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Project Status SPEEDY_HTS – An HTS retrofit rotor for a mid-speed wind power generator

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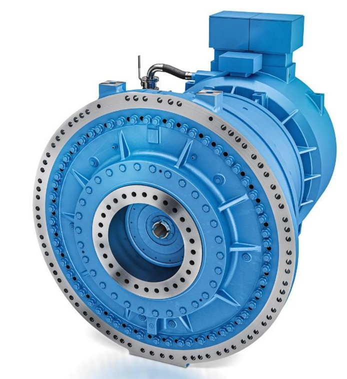
Introduction

- Business opportunity for mid-speed HTS genos due to a reduction in RE & performance increase
- High-current Cu-stator favors HTS instead of PM
- Challenges in geometry (L/D ratio), cooling/ heat loads, A-turns, torque transmission, excitation, stability, etc.
- Mid-speed → very small HTS-need / MW

$D \approx 12$ m

14 MW direct drive
RE-PM generator
RE-mass: > 1500 kg
(RE: rare earth)

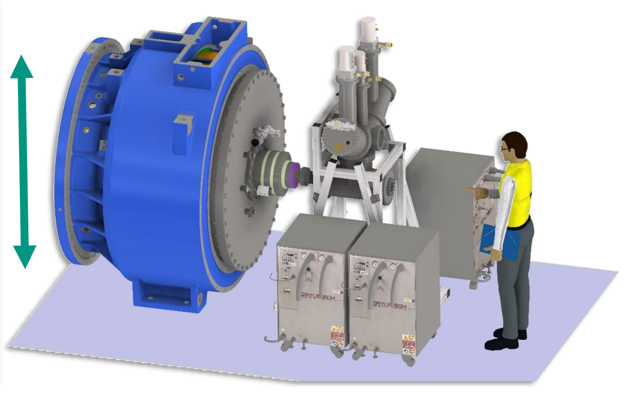
600 rpm



14 MW hybrid
RE-PM generator
max. efficiency: 98.4%
RE-mass: > 150 kg

HTS

$D \approx 1.8$ m

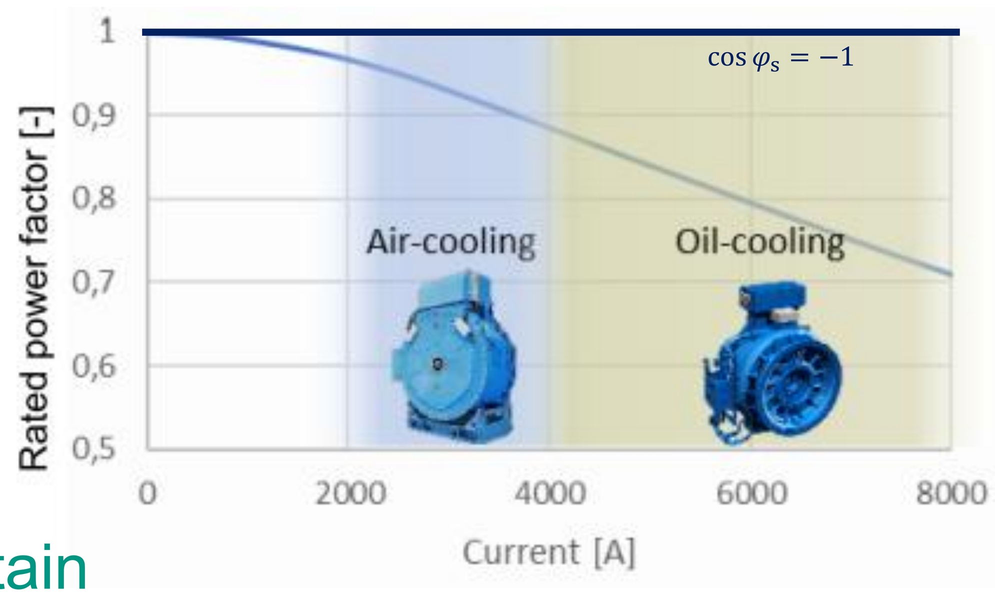


14 MW medium speed
HTS generator (test stand)
max. efficiency: 97%
RE-mass: < 40 g

Electromagnetic machine design

Initial situation

- Increase of stator current reduces power factor of PM-generator



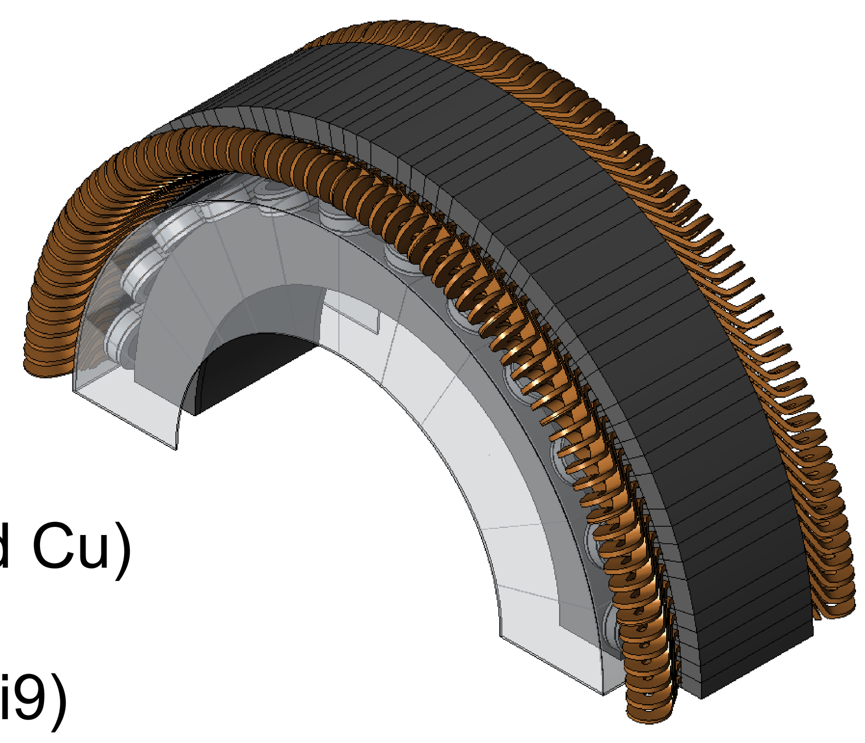
