Commissioning of the 3 MW superconducing EcoSwing wind power generator

Markus Bauer

Forschungsfeld HTSL - Treffen, 23.10.2019, Miltenberg

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Our ambitions

ENVISION
ECO5
JEUMONT Electric
DELTA ENERGY SYSTEMS
THEVA
SHI Cryogenics Group
Fraunhofer
UNIVERSITY OF TWENTE.
DNV·GL
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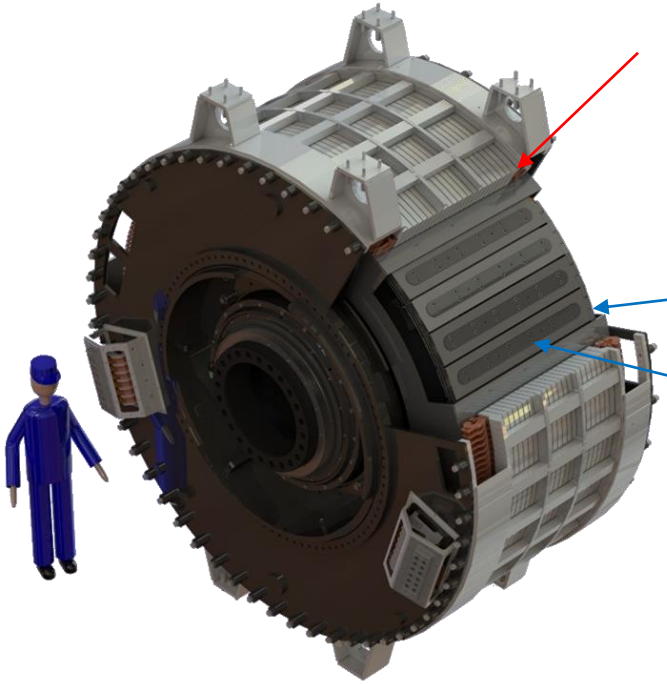
Superconductivity has matured sufficiently that we can follow an ambitious plan:

- Design, develop and manufacture a full-scale multi-megawatt superconducting wind generator
- Install this superconducting drive train on an existing modern wind turbine in Thyborøn, Denmark, replace existing PM generator (3 MW Class, 14 rpm, 128 m rotor)
- Prove that a superconducting drive train is lighter, smaller and cost-competitive.
- Start Date: 2015-03-01
  End Date: 2019-04-30

