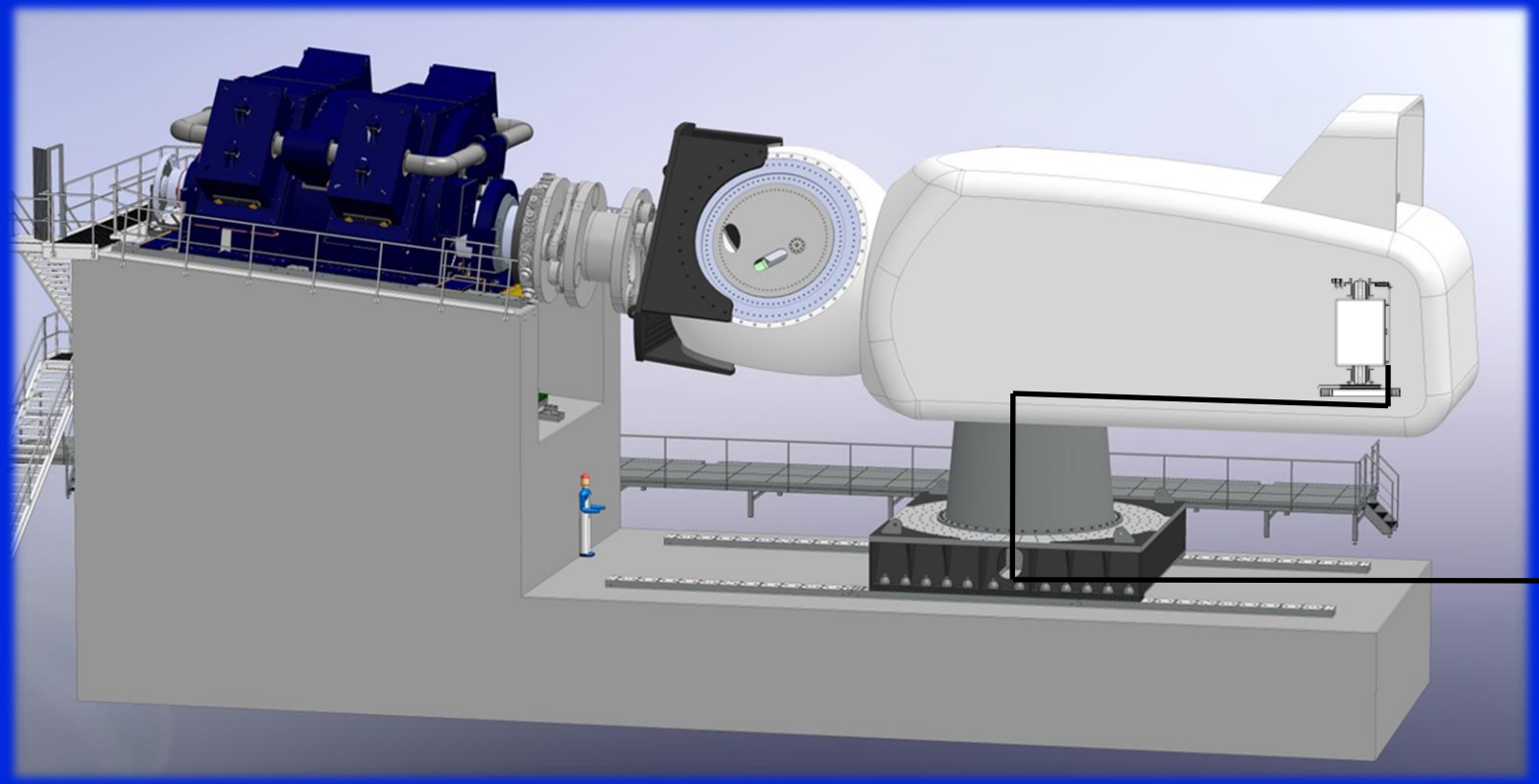
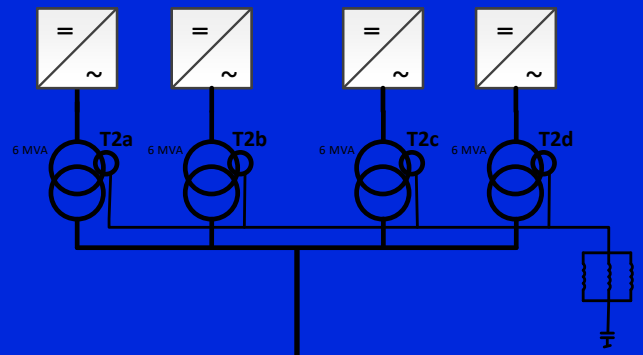
33kV – 21MVA
Grid emulator for wind turbine testing





Lindø Offshore Renewables Center

Lars Stylsvig Rasmussen, Operations Manager, LORC Nacelle Function Testing

Introduction to LORC

- **LORC**
  - **L**indø **O**ffshore **R**enewable **C**enter
- Founded in 2009 by the former Danish Prime minister Poul Nyrup Rasmussen
- LORC is non-profit commercial foundation
  - No owners, no shareholders, profit needs to be re-invested in new facilities
- The ship yard (Lindø) was ending ship production and to promote the area for the renewable sector, test facilities was to be established.
- The board of directors from the Danish offshore wind companies

Ørsted Vestas SIEMENS Gamesa RENEWABLE ENERGY FORCE TECHNOLOGY ENERGINET Stiesdal®

- & the Danish universities (Wind Denmark as observer)

DTU Danmarks Tekniske Universitet AALBORG UNIVERSITY SDU Syddansk Universitet wind denmark

- Test center was built under 1000T (1200T) gantry crane
  - 14MW FUNCTION tester in 2014
  - 16MW HALT tester in 2016
  - 25MW XL-HALT tester 2021

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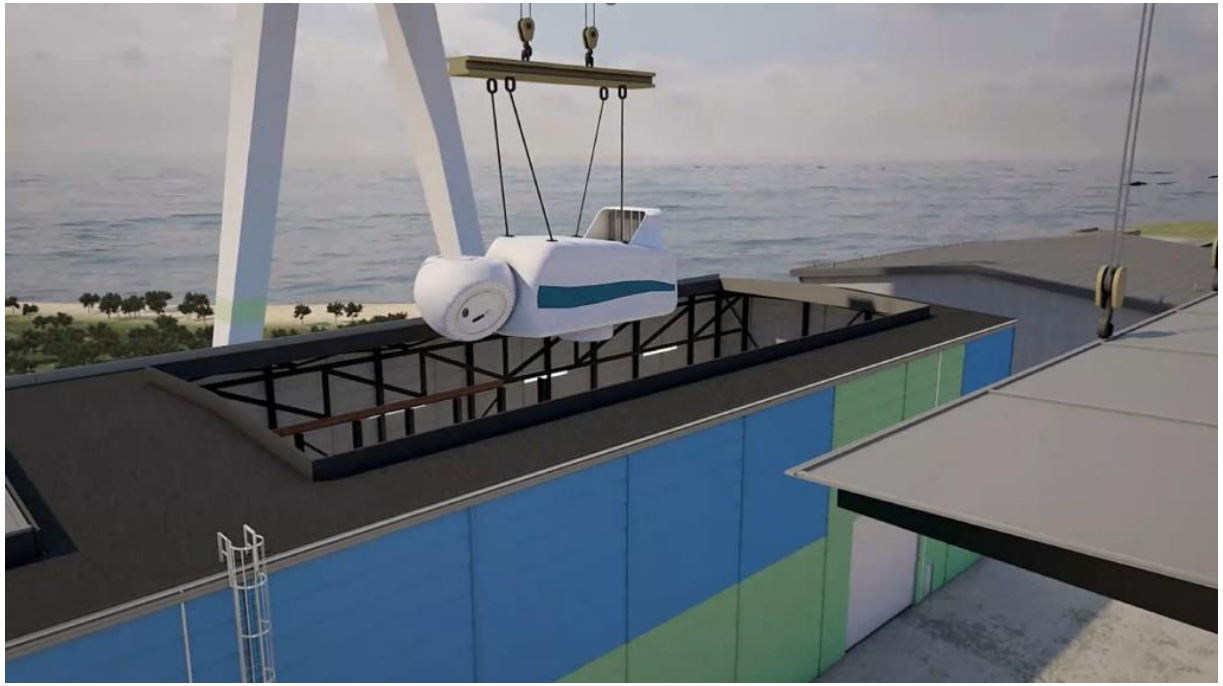
The Lindø site today

Vestas

BLADT INDUSTRIES

Infrastructure Lindø site

- Nacelle testing facility located under the 1000T gantry crane



Infrastructure Lindø site

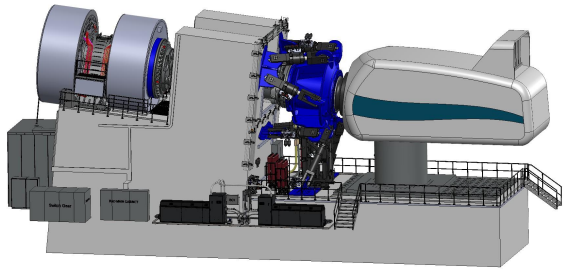
- Nacelle testing facility located under the 1000T gantry crane

