Suprapower and other Superconducting Devices for the Optimization of Renewable Electric Power Systems

Prof. Dr.-Ing. Mathias Noe, Institute for Technical Physics, Karlsruhe Institute of Technology (KIT)

Superconducting Generators: A Fresh Breeze in Renewables
DBU, Osnabrück, 20.4.2016
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  - Transformers
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• A 10 MW Concept: SUPRAPOWER
• Scale Machine Validator

This project has received funding from the European Union’s Seventh Programme for research, technological development and demonstration under grant agreement No 308793
SUPRAPOWER project Outline

• Funded by the European Union’s FP7 Programme under grant agreement 308793
• Time scope: Dic 2012 – May 2017
• Total Budget: 5.4 M€, EC funding: 3.9 M€
• TECNALIA leads a consortium of 8 partners:

  Coordinator:

  Industrial Partners:

  Research centres and Universities:
SUPRAPOWER project Outline

• Suprapower aims to develop a new concept of innovative, lightweight, robust and reliable wind turbine for offshore applications using superconducting technologies
• 10 MW class generator: more than 30% weight and size reduction of the generator
• Scale machine to study and validate the 10 MW generator concept
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• Scale Machine Validator
A 10 MW Concept: SUPRAPOWER

- Salient pole synchronous generator for direct driven trains
- MgB$_2$ Superconducting field coils
- Air-gap armature winding: no iron teeth
- Warm iron poles configuration:
  - Torque transmission (mostly) at environmental temperature
  - Cryogenics is only in field coils
- Cryogenics:
  - Cryogen-free
  - Modular cryostats
### A 10 MW Concept: SUPRAPOWER

<table>
<thead>
<tr>
<th>Power</th>
<th>Value</th>
<th>Specific shear stress in airgap</th>
<th>112 kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>8.1 rpm</td>
<td>Rated voltage</td>
<td>2,280 V</td>
</tr>
<tr>
<td>Torque</td>
<td>11.8 MN·m</td>
<td>Rated current</td>
<td>2,665 A</td>
</tr>
<tr>
<td>Number of poles</td>
<td>48</td>
<td>Armature current density</td>
<td>3 A/mm²</td>
</tr>
<tr>
<td>Frequency</td>
<td>3.24 Hz</td>
<td>Armature current load</td>
<td>120 kA/m</td>
</tr>
<tr>
<td>Location of armature</td>
<td>External</td>
<td>Mechanical airgap</td>
<td>15 mm</td>
</tr>
<tr>
<td>Field source</td>
<td>MgB₂ coil</td>
<td>Armature winding cooling</td>
<td>Forced air</td>
</tr>
<tr>
<td>Field source operating</td>
<td>20 K</td>
<td>Induction peak value in airgap</td>
<td>1.5 T</td>
</tr>
<tr>
<td>temperature</td>
<td></td>
<td>Pole body height / width</td>
<td>191 / 304 mm</td>
</tr>
<tr>
<td>Armature winding</td>
<td>Copper, Class F</td>
<td>Efficiency at rated power</td>
<td>95.2 %</td>
</tr>
<tr>
<td>Armature diameter</td>
<td>10.10 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross magnetic core length</td>
<td>744 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polar pitch</td>
<td>660 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• The conceptual design of a 10 MW superconducting (SC) generator was started.
• First approached for the mechanical integration of a 10 MW SC generator in a wind turbine.
A 10 MW Concept: Comparison to PM technology for a 10 MW generator

Total weight of SC solution (including structural parts) is 30% lighter than PM solution.

Cost comparison ratio SC/PM generator.

Efficiency comparison SC/PM generator
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## Scale Machine Validator: a comparison to full scale and scale generator (SG)

<table>
<thead>
<tr>
<th></th>
<th>10 MW</th>
<th>SG</th>
<th>SMV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power</strong></td>
<td>10 MW</td>
<td>550 kW</td>
<td>-</td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>8.1 rpm</td>
<td>121.5 rpm</td>
<td>30 rpm</td>
</tr>
<tr>
<td><strong>Torque</strong></td>
<td>11.8 MN·m</td>
<td>43.2 kN·m</td>
<td>-</td>
</tr>
<tr>
<td><strong>Number of poles</strong></td>
<td>48</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>3.24 Hz</td>
<td>4.05 Hz</td>
<td>-</td>
</tr>
<tr>
<td><strong>Location of armature</strong></td>
<td>External</td>
<td>Internal</td>
<td>-</td>
</tr>
<tr>
<td><strong>Operating temperature</strong></td>
<td>20 K</td>
<td>20 K</td>
<td>20 K</td>
</tr>
<tr>
<td><strong>Armature winding</strong></td>
<td>Copper</td>
<td>Copper</td>
<td>-</td>
</tr>
<tr>
<td><strong>Magnetic core length</strong></td>
<td>744 mm</td>
<td>528 mm</td>
<td>528 mm</td>
</tr>
<tr>
<td><strong>Armature current density</strong></td>
<td>3 A/mm²</td>
<td>3 A/mm²</td>
<td>-</td>
</tr>
<tr>
<td><strong>Induction peak value in airgap</strong></td>
<td>1.5 T</td>
<td>1.5 T</td>
<td>1.5 T</td>
</tr>
<tr>
<td><strong>Peak field in the superconductor</strong></td>
<td>1.37 T</td>
<td>1.36 T</td>
<td>1.25 T</td>
</tr>
<tr>
<td><strong>Working point in the load line</strong></td>
<td>65 %</td>
<td>65 %</td>
<td>60 %</td>
</tr>
</tbody>
</table>
Scale Machine Validator: manufacturing ongoing