Research question:

Can an HTS rotor maintain a high $\cos\varphi$?

Requirements

$P_{\mathrm{el,N}} = -13$ MW, $n_{\mathrm{N}} = 600$ /min (3-stage gearbox),
$U_{\mathrm{N}} = 750$ V, $I_{\mathrm{sN}} = 10$ kA, $\cos\varphi_{\mathrm{sN}} = -1$, $m_{\mathrm{s}} = 3$, $2p = 24$,
$f_{\mathrm{sN}} = 120$ Hz
Geometry: $d_{\mathrm{so}} \approx 1.8$ m, $l_{\mathrm{Fe}} \approx 0.3$ m, $\delta = 35$ mm

Approach



Stator & rotor

Stator:
- unchanged (oil-immersed Cu)

Rotor:
- cold nucleus (FeNi9/X8Ni9)
- poles: PM replaced by HTS-coils
- rotating cryostat

Results

Performance (according simulation):
- Magnetic flux profile nearly unchanged
- 6 MW → 13 MW in same housing
- $\cos\varphi \equiv 1$ (minimizing inverter)

Cooling concept

Initial situation

- PM-rotor (only airgap flow cooling)
- Central stationary (warm) rotor feedthrough required (pitch control)
- All loss shares effective at ambient temperature

Research questions for test stand

- How can all losses and heat flows be cooled at elevated cryogenic temperatures?

