / Nₚsec</td>
<td>500 / 25</td>
<td>-</td>
</tr>
<tr>
<td>critical current sec. winding</td>
<td>Iₚcrit</td>
<td>1680</td>
<td>A</td>
</tr>
<tr>
<td>grid frequency</td>
<td>fₚgrid</td>
<td>50</td>
<td>Hz</td>
</tr>
<tr>
<td>short-circuit impedance</td>
<td>ρₘ</td>
<td>2.98</td>
<td>%</td>
</tr>
<tr>
<td>fault duration for current limitation</td>
<td>tₚfault</td>
<td>60</td>
<td>ms</td>
</tr>
</tbody>
</table>

Mass Flow Analysis - Methodology

Evaporation of LN₂ inside the cryostat is determined by measuring the mass flow of N₂ gas leaving the cryostat, via a mass flow meter.

**Pros / Cons**
- Precise measurement possible
- Requires gas tight cryostat
- Unknown Qₑ makes calibration necessary

**Heat intake into the cryostat is calculated from the changes in the LN₂ filling level. The level is determined via a laser level sensor measuring the distance to a styrofoam floater on the surface of the LN₂ reservoir inside the cryostat.**

**Pros / Cons**
- No gas tight cryostat needed
- No lid on cryostat required
- Laser sensor can be far away from any high electric- or magnetic fields
- Sensitive to thermal contractions in measurement setup

LN₂ Laser Level Analysis - Methodology

Heat intake into the cryostat is calculated from the changes in the LN₂ filling level. The level is determined via a laser level sensor measuring the distance to a styrofoam floater on the surface of the LN₂ reservoir inside the cryostat.

**Pros / Cons**
- Precise measurement possible
- Requires gas tight cryostat
- Unknown Qₑ makes calibration necessary

**Results**

1-phase → 3-phase conversion:
- Three separate coil pairs in separate cryostats
- Common iron core (4216 kg → 7418 kg)
- \( \eta_{cooling} = 6.5\% \)

**1-phase and 3-phase – total efficiency**

**1-phase and 3-phase – total efficiency**

- Measurements
- Single phase (5)
- Three phase (20)