Elements of the EcoSwing superconductive generator

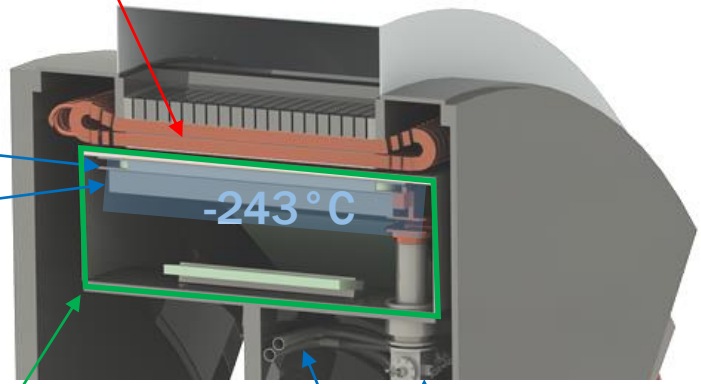


High power density stator with copper coils

Rotor

Superconductor coils

Cold iron yoke



Self sustaining thermal insulation vacuum

Cryocooling

Coldhead

Working gas pipes + compressors in nacelle

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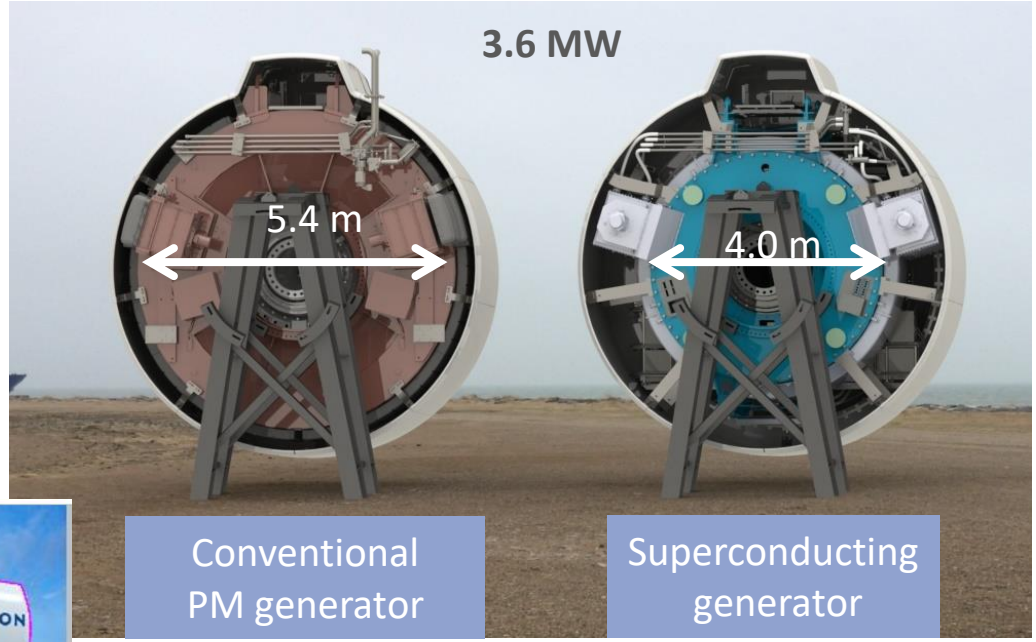
EcoSwing design

- Decreased diameter from 5.4 m (PM generator) to 4 m
- Built **EcoSwing generator**: **25 % weight reduction** compared to PM generator of same diameter
- Commercial design: **40% weight reduction** compared to PM generator.



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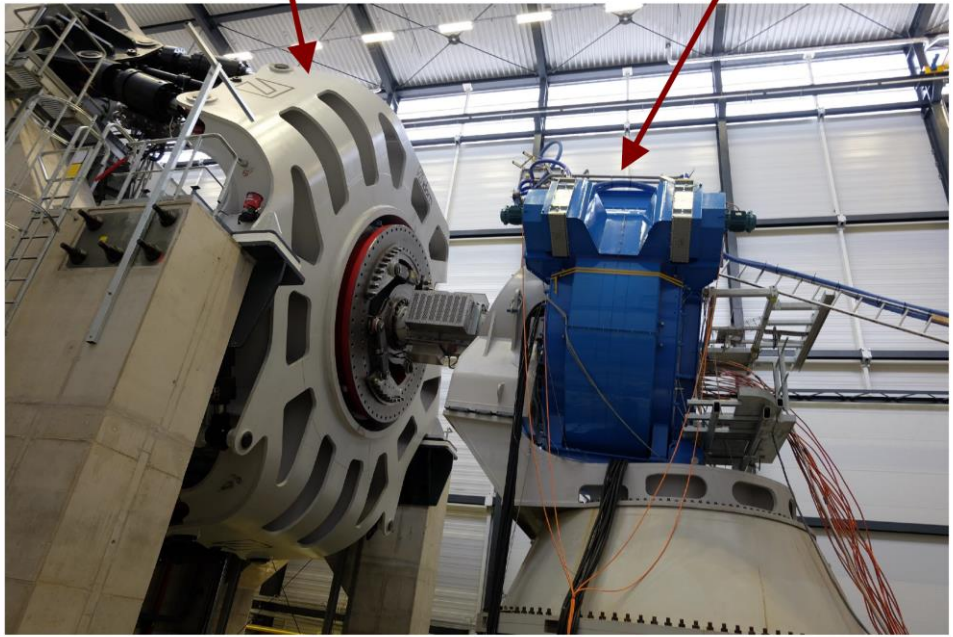
Ground testing at IWES

Steps during ground testing at DyNaLab of IWES in Bremerhaven:

- Mounting hub adaptation and generator
- Rotor cool down
- Excitation of the rotor at standstill
- Rotation
- Short circuit test
- No load test
- Power generation



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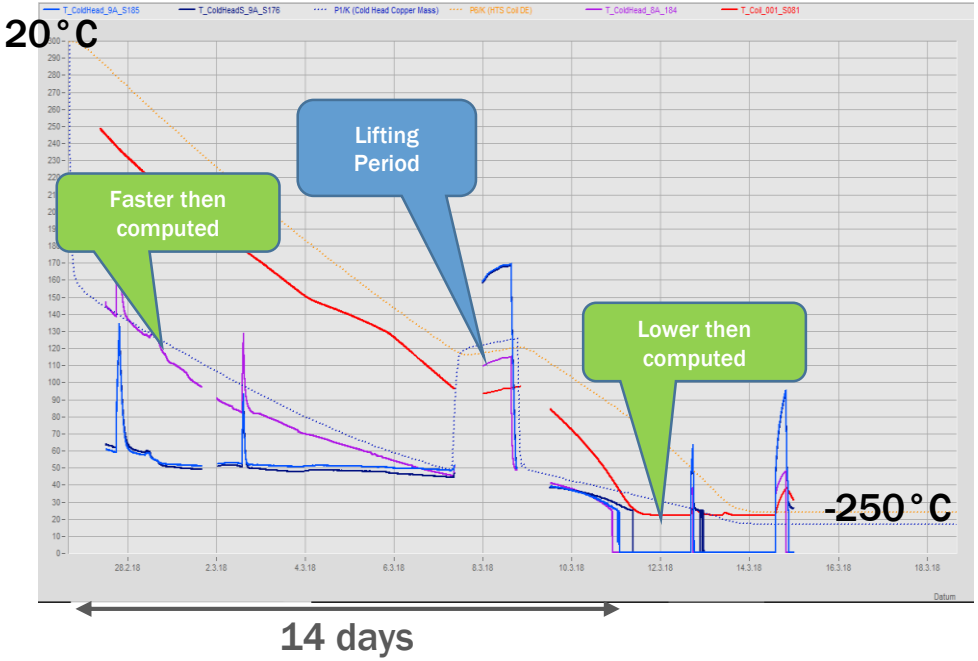
Fraunhofer IWES

1st cool down before ground test



Cooling down period faster then calculated 14 days compared to 18 days

- Cooling power exceeds expectations

Overall temperature level was lower than anticipated

- Thermal design conservative

Cryostat vacuum better then expected

- $2.7 \cdot 10^{-10}$ bar and self-sustaining
- No pump required during operation

Cryogenic system fulfilled all specifications!

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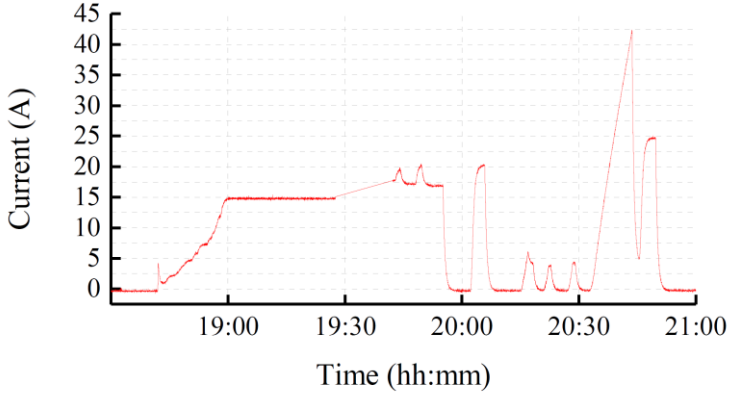
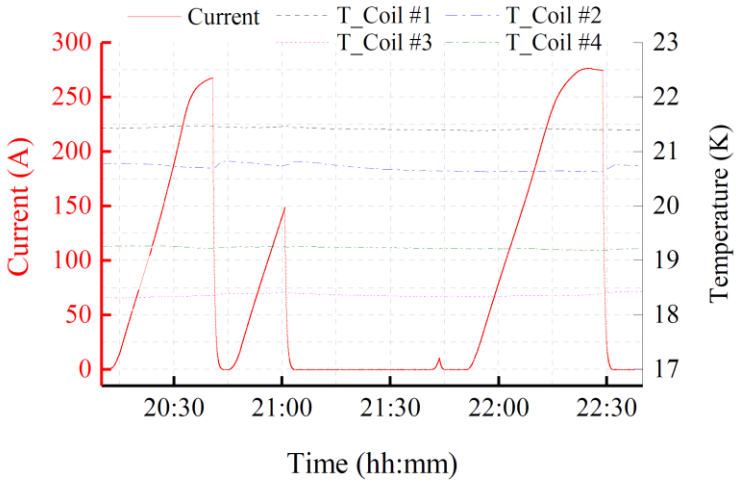
Excitation of HTS field windings