Research Questions for product development

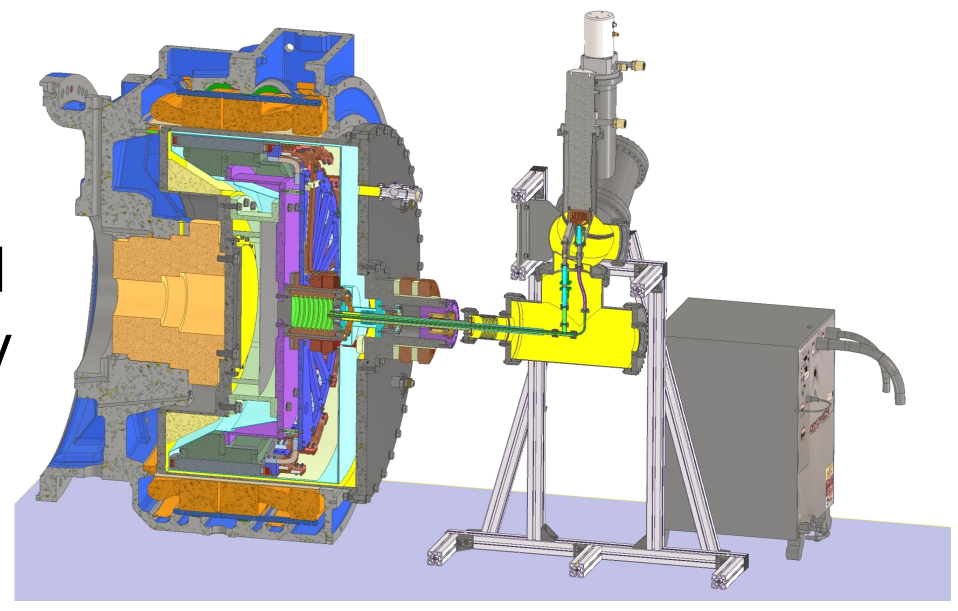
- Central warm pitch control feedthrough possible?
- Suitable excitation system feasible?

Requirements (product)

- Cooling power
  $P(T = 30\,\mathrm{K}) \leq 130$ W
  → Min. heat loads allowed
- Non-drive end access only

Requirements (test stand)

- High cooling power for test transients



Approach (test stand)

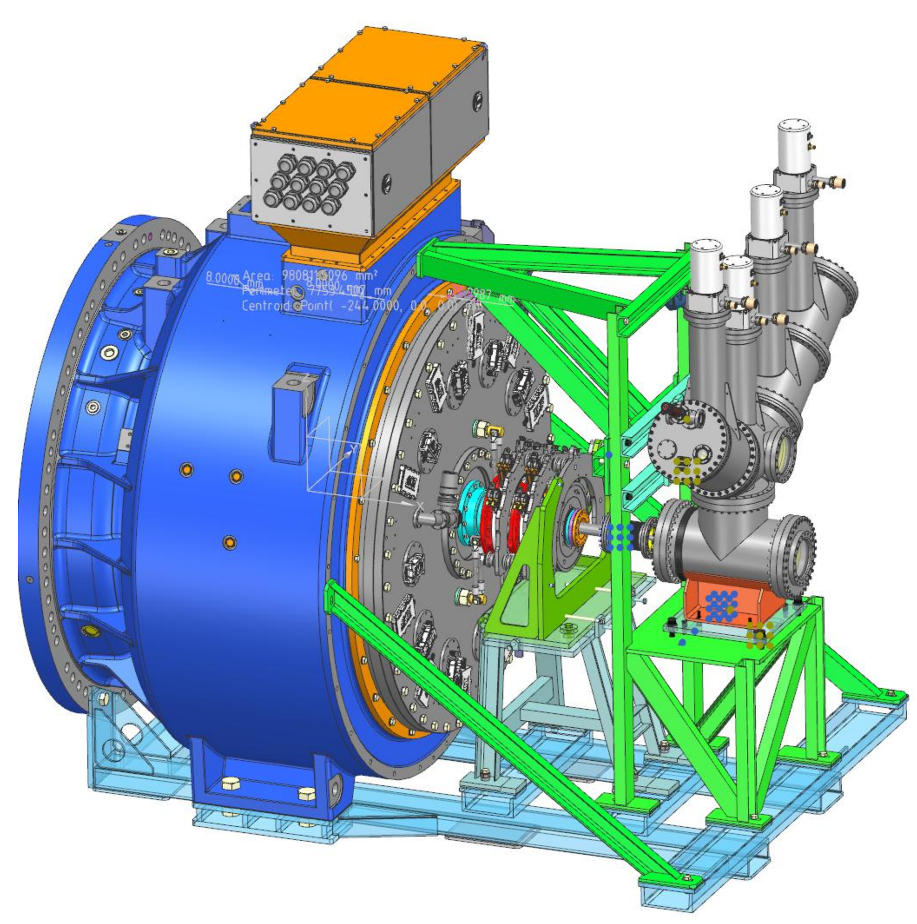
- Ne-thermosyphon with 4 coldheads
- Cu-cold bus from central reservoir to coils