LORC test facilities timeline

Year 2016

16MW@10 RPM

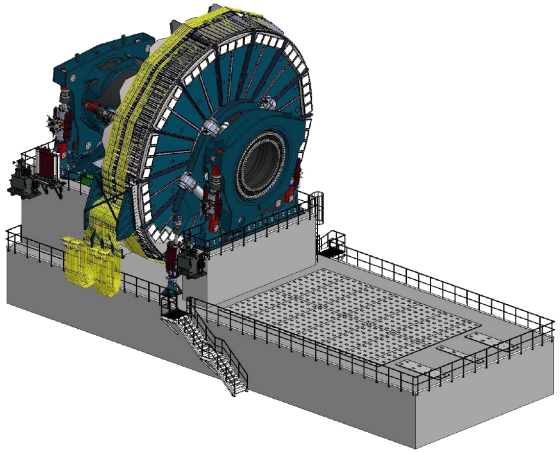
HALT



Year 2021

25MW@7,4 RPM

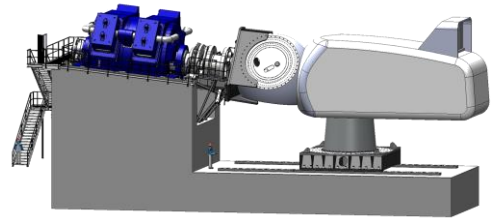
XL-HALT



Year 2014

14MW@10,5 RPM

Functionality



LORC

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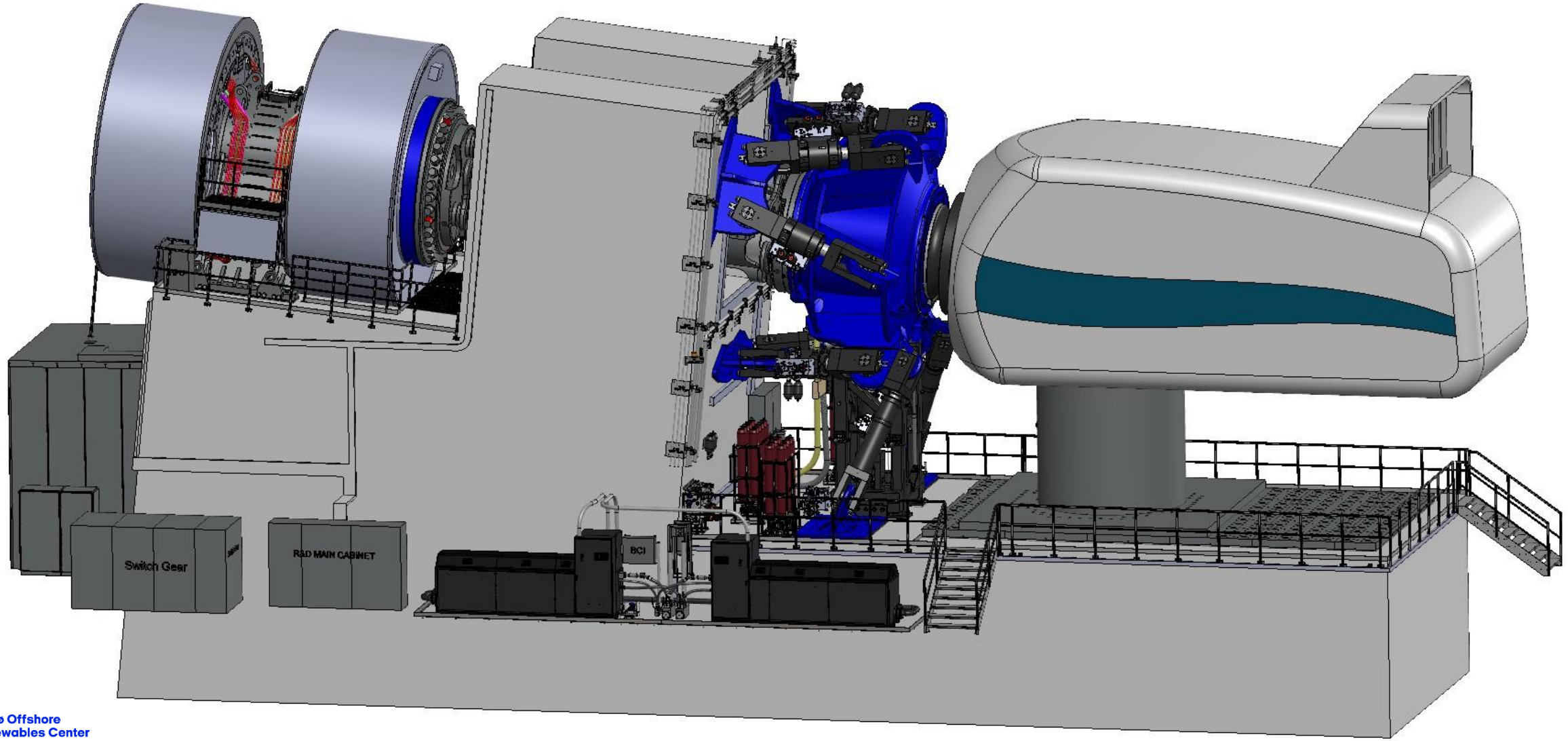
16MW HALT 3D model



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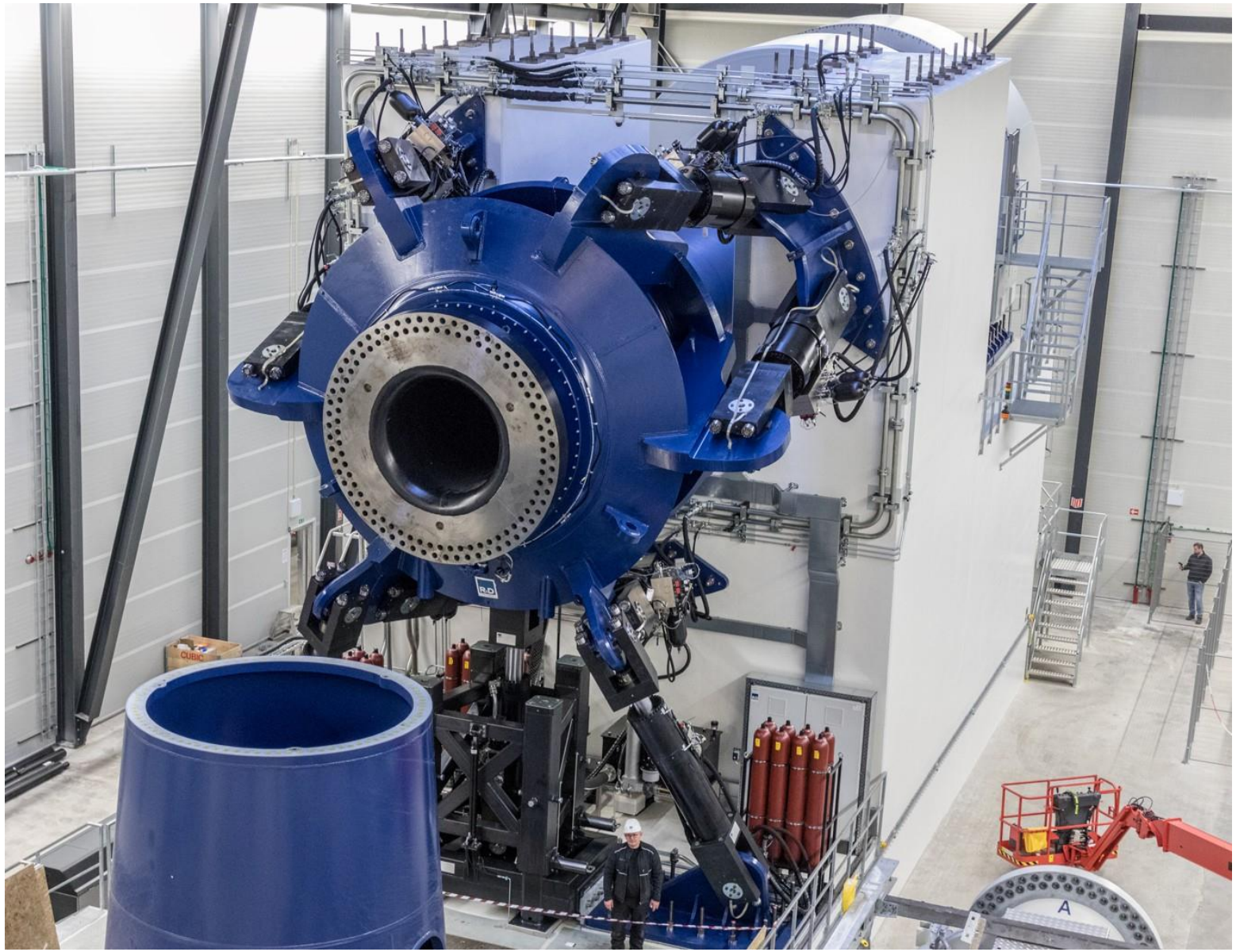
16MW HALT picture



LORC

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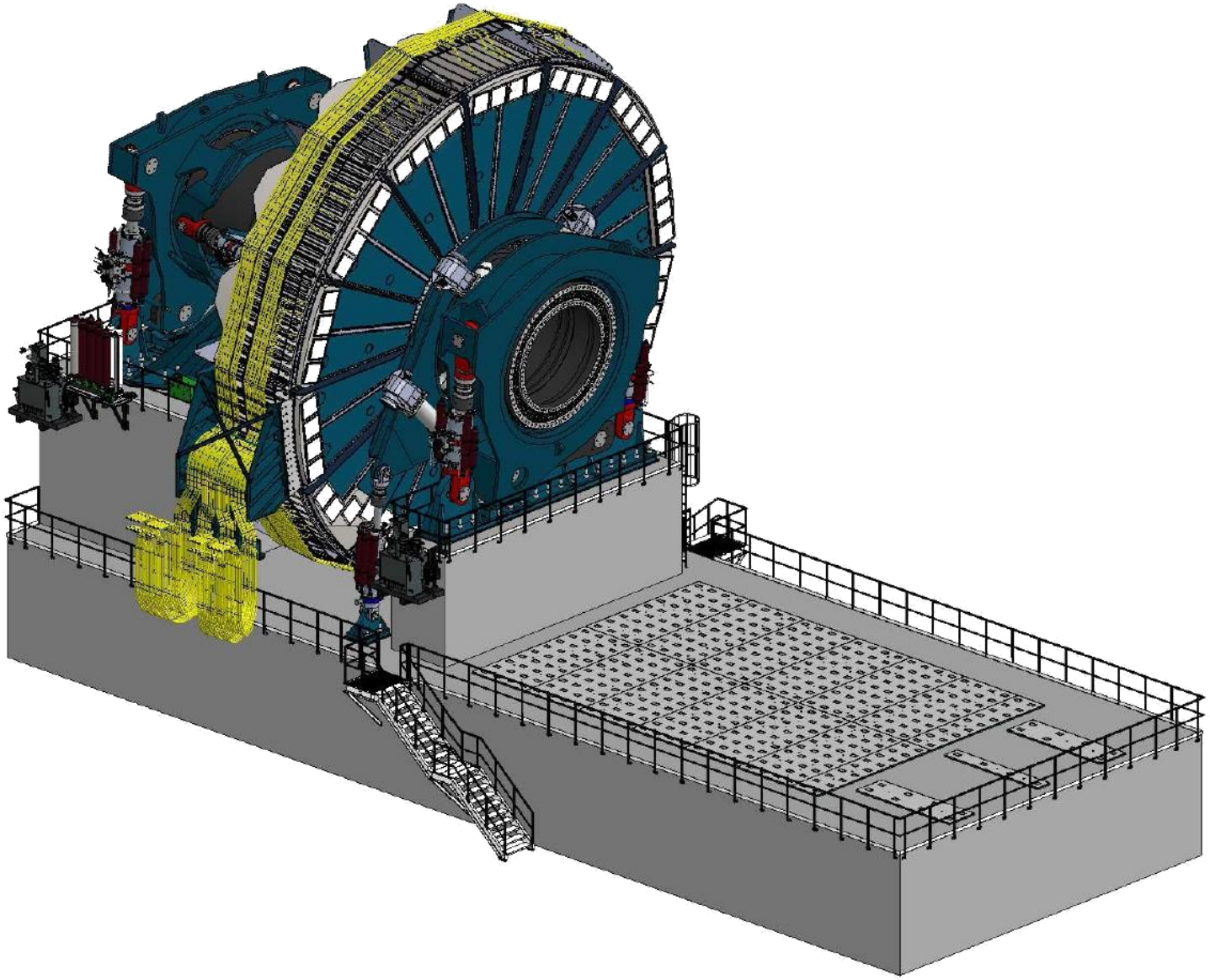
25MW XL-HALT 3D model



