

The Supernet NL Project: The Netherlands High Voltage HTS Cable Project

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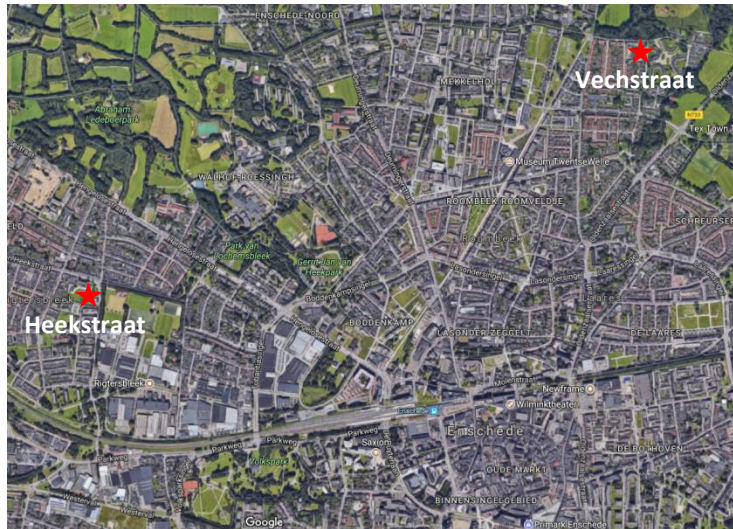
Outline

- Supernet NL project
 1. Overview
 2. Project outline
- Electrical insulation system
 1. Testing
 2. Insulation aging
 3. Modelling of aging
 4. Cable length effect
- Cooling System
 1. Requirements
 2. Testing
- Monitoring
- Recommendations

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Supernet NL project



Supernet NL project:
High temperature superconducting cable
150 MVA/110 kV , ~3.4 km
Enschede, the Netherlands

- The aim of the project:
Qualifying the HV-HTS cable system in the Netherlands grid
(Technology Readiness Level (TRL): 8 up to 9)

Supernet NL project

- Project started in August 2015
- Project partners:
 1. **TenneT TSO:** operator of the grid and the project leader
 2. **TU Delft:** electrical and electromagnetic behaviour
 3. **University of Twente:** cooling system
 4. **HAN University of Applied Sciences:** monitoring
 5. **IWO:** reliability and availability
 6. **RH Marine:** system integration
- Tender process started in July 2017
- Commissioning will be in 2019
- Installation planned to be completed by 2020

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Electrical insulation system

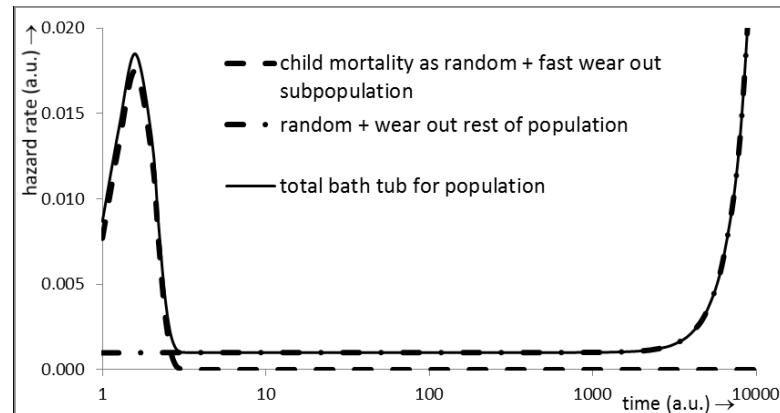
- Electrical insulation system tests for quality checking of the cable:
 1. Pre-qualification test
 2. Type test
 3. Sample test
 4. Routine test
 5. After installation test
- These tests should design based on a pure experimental background
 1. Most of the R&D projects are based on insulation material samples and model cables
 2. Long term experience with HTS cable needs to grow
 3. Experiment with full scale cable needs to grow

Electrical insulation system

- Aging mechanