Design and Testing of a Gas-helium Conduction Cooled REBCO Magnet for a 300 kvar HTS Synchronous Condenser

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Outline

➢ Background

➢ Project overview

➢ Test of the magnet prototype

➢ Summary
Transmission Lines: UHVDC
- Voltage and current, the same phase
- All active power

Distribution Lines: AC
- Voltage and current, with phase lag
- Active and Reactive power

✓ Lack of reactive power in UHVDC, in rectification or inverter operation.
✓ Stable and reliable **reactive power condensers** are in need in China.
**Background**

**Dynamic synchronous condenser**

**Conventional DSC:**
- A special case of synchronous motor
- No mechanical load, only reactive power
- Excitation current to control output

![Sketch of synchronous motor](image)

**Technical merits of HTS DSC**
- High efficiency (nearly no heat loss in rotor)
- Long lifetime of HTS rotor
- Small synchronous reactance, fast response time
- Small volume, light weight
- Strong capability of VARs compensation

Background

30MVA superconducting DSC
Mitsubishi, Japan, 1985
IEEE Trans. Magnetics, VOL. MAG-21, NO. 2, MARCH 1985

70MVA superconducting generator
Hitachi, Japan, 1997

AMSC --- 8 Mvar/13.8 kV SuperVAR™ HTS DSC
Project overview

10 Mvar HTS synchronous condenser (2018-2021)  
Funded by China Southern Power Grid

- 10 Mvar, 1500 rpm
- REBCO rotor magnets
- Gap field > 1.4 T
- Non-ferro teeth
- Cooled by 20 K gas helium

Phase 1 (2018-2019): 300 kvar prototype  
Under construction
Consider the angular dependence of REBCO tapes

- 30° field at point 2
- 320 A @ 25 K
Distributed Pipes In Plates (DIP) structure for cooling magnets

<table>
<thead>
<tr>
<th>Items</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coils type</td>
<td>Racetrack shaped double pancake</td>
</tr>
<tr>
<td>Wires</td>
<td>REBCO 5 mm tape from SSTC</td>
</tr>
<tr>
<td>Rated current</td>
<td>280 A @ 20 K</td>
</tr>
<tr>
<td>Efficient length</td>
<td>300 mm</td>
</tr>
<tr>
<td>Coils Turns</td>
<td>170, 230, 270, 310</td>
</tr>
</tbody>
</table>

Test of the magnet prototype

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Test of the magnet prototype

Coil 2: 103 A @ 77 K
Coil 3: 90 A @ 77 K

Graph showing normalized voltage (µV/cm) vs. current (A) for DP Coil 2 and DP Coil 3.
Test of the magnet prototype

Temperature sensors: T1 - T4
Voltage taps: V1 - V5
Hall sensors: B1 - B3

Acknowledgement to ASIPP
Surface temperature of Coil 2&3 was 2 K higher than the helium gas.
Surface temperature of Coil 2&3 was very close.
• Current manually increased up to 281 A
• Voltage fluctuations were caused by inductance
• A stable operation current at 281 A was achieved

• The body resistance of Coil 2 is quite high, suggesting a bad connection between copper terminal and HTS tape
Test of the magnet prototype

- Surface field reached up to 1.16 T
- The result was in good agreement with the simulation

- Both Coil 2 and Coil 3 can reach a thermal stable state.
- Up to 281 A, the temperature difference between coils and helium gas remained ~2 K.
Hold the operation current @ 281 A

Adjust temperature of helium gas from 20 K to 25 K.

Temperature of coils rose from around 22.5 K to 27 K.

Temperature of coils could come back to stable again.
Test of the magnet prototype

<table>
<thead>
<tr>
<th>Current (A)</th>
<th>Voltage (mV)</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td>80</td>
<td>30</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>120</td>
<td>50</td>
</tr>
</tbody>
</table>

**Coil Performance**

<table>
<thead>
<tr>
<th>Coil</th>
<th>Current @ 77 K (1 μV/cm)</th>
<th>Current @ 77 K (0.1 μV/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>101</td>
<td>93</td>
</tr>
<tr>
<td>2</td>
<td>103</td>
<td>95</td>
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<tr>
<td>3</td>
<td>109</td>
<td>100</td>
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<td>4</td>
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<tr>
<td>5</td>
<td>110</td>
<td>103</td>
</tr>
<tr>
<td>6</td>
<td>95</td>
<td>89</td>
</tr>
<tr>
<td>7</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>96</td>
<td>90</td>
</tr>
</tbody>
</table>
Ongoing project

Assemblage before November

Test at the end of 2019

Cryogenic rotary joint

HTS rotor coils

HTS rotor magnet for test
✓ A 300 kvar HTS synchronous condenser is under construction as Phase I of a 10 Mvar HTS DSC project in China.

✓ A gas-helium conduction cooled structure was proposed, and magnet prototype was designed and fabricated.

✓ Testing results showed the DIP structure could help coils work safely under rated conditions.

Acknowledgement

✓ Magnet Producer: Xi'an Superconducting Magnet Technology Co., Ltd

✓ HTS material:

✓ Stator:
THANKS
For Your Attention

敬请指正赐教！