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25MW XL-HALT picture

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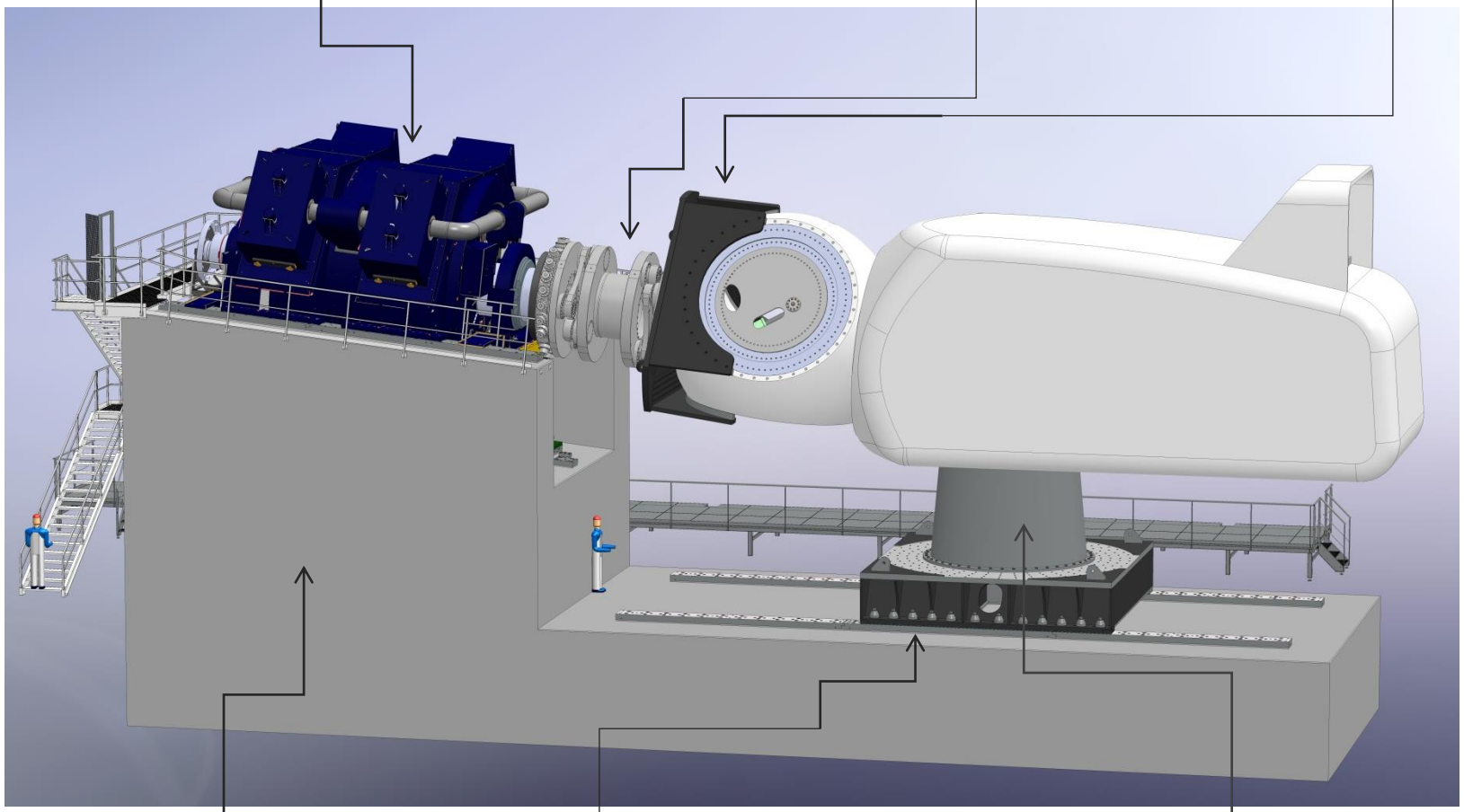
LORC Function tester



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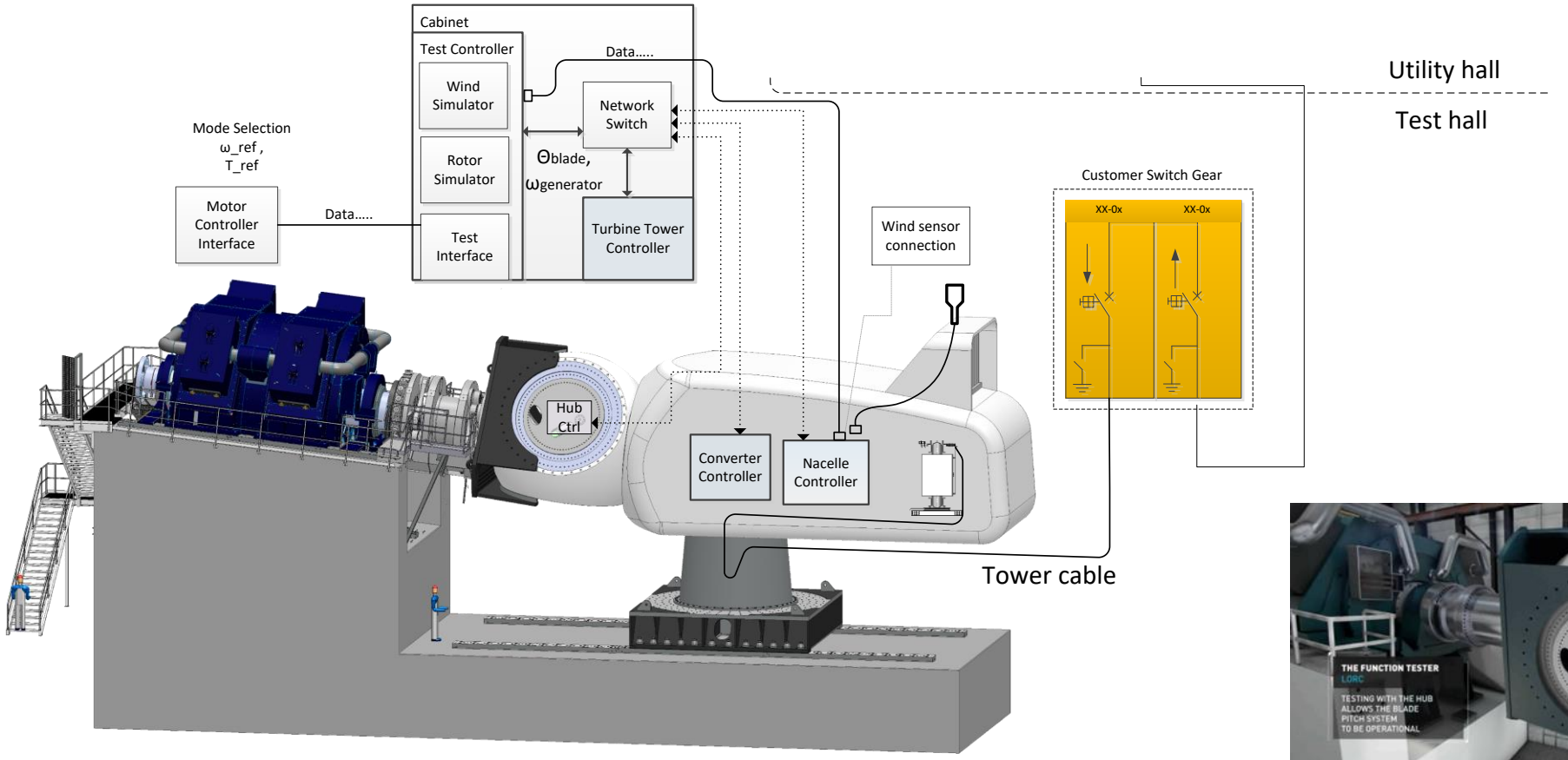
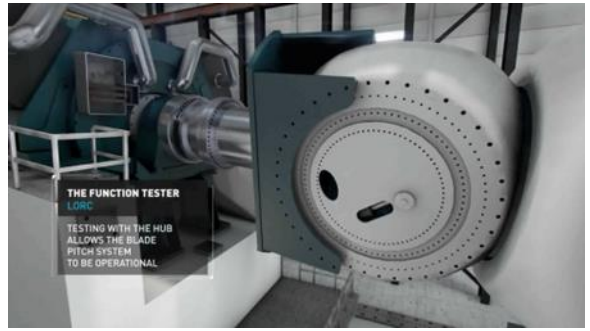
LORC Function tester pictures

Test rig control (Torque mode / mHiL control)

Mode 3:
Torque ctrl. mode





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Function tester electrical system

Grid Supply

63 / 33 kV
16 MVA
OLTC:
(+/- 14%)
2% steps

Transformers

T1: 33/3kV; 16 MVA
T2: 3/33kV 11 MVA

MV Inverters

GE MV7315 3.3kV
6 x 15MVA (DC/AC)

MVSG

36 kV
(40,5 kV)

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Function tester power flow

Option 1:

Public Grid

33 kV; 50 Hz

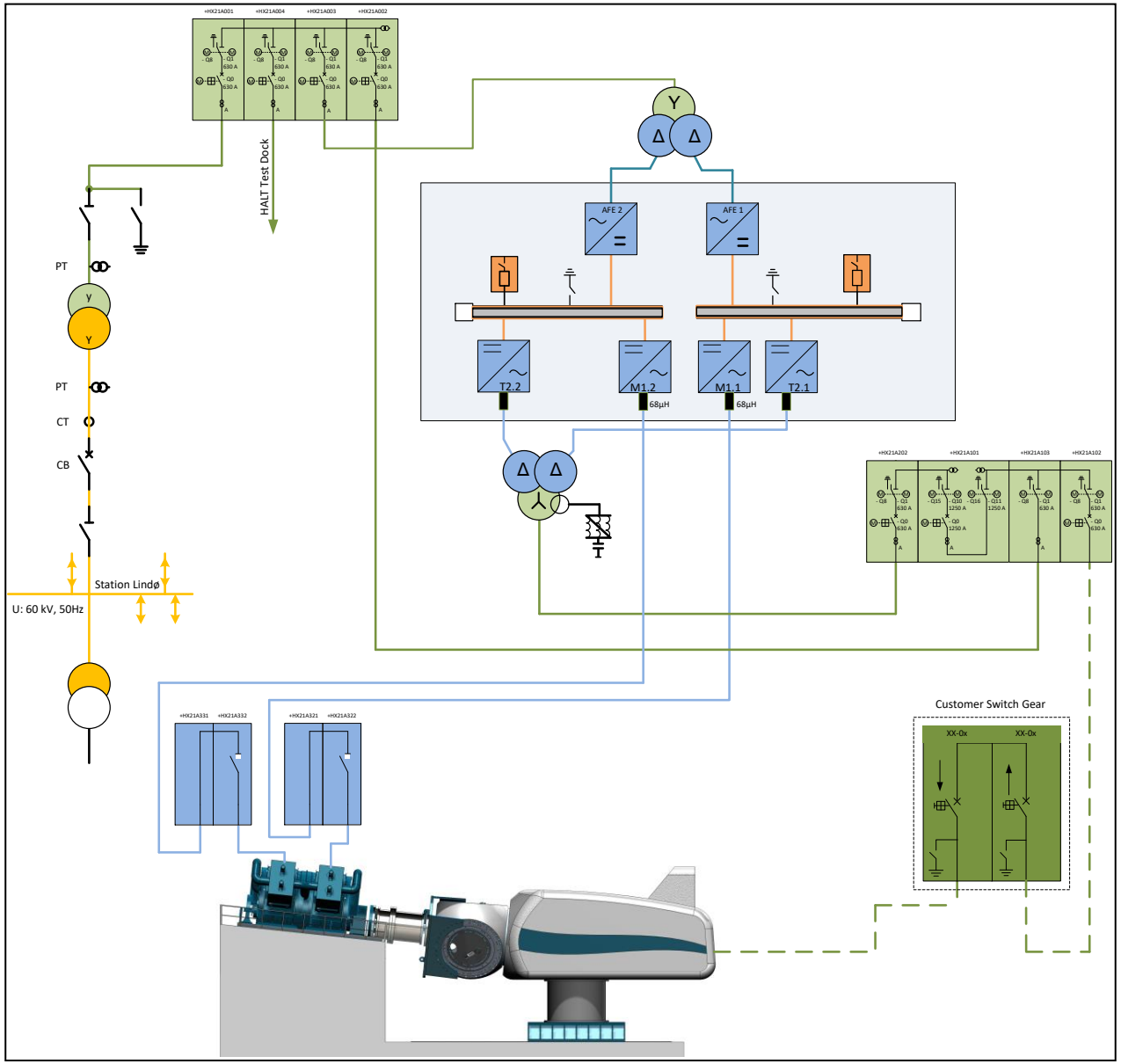
- Fixed frequency (50Hz)
- OLTC to control voltage level
- 14 steps of 2% (Max 36kV)
- Low Harmonics (PQ measurements)

Option 2:

Grid Emulation

0 – 40 kV; 45 – 65 Hz

- Variable frequency (45-65Hz)
- SW controlled voltage regulation
- Low Voltage Ride Through (LVRT)
- High Voltage Ride Through (40kV)



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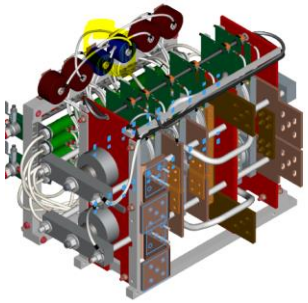
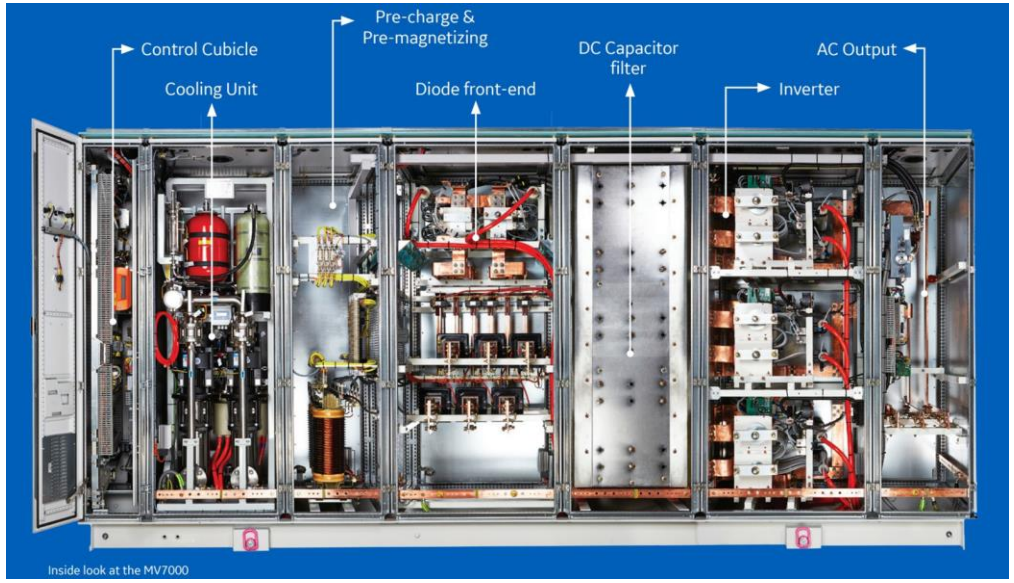
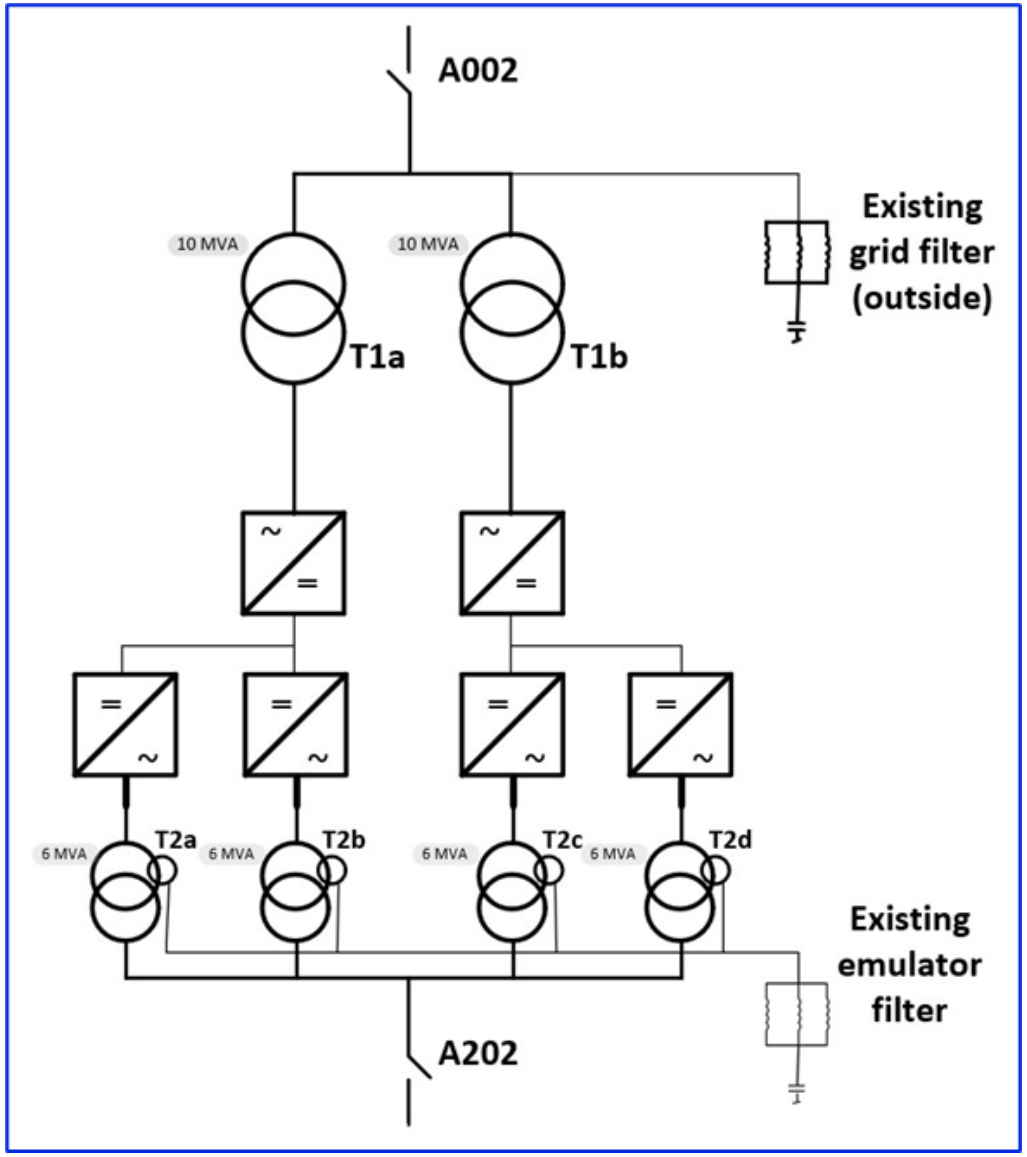
Emulator upgraded from 10MVA to 21MVA

- Upgrades
  - One T1 transformer (16MVA) replaced with Two T1a-T1b
  - One T2 transformer (11MVA) replaced with four T2a-d
  - Cables upgraded
  - Power stacks upgraded snubber circuit
    - Increased switching frequency (1350Hz)
  - Updated control SW
  - Updated harmonic filter configuration







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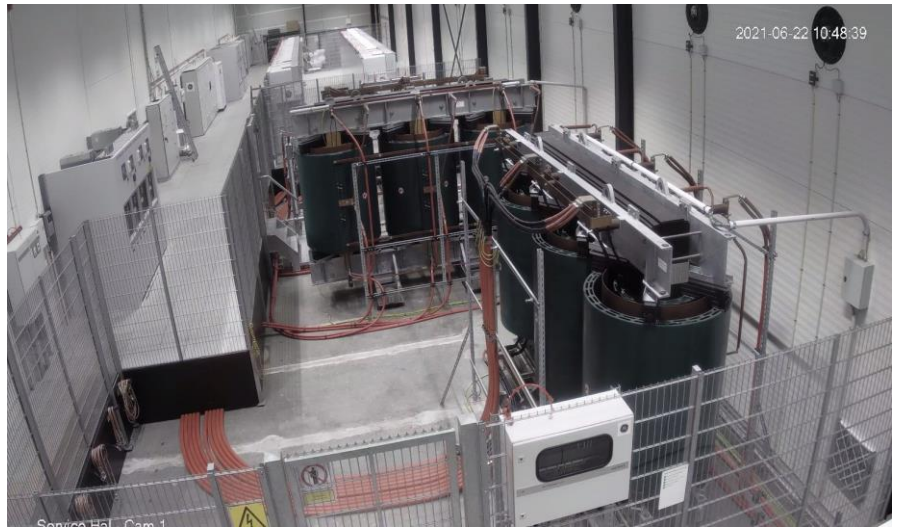
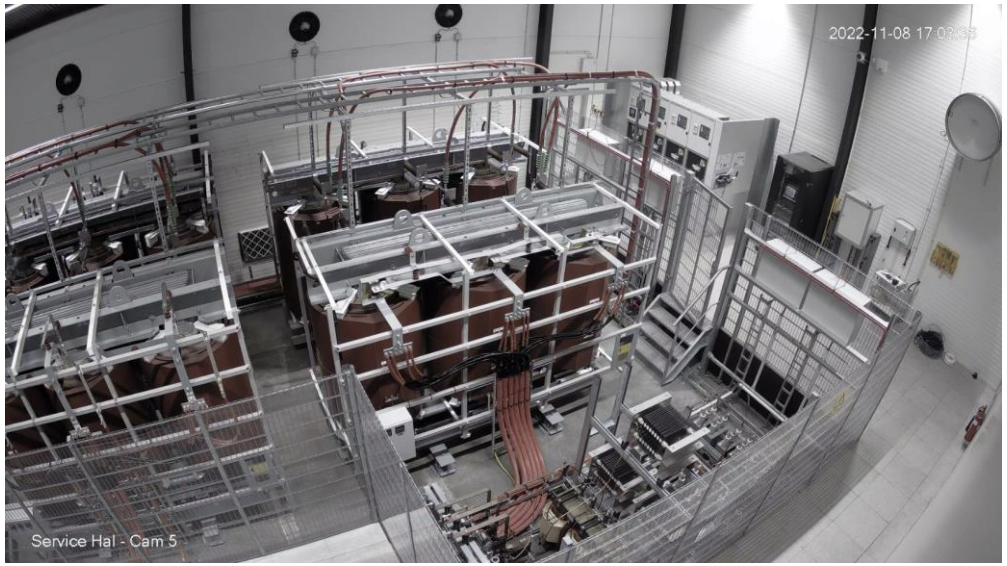
Emulator upgraded from 10MVA to 21MVA