Result (test stand):

- Cooling power:
  4×130 W
- Reserve heating power (worst transient condition)
  ≈ 50 W

Result (product):

- Cooling power:
  1×130 W
- Reserve heating power (worst transient condition)
  ≈ 25 W



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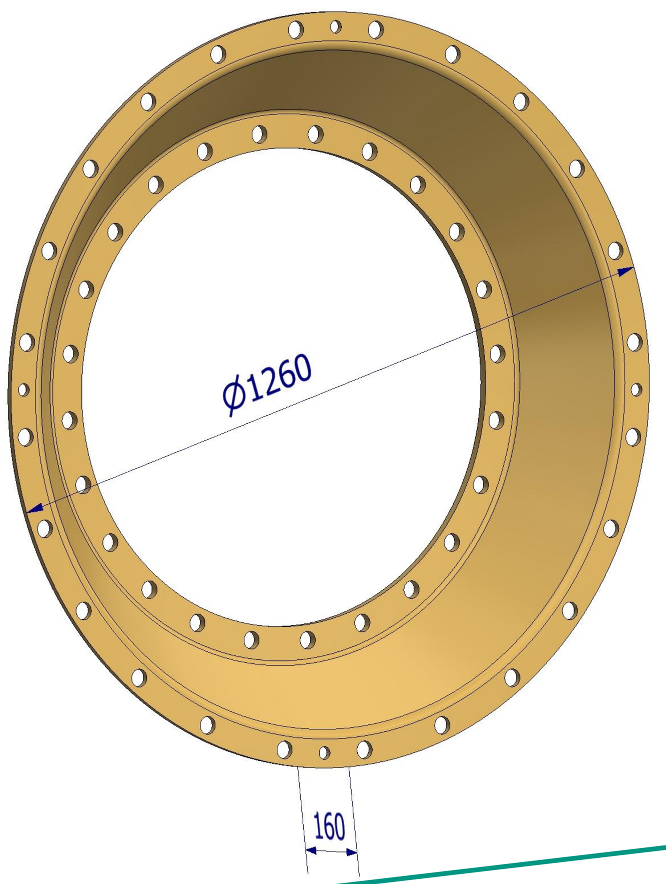
Mechanical concept

Initial situation
Small active length of machine requires very compact torque transfer element.

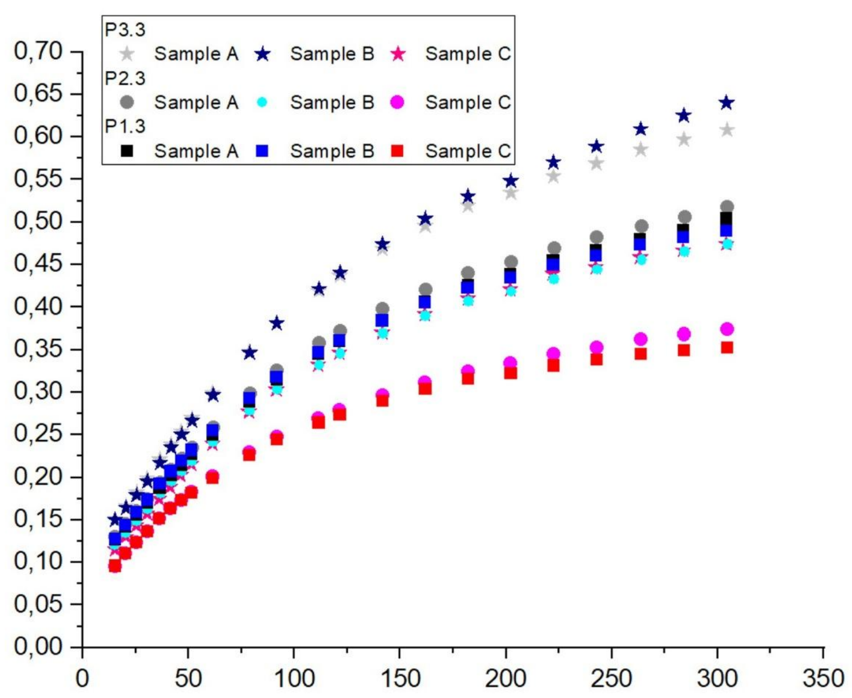
Research question
How to balance low heat flow with torque requirements?