ecoswing

First excitation of HTS field winding at standstill in Bremerhaven





- Debugging of control and QD system
- Optimization of filter constants and threshold values of QD system
- Test of shutoff safety chain

Excitation up to 275 A

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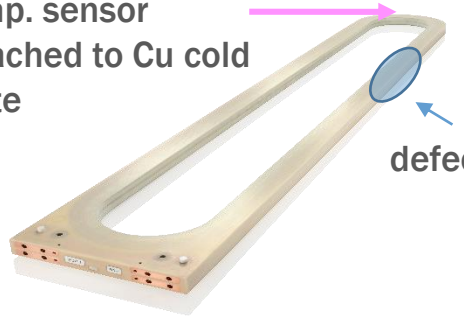
Quench of one coil

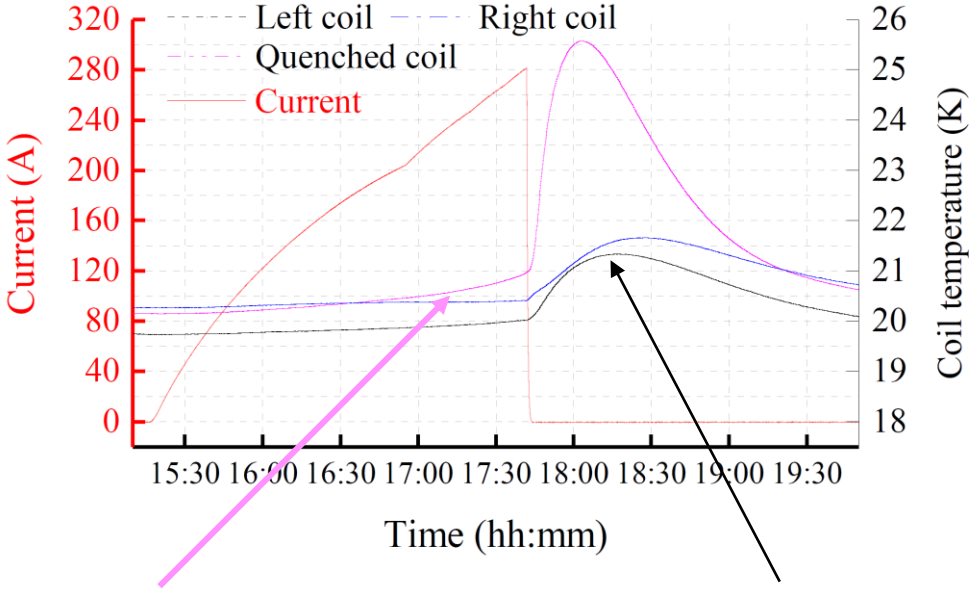
During further increase of excitation current one coil quenched

- voltage rise detected by QD system
- automatic shut down
- temperature rise in quenched coil of up to 4.5 K

temp. sensor attached to Cu cold plate



defect



temperature rise prior to quench

temperature rise due to dI/dt

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Analysis of quench

Detailed analysis of temperatures and voltages

→ Only one coil with defect already before the quench

After the quench

→ higher resistance in quenched coil (1.7 mΩ)

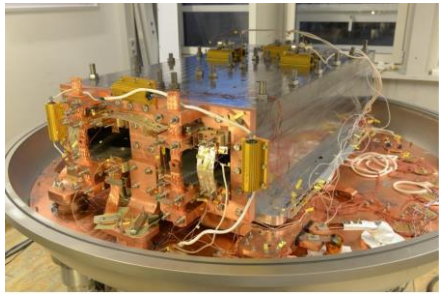
No damage to other coils

→ QD system prevented further damage

Possible reasons:

- Coil only tested in LN2
  → conditions (T, B) differ from final operation conditions
  →Damaged wire with local I_c drop not detected
- Insulation failure leading to local heating
- Damage of coil after the QC test

30 K test: 4 coils per 2 weeks



77K test: 2 coils per day

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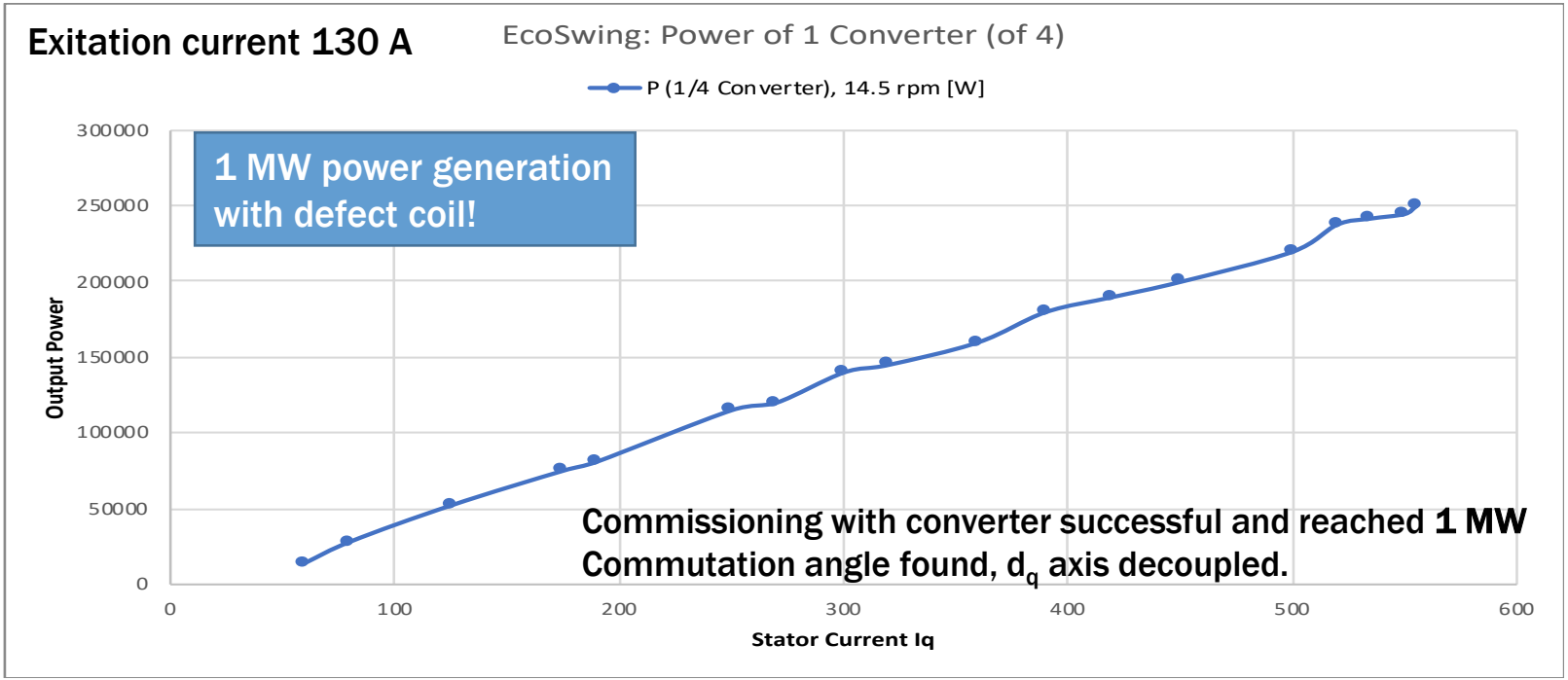
Some detail findings
Partial power test with defect coil



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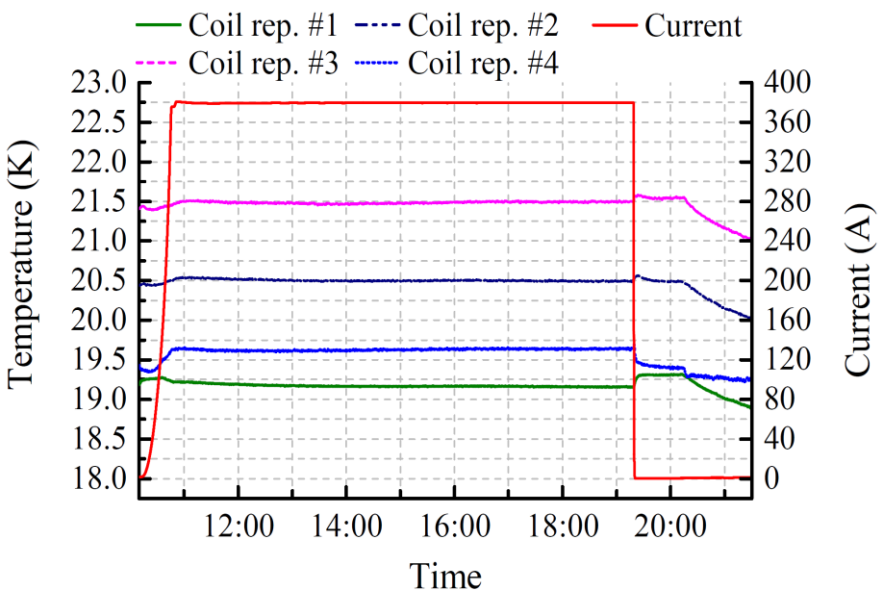
Repair of the rotor

Repair steps

- Transport of the generator to suitable place (cranes, welding..)
- rotor and stator separated
- vacuum recipient opened by cutting open the welding seam
- coil exchanged
  - MLI, el. + thermal connections, screws…
- Reassemble, re-weld, evacuation



Excitation test at standstill: 380 A (8h) ✓

Excitation for operation: 330 A ✓

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Commissioning on turbine in Thyborøn, Denmark

Commissioning on the wind turbine:

- Preinstallation of components
- Mounting of generator, converter, water cooling, DAQ, …
- Connection to PLC of wind turbine
- Safety testing
- Rotor cool down
- Excitation of the rotor
- No load rotation
- Stepwise increase to full power production

"Anything that is not ready when the crane is there will have to be done by partners in the air."

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2nd cool down on turbine

300 K

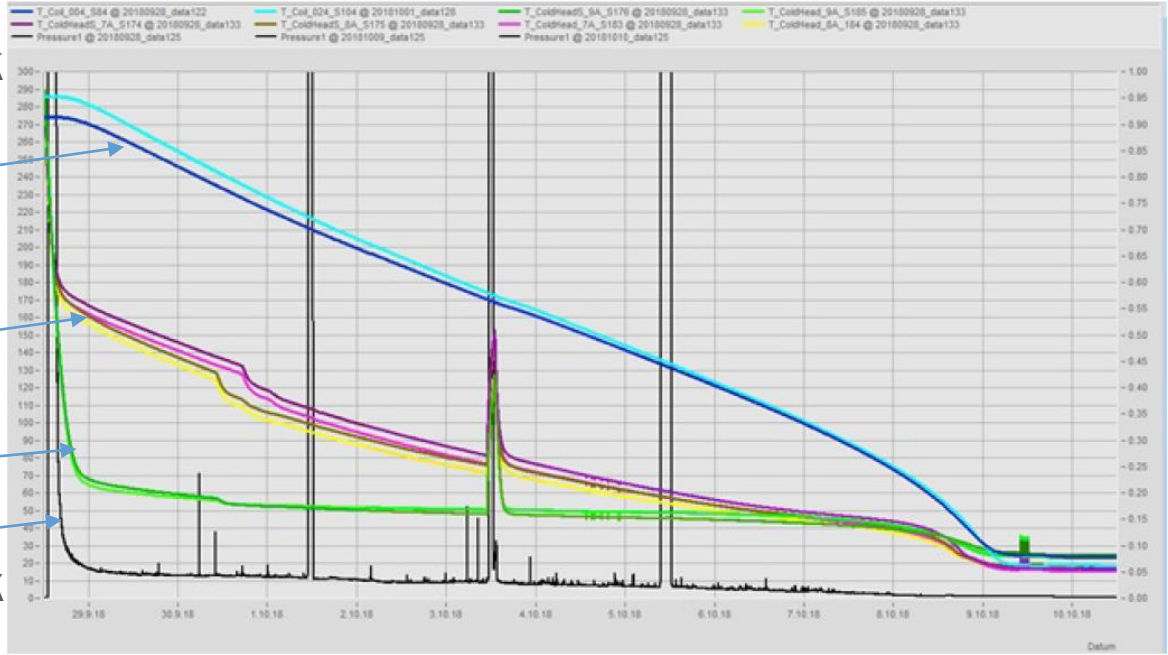
HTS coils

Cold heads

Cold head at current feed trough

pressure

0 K



~20 K

12 days from 28.9.2018 until 9.10.2018

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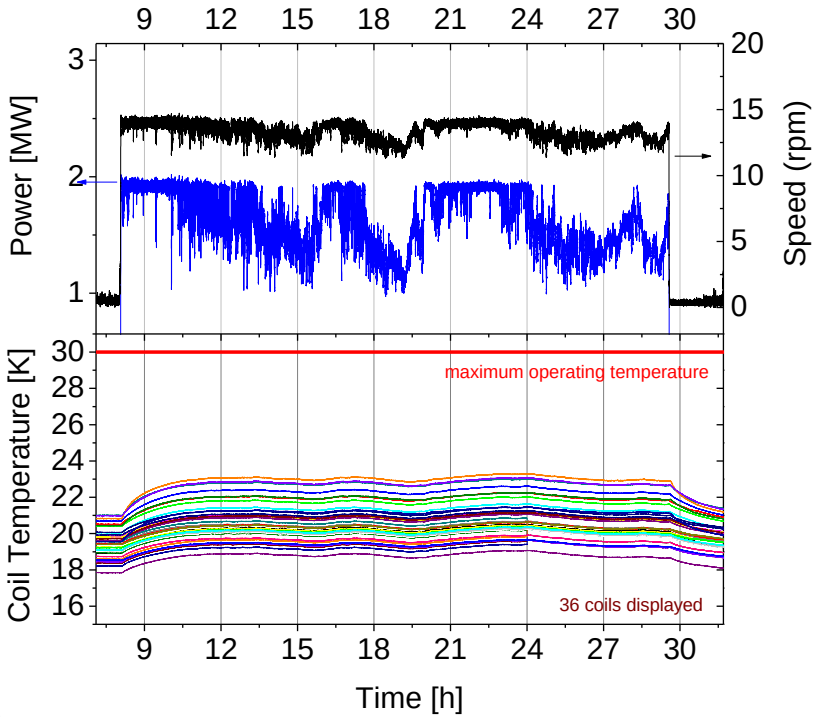
Power generation and cooling

2 MW test run
255 A excitation

Installed on wind turbine



Experience with cooling system

- Off the shelf components worked as specified
- Rotation of cryocoolers is no problem (15 rpm)
- Conduction cooling is reliable
- Influence of power generation on temperatures is small

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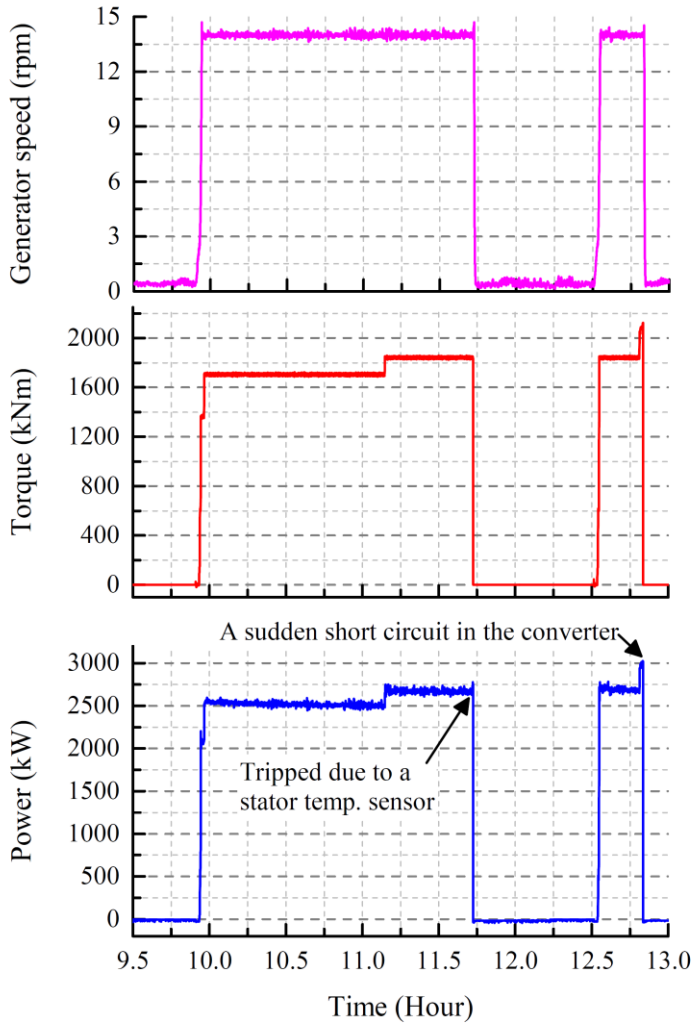
Power production



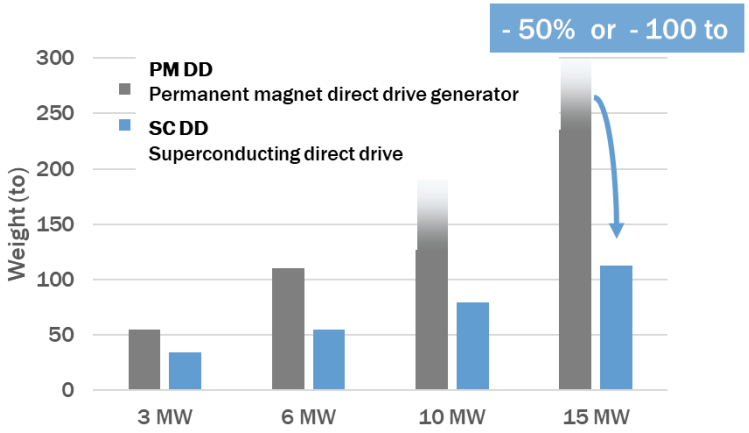
- Stable operation at 2 MW power level in unattended mode
- 2 weeks of continuous operation (remotely monitored)
- Short circuit in the converter system at 3 MW prevented reaching final 3.6 MW
  - Resonance in generator-tower cables-inverter - conventional technology
  - No problems in the rotor, no doubt that 3.6 MW are possible

In total power was fed into the grid for 650h! Many Danish households could claim "powered by superconductivity".

3 MW test run
330 A excitation

Conclusions

- The world's first superconducting generator was successfully built and operated on a wind turbine.
- This in general demonstrates
  - **Compact, simple and relialbe** use of superconductors,
  - cryocooling **is stable and robust.**
- Superconducting generators can be
  - **much smaller** than present day "state of the art" generator
  - **much lighter** than present day "state of the art" generator
- The same technology can be applied to other slow rotating machines
  - Motors and generators for ship propulsion
  - Hydro power generators



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The EcoSwing Story

See
https://www.theva.com/video-zum-abschluss-des-ecoswing-projekts/
Or
https://www.youtube.com/watch?v=NxMkZHyM9UQ

Publications (published):

- Song et al.: Designing and Basic Experimental Validation of the World's First MW-Class Direct-Drive Superconducting Wind Turbine Generator, IEEE Transactions on Energy Conversion DOI: 10.1109/TEC.2019.2927307
- Winkler et al.: The EcoSwing Project, IOP conf. series: Mat. Sc Eng. DOI:10.1088/1757-899X/502/1/012004
- Slides on AC loss calculation (in German): **https://elenia.tubs.de/fileadmin/content/sls/9sls/04_Krause.pdf**

Publications (submitted)

- SUST: Design and in-field testing of world's first ReBCO rotor for a 3.6 MW wind generator
- IEEE TEC:
  Ground Testing of the World's First MW-Class Direct-Drive Superconducting Wind Turbine Generator
- Applied Energy:
  Commissioning of the World's First MW-Class Direct-Drive Superconducting Generator on a Wind Turbine

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Vielen Dank!

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