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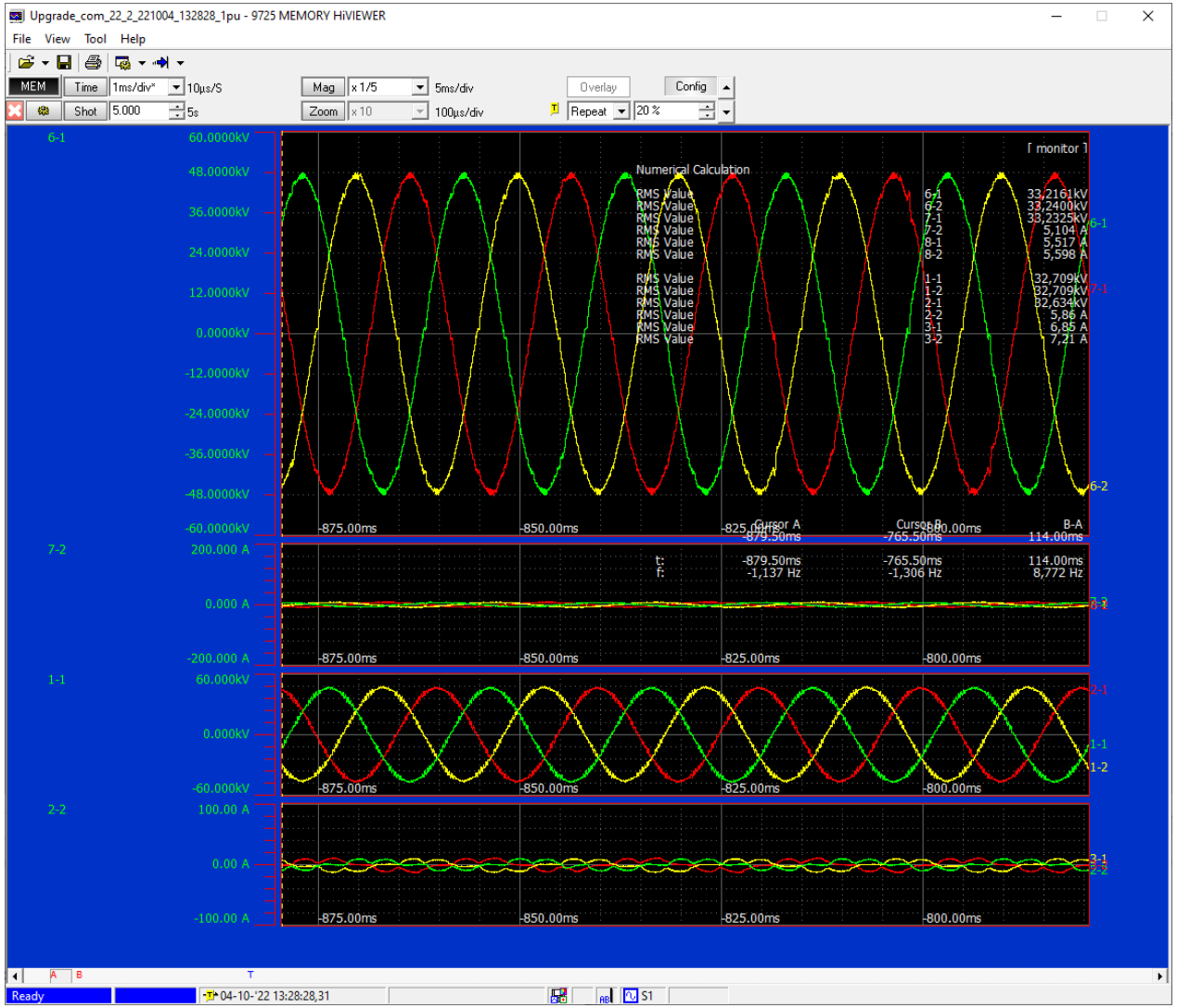
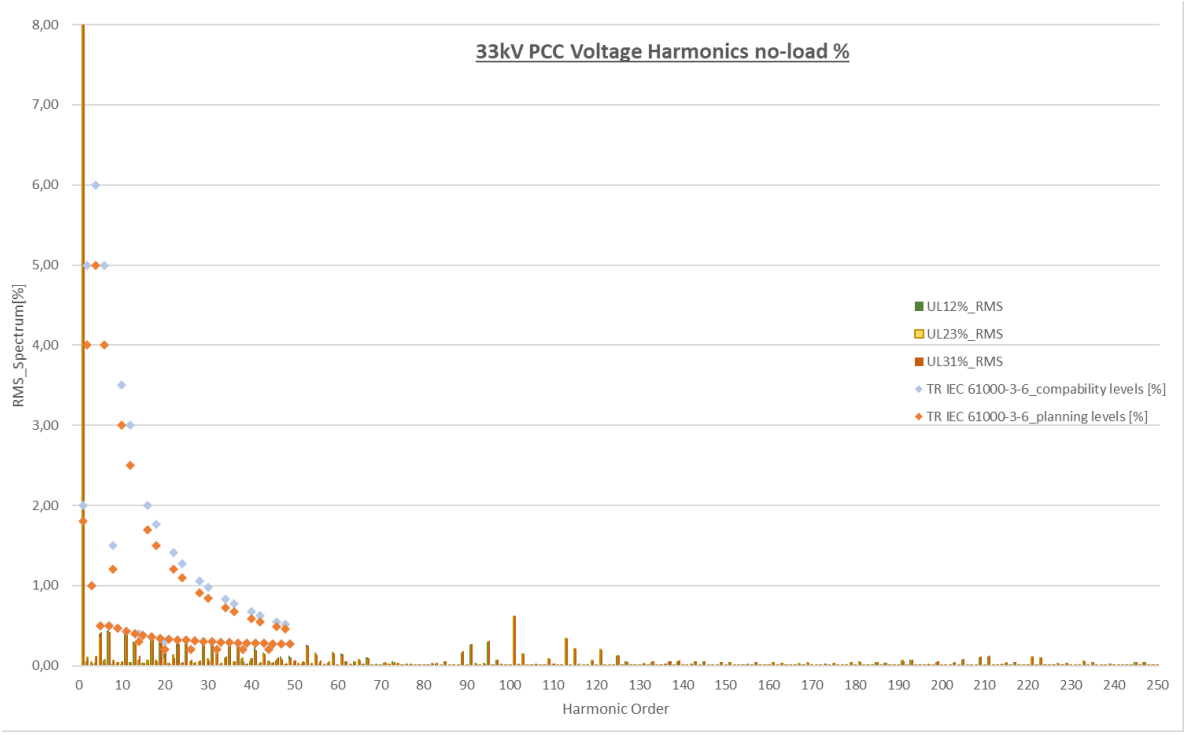
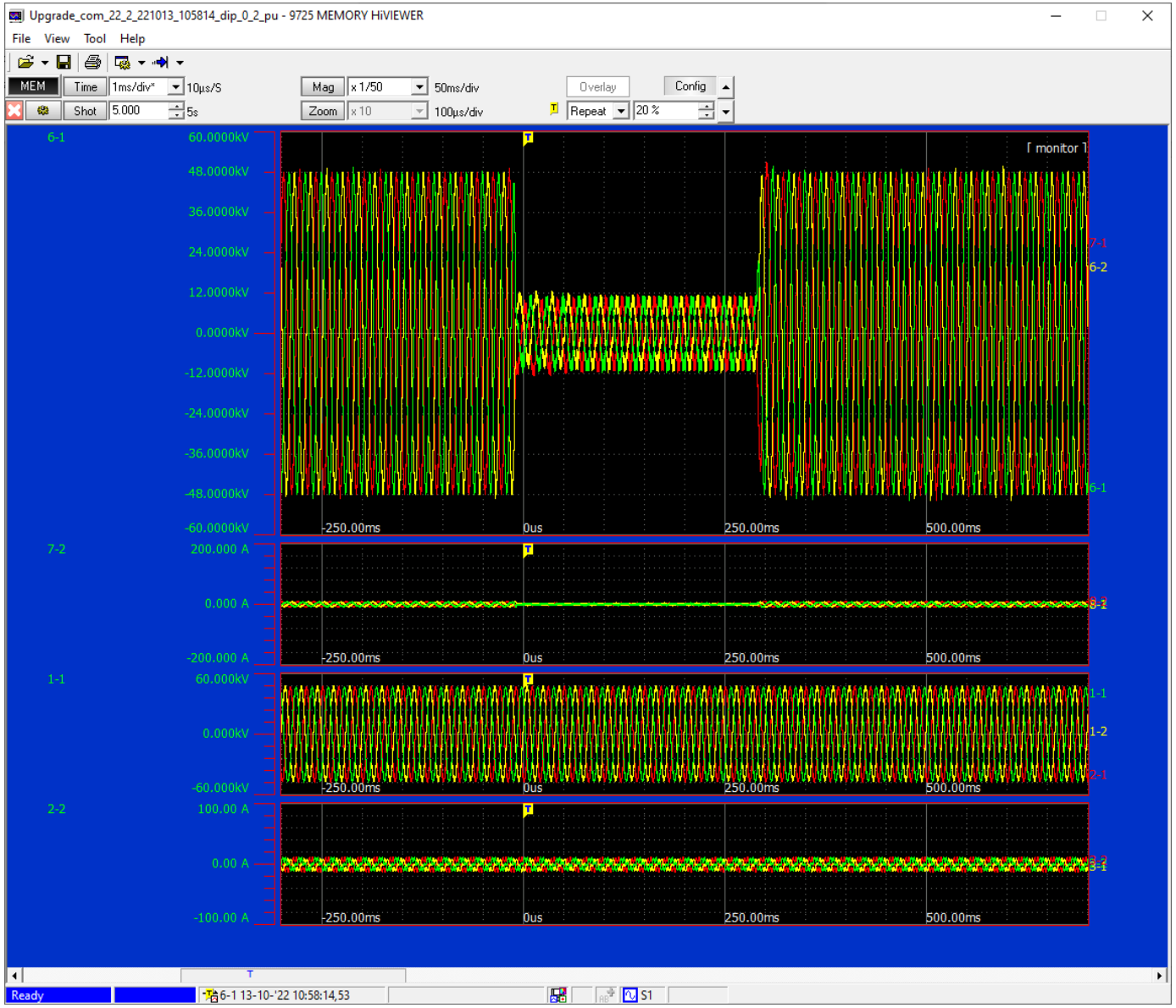
Results upgraded emulator no-load





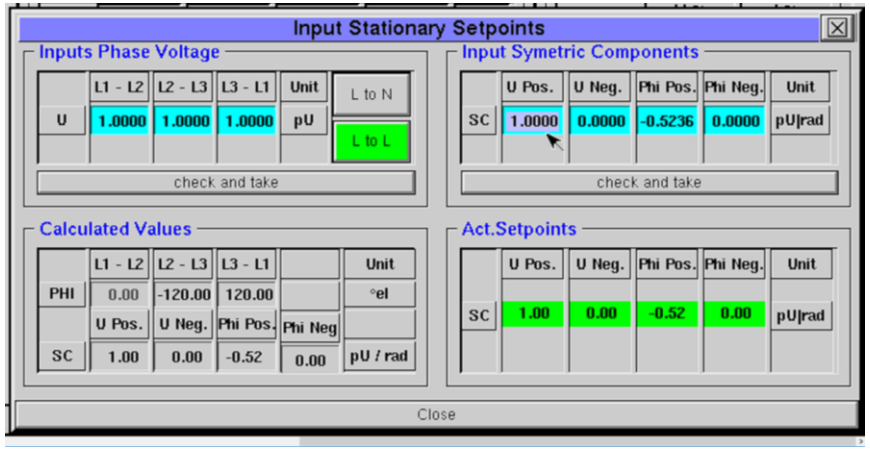
	UL12	UL23	UL31
THD50	1,26 %	1,16 %	1,24 %
THD100	1,39 %	1,29 %	1,37 %
THD250	1,63 %	1,54 %	1,61 %

Results upgraded emulator no-load

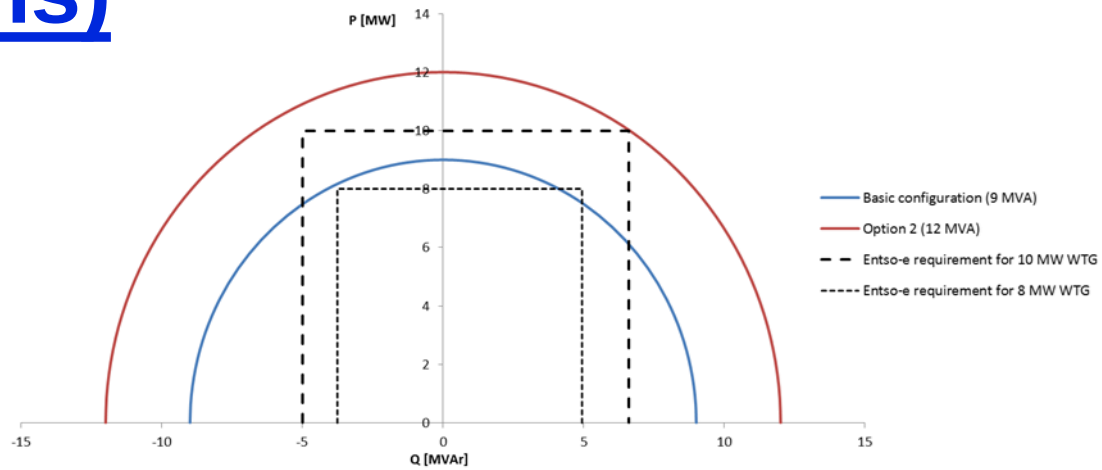


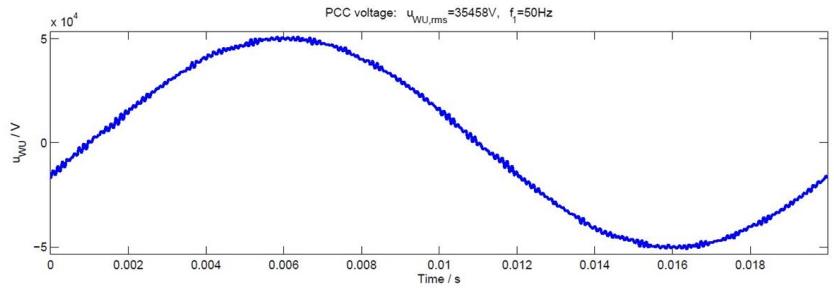
Test example 1 (PQ – chart @ voltage range) (Heat runs)

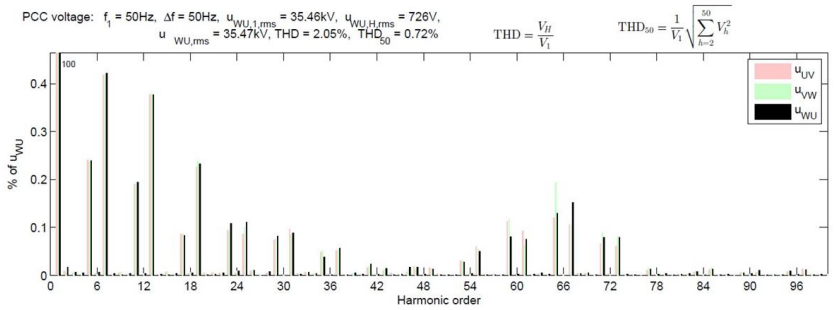
- Running the turbine in all corners of the P-Q chart
  - At nominal voltage (1pu)
  - At low voltage (typical 0,85pu)
  - At high voltage (typical 1,13pu)
- Adjusting the voltage on the 33kV side on the 4th digit



  - To compensate for transformer reactance
- Verifying thermal design by running 6-10h in corners
  - Typically chokes, transformers, busbars and cables are checked







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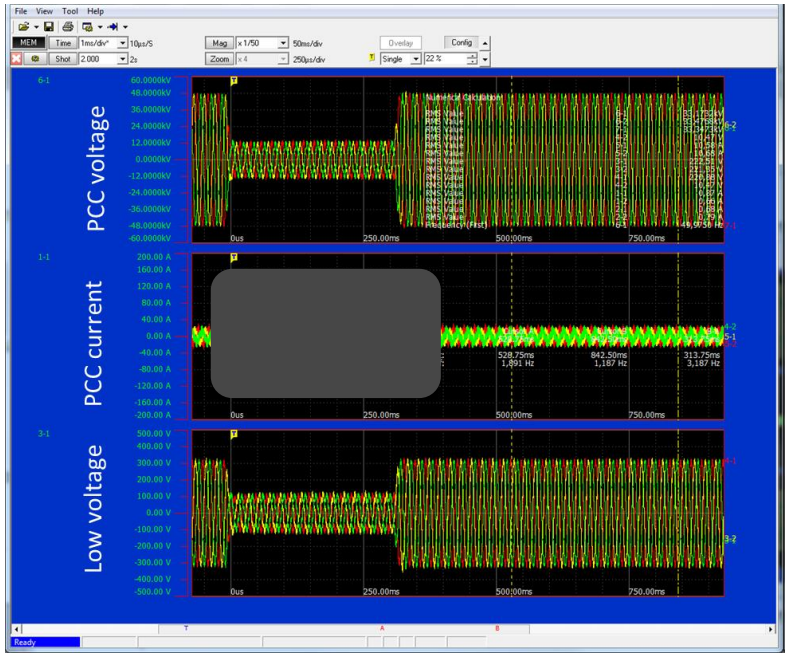
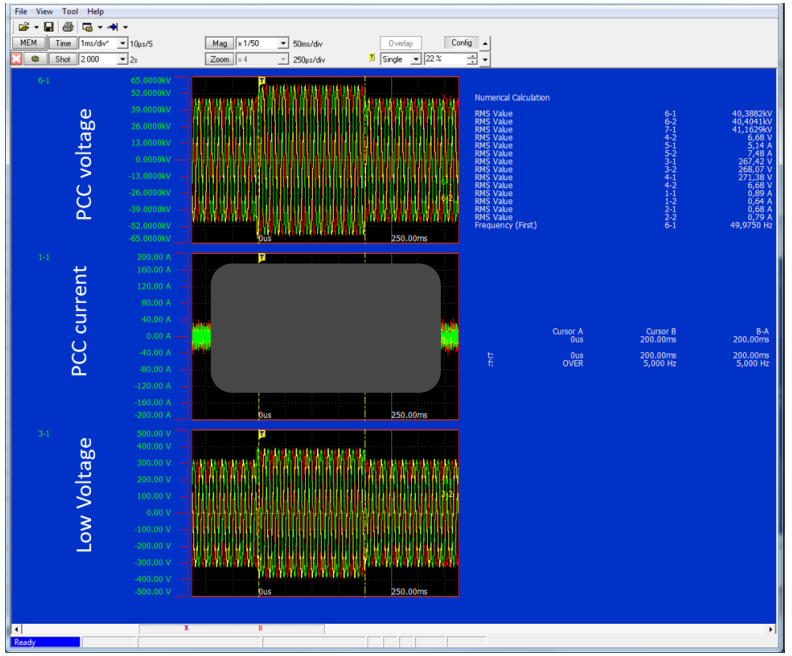
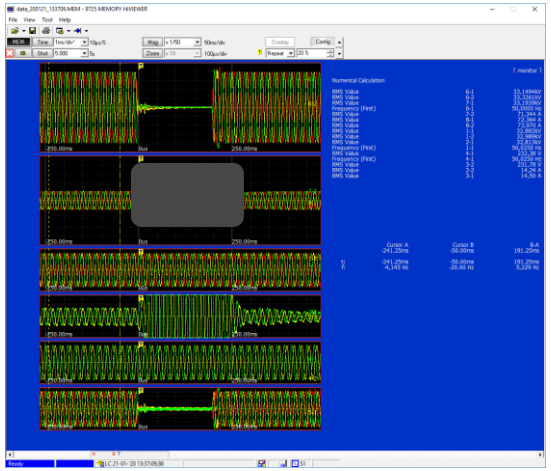
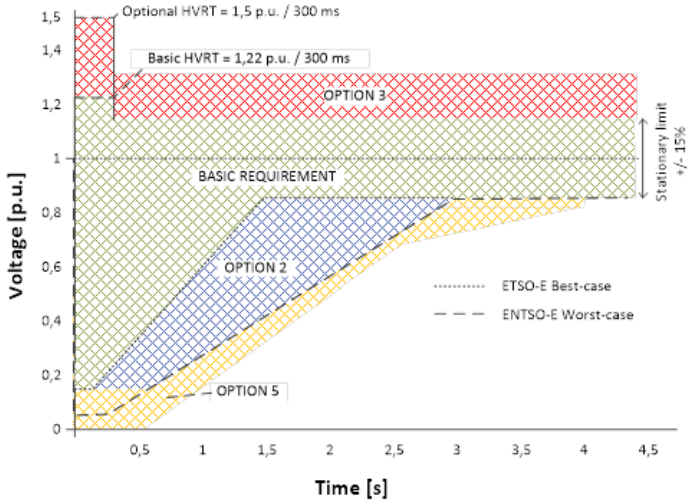
Test example 2 (LVRT – OVRT capability)