- DRIVING TEST BENCH
- TRANSMISSION SYSTEM
- SHAFT
- SLIP RINGS
- BALANCING RINGS
- DRAGGING SUPPORT
- BEARINGS
- MODULAR CRYOSTAT
- ELECTRONIC COMPONENTS
- NON-MODULAR CRYOSTAT
- ROTOR BACK YOKE
- ROTARY JOINT

suprapower
Coils is based in an stack of 9 DPs

Prototype coil SC4, by TECNALIA

First DP by Columbus
Non-modular cryostat adopts pipe design with copper bar
dummy coil for testing the new cryostat concept regarding support structure and thermal insulation
thermal shield at about 80 K between coil (20 K) and vacuum vessel (300 K)
Scale Machine Validator: Cryogen System – modular cryostat

vacuum vessel with windows for mounting the support structure
• It took about **20 hours** for the first stage thermal anchor to reach the lowest temperature, which is around **33 K**

• The second stage thermal anchor together with the linked dummy coil required **56.5 hours** to reach the lowest temperature, which was around **9.8 K and 9 K** respectively

• Simulated lowest temperatures are nearly the same with the experiment results.

• The trends of simulated cooling down curve agree with the experiment results.

• The experiment requires more time for the coil to reach the lowest temperature. The exceed time is around **7.5 hours**
Most of components can be used in case of an upgrade to a small scale generator featured by:

- Same coils and modular cryostat size
- Same specific shear stress, cooling system and torque transmission
- ~0.5 MW, ~120 rpm and ~40 kN·m
- 4 warm iron poles, 230 kA·m
- ~750 mm air-gap diameter
- 0.52 m stack length
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Further superconducting devices for integrating renewable energy

**DC superconducting generator**

- DC generation and transmission for offshore wind farm
- Less conversion steps and higher efficiency

Present grid connection of wind turbines

\[ \eta = 89.5\% \]
Further superconducting devices for integrating renewable energy

**DC superconducting generator**

- DC generation and transmission for offshore wind farm
- Less conversion steps and higher efficiency

Considerable increase in efficiency with HTS DC wind generator connection at DC.

Further superconducting devices for integrating renewable energy  

**HTS transformer to connect off-shore wind power**

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Further superconducting devices for integrating renewable energy

HTS DC high current lines to connect PV

Conventional configuration of large solar power plant
Further superconducting devices for integrating renewable energy  HTS DC high current lines to connect PV

HTS configuration of large solar power plant

Simplified connection of large solar power plants with HTS DC lines

W. Reiser, M. Noe, K. Glöser, Internal report, Vision Electric Superconductors
Further superconducting devices for integrating renewable energy **HTS DC high current lines**

**Increasing energy efficiency and cost saving**

Loss of two conventional 600 m, 105 kA DC current busbar for an Aluminium plant

**2.7 MW**

Loss energy 2.7 MW * 8760 h

**23 625 MWh/a** equals **13 442 tons CO₂/a**

Loss energy cost 2.7 MW * 8760 h * 30-50 €/MWh

**709 560 € - 1 182 600 €**

W. Reiser, S. Huwer, C. Räch, F. Schreiner, Application study, Vision Electric Superconductors

HTS at 20 K and LN₂ cooling for the current leads less than 50 % operation cost

HTS at 20 K and cryocoolers for the current leads less than 30 % operation cost

**Significant reduction of energy losses with HTS DC high current busbars**

1) According to energy mix 569 g CO₂ per kWh
Further superconducting devices for integrating renewable energy

Fault current limiter

Maximum photovoltaic generation power (with and without SFCL) that can be connected to 15 kV bus-bars considering 5% Psc restriction

- $P_{\text{renewable without SFCL (MW)}}$
- $P_{\text{renewable with SFCL (MW)}}$
- $\Delta P_{\text{renewable (MW)}}$

<table>
<thead>
<tr>
<th>Location</th>
<th>$P_{\text{max}}$ (MW)</th>
<th>$P_{\text{renewable without SFCL}}$ (MW)</th>
<th>$P_{\text{renewable with SFCL}}$ (MW)</th>
<th>$\Delta P_{\text{renewable}}$ (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLOM</td>
<td>13.7</td>
<td>9.2</td>
<td>4.5</td>
<td>4.2</td>
</tr>
<tr>
<td>POBLA</td>
<td>17.0</td>
<td>10.8</td>
<td>6.2</td>
<td>4.2</td>
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<tr>
<td>POLLENÇA</td>
<td>14.5</td>
<td>10.3</td>
<td>4.2</td>
<td>4.2</td>
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<tr>
<td>S. JORGE</td>
<td>14.5</td>
<td>7</td>
<td>1.8</td>
<td>6.3</td>
</tr>
<tr>
<td>TORRENT</td>
<td>10.6</td>
<td>6.8</td>
<td>2.1</td>
<td>4.9</td>
</tr>
<tr>
<td>VINYETA</td>
<td>16.9</td>
<td>8.9</td>
<td>6.3</td>
<td>4.2</td>
</tr>
</tbody>
</table>

$\Delta P_{\text{max}}$ (MW)

$P_{\text{average with SFCL}} \approx 13.3 \text{ MW}$

$P_{\text{average without SFCL}} \approx 9.1 \text{ MW}$

$\Delta P_{\text{average}} \approx 4.2 \text{ MW}$

Significant increase of renewable power connection by coupling medium voltage busbars

Eccoflow WP6, Final review meeting, February 2014, Palma de Majorca
Many thanks for your attention!