Requirements
- Torque: $T > \frac{14\ \text{MW}}{2\pi\, n} = \frac{14\ \text{MW}}{2\pi\ 600 \cdot \frac{1}{60\ \text{s}}} \approx 0.25\ \text{MNm}$ **!**
- Heat flow limit $\dot{Q}_{TTE} \leq 100\ \text{W}$

Approach
- Dedicated FRP rim as Torque Transfer Element (TTE)



Measurements & Results
- Thermal conductivity $\lambda(T)$
- Integral thermal conductivity for selected FRP-option $\int_{30\ \text{K}}^{304\ \text{K}} \lambda(T)\, dT \approx 110\ \text{W/m}$
- Heat load $\dot{Q}_{TTE} \approx 25\ \text{W}$

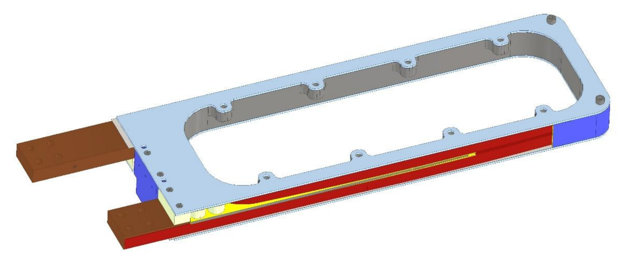


HTS coil concept

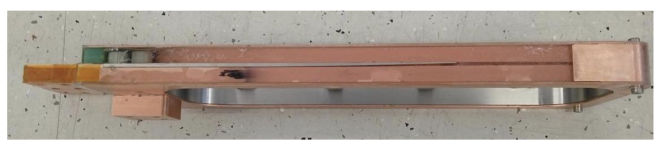
Initial situation
- Not sufficient electric stabilizer on tape
- No room for insulation
- Keep simple → no quench handling

Research question:
Can HTS coils provide the required flux profile, meet the dynamic requirements, and operate safely?

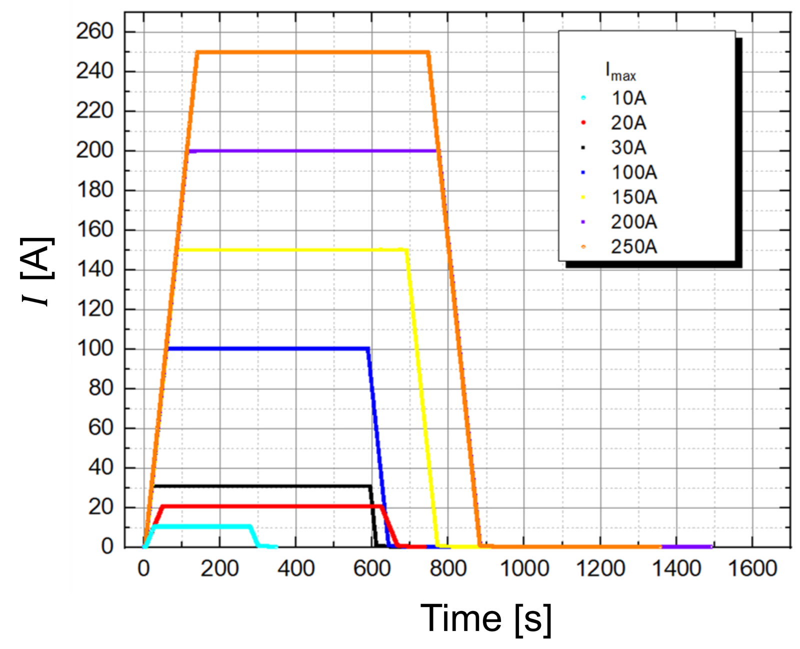
Requirements
- 24 poles
- Serial connected poles
- Operating current 1000 A (T=30 K)