- Running Low Voltage Ride Through (LVRT) within profile
  - Turbine must run through (no trip)
  - Document controller response (dip-detected….)
  - Reactive power injection during faults (k-factors)
  - Active power recovery ramp rate
  - Measure temperature of chopper units
  - Verifying at different power levels (changing wind, not derate)
- Running LVRT outside profile
  - Turbine must trip
  - Document controller response (dip outside profile)
  - Measure temperature chopper units
- ZVRT possible after SW upgrade 2019 (D-FIG requires investigations)



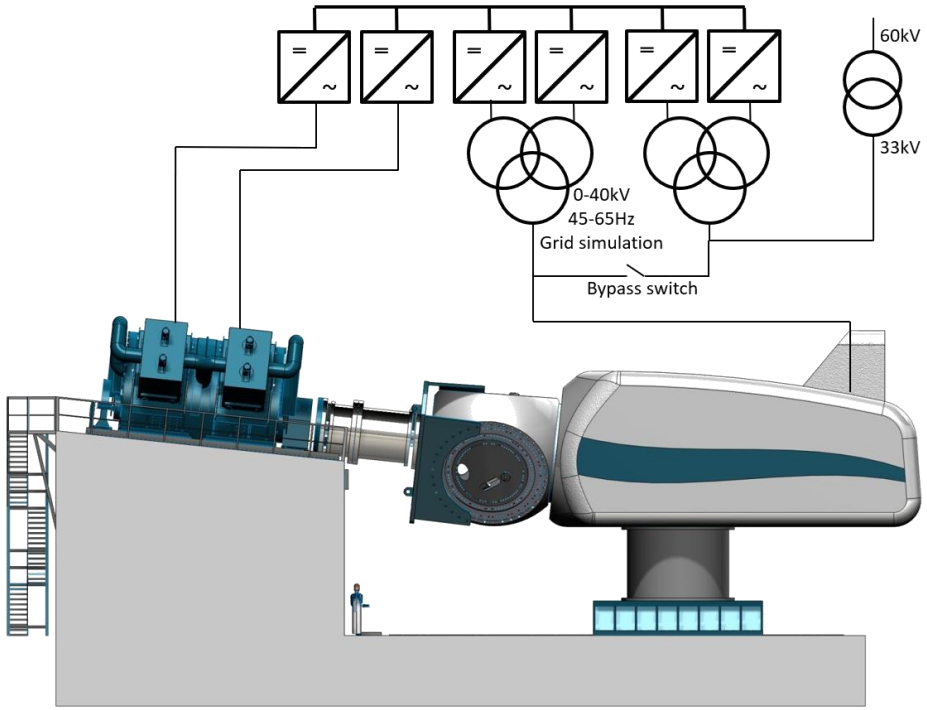


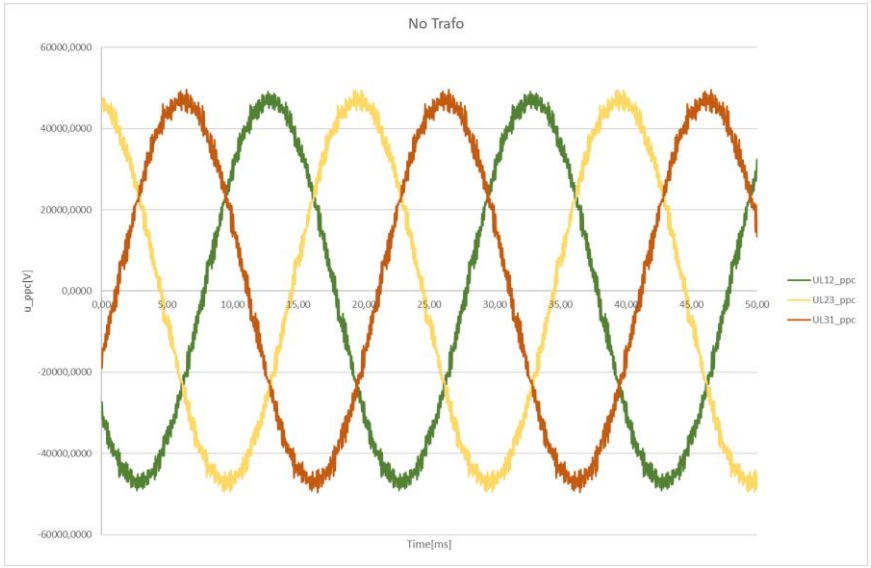


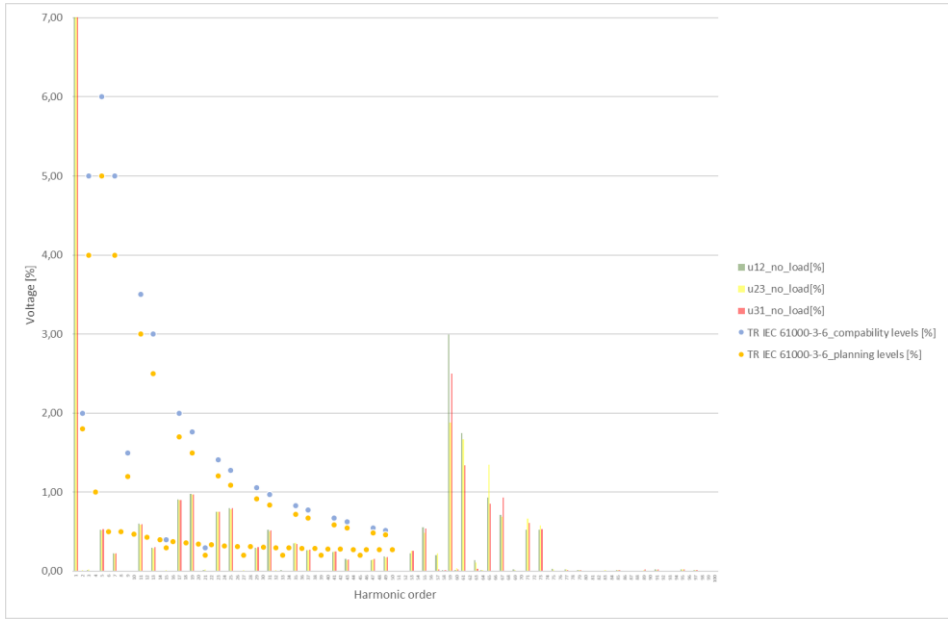


Test example 3 (Harmonics)

- Evaluating harmonic emission from turbine
  - Running public grid connection to have “realistic” grid
  - Evaluating different converter filter designs
  - Evaluating different converter control PWM
- Testing at different power levels
  - Changing wind reference (low turbulence)
  - Derating not necessary







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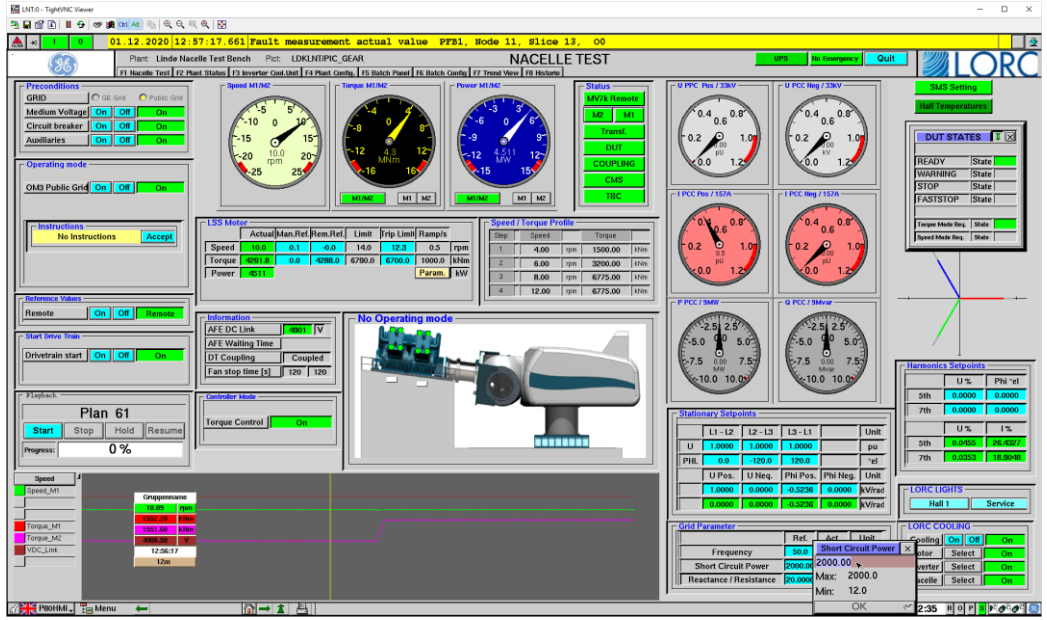
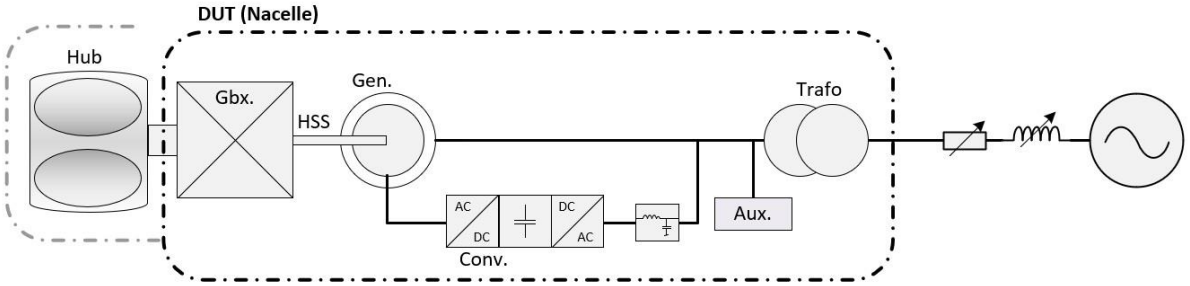
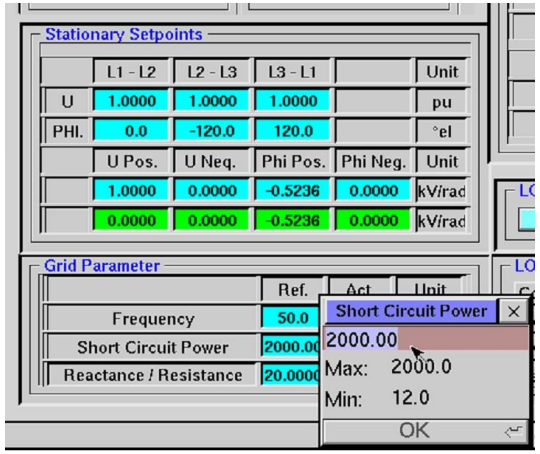
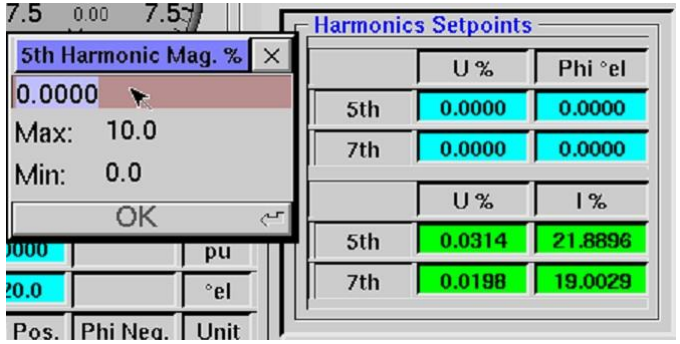
Test example 4 (SCR and harmonic injection)

- Adjusting the grid “strength” (Short circuit power and impedance)
  - Verifying stable operation at strong/weak grid
  - Voltage suppression control features
- Injecting 5th and 7th harmonics
  - Check filter loadings and protection
  - Stability of electrical grid system at extreme grids



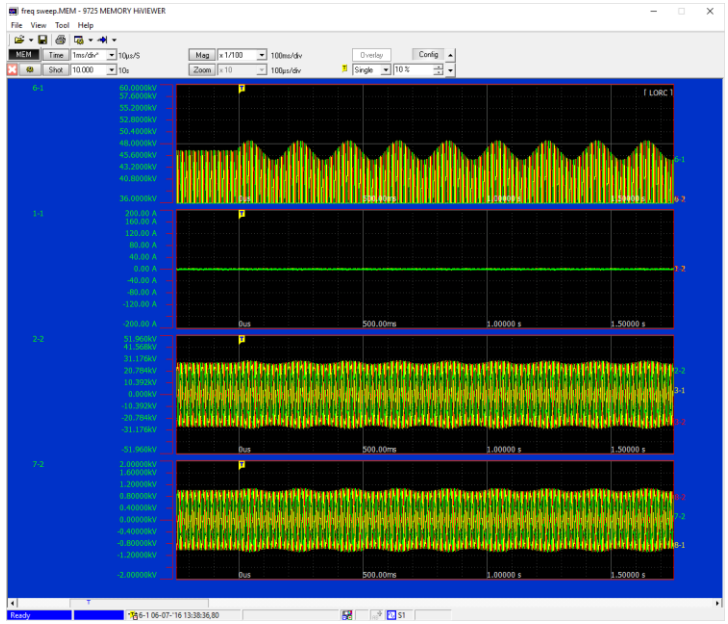






Test example 5 (Emulator fluctuating grid)

- Sub synchronous resonance tests on 60Hz D-FIG
  - Paper published on wind integration workshop Vienna
  - Data from simulation feed into emulator
  - Mitigation turbine SW developed, uploaded and tested



Experimental Full Scale Assessment of Subsynchronous Resonance Behavior of a Wind Turbine with Doubly Fed Induction Generator

Torsten Lund, Poul Møhl Dyrlund,
Gert Karmisholt Andersen Morten Sloth Sogaard
Leif Svinth Christensen
Vestas Wind Systems

Lars Stylsvig Rasmussen, Johnny Rusbjerg
LORC Nacelle Test Center

Massimo Bongiorno, Selam Chernet
Chalmers University of Technology

***Abstract*—The paper presents an experimental assessment of the impedance characteristics in the subsynchronous frequency range of a wind turbine comprising a doubly fed induction generator. The impedance characteristics have been identified under different working conditions, and the effect of different current controller settings has been investigated. The tests have been performed on a 2 MW 60 Hz Vestas DFIG wind turbine nacelle at LORC Nacelle Testing Facility.**

SSR, DFIG, Full scale test, Impedance characteristic

source, the network and the load [6][7]. Figure 1 shows a generalized small signal representation of a network.

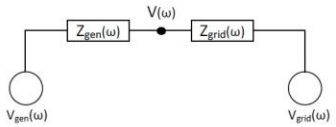
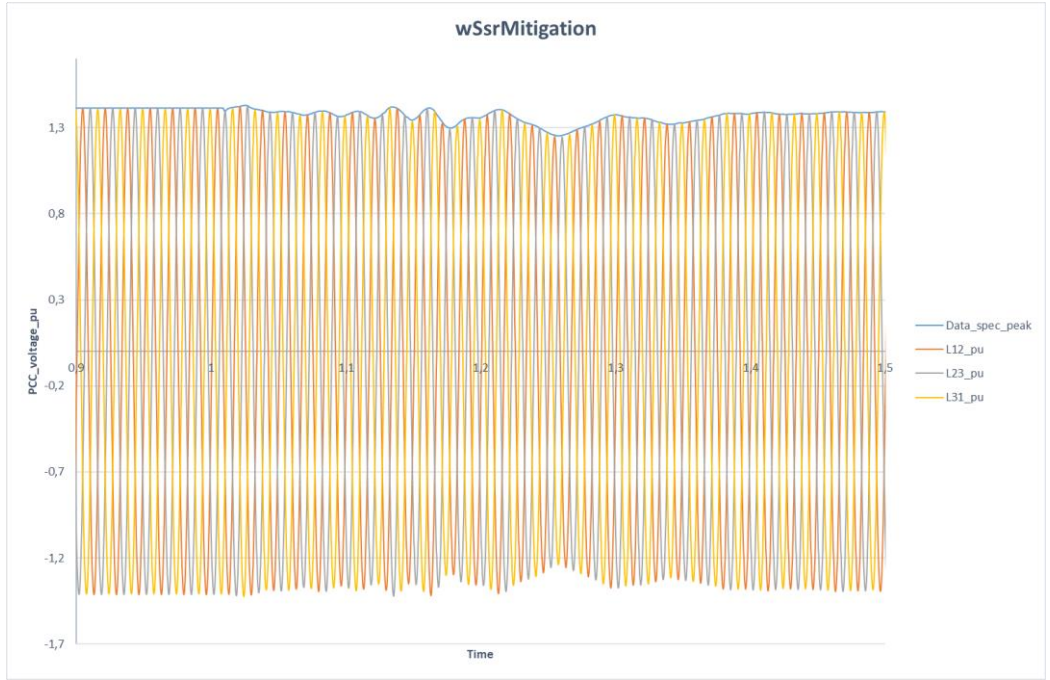


Figure 1 Small signal Thévenin representation of a grid



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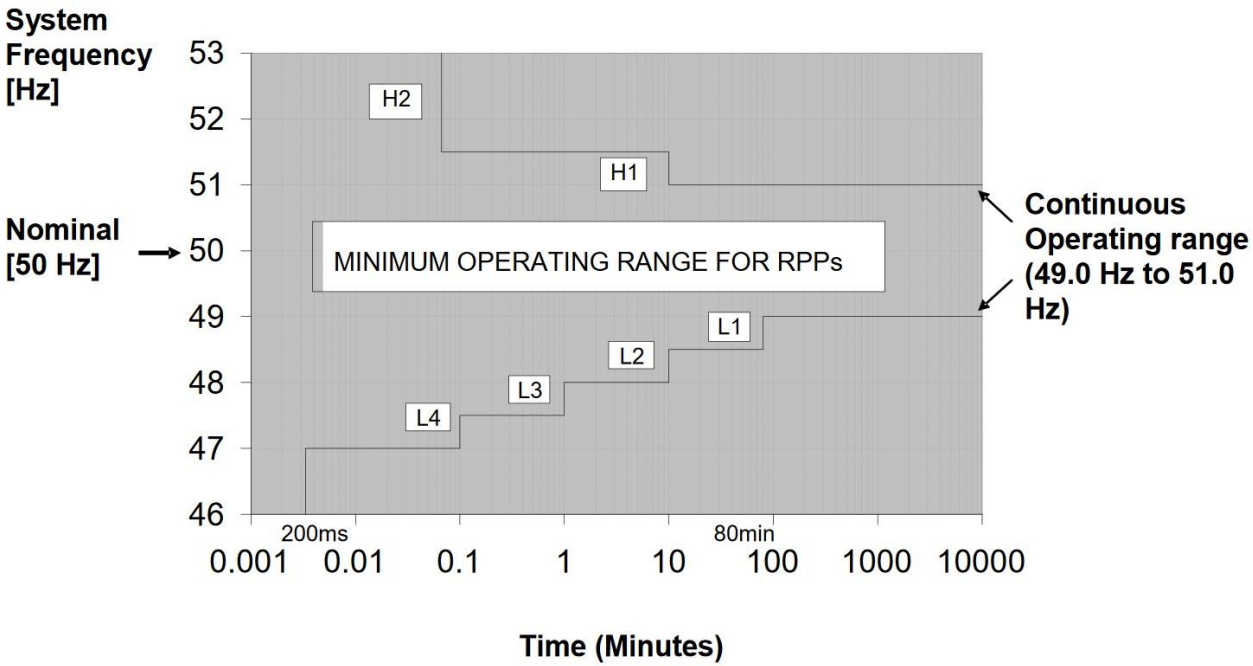
Test example 6 (Frequency tests)

- Running partial / full load tests at corners of voltage and frequency
  - Checking pumps / thermal relays and control is working (not tripping)
  - Testing with Power Plant Controller to verify frequency response
  - RoCoF (Rate of change of Frequency) programmed in emulator

- Testing 60Hz turbine versions (emulator only).



EMC tests

- Measuring emission inside hall
  - Disturbance from other systems
- Measuring CM currents inside nacelle
  - Isolation towards PM machine
- Measuring magnetic fields inside nacelle