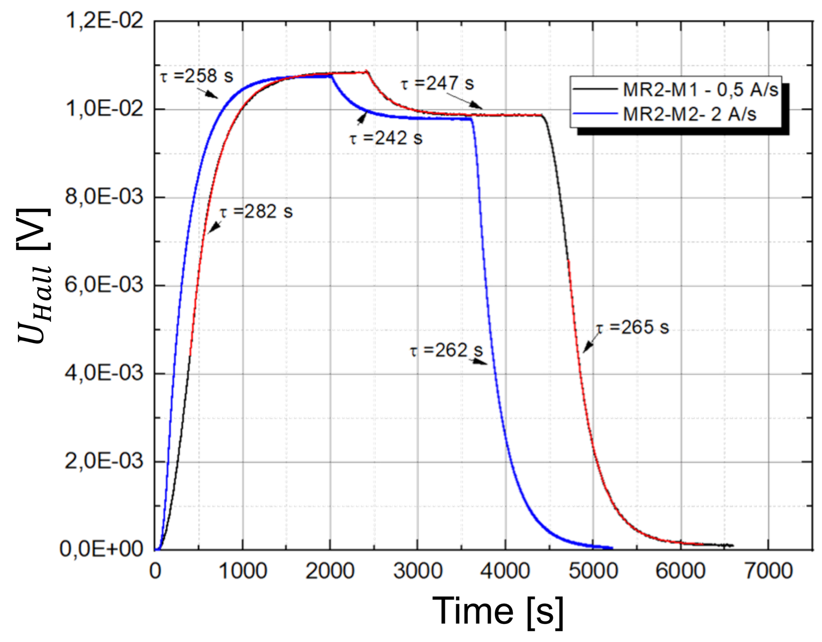


Approach
NI-VPI-double pancake coils (non-insulated, vacuum pressure impregnated, w/o inner joints)



Measurements ($T = 77$ K)





Telemetric data transfer (on test stand)
- Battery powered A/D conversion & wireless transmission for all signals on rotor (temperatures, voltages, pressure)

Conclusions & Status

Replacing a PM-rotor with a 2G-HTS-rotor in a high-current stator enhances the performance of a mid-speed wind power generator considerably – power density, power factor, simplified grid connection, etc.
- Electromagnetic performance, cooling, mechanics & HTS concept fulfill requirements
- Torque Transfer Element specified and material characterized
- First NI-VPI 2G-HTS coils characterized – in accordance with requirements (time constant vs. excitation requirements)
- Test setup for “series production” designed, in erection
- Total HTS (12 mm width) needed: 2 km
- Wireless data acquisition system developed and tested
- Design freeze milestone successfully passed; assembly process defined
- Cooling setup in erection, winding ongoing

Next steps
- Building & Testing components
- Assembling at test stand
- Testing performance and transients

Further resources:
R. Köster et al. – “Speedy_HTS: Ein Windkraftgenerator mit supraleitendem Rotor”, ZIEHL X, 16.04.2026, Berlin, Germany, https://ivsupra.de/wp-content/uploads/2026/05/ZIEHL-X-2-4-Koester.pdf
T. Arndt et al. - "Speedy_Hts – an HTS Rotor for an Uprated Mid-Speed Wind Power Generator." *IEEE TAS 36, no. 3 (2026): 1-4* https://doi.org/10.1109/tasc.2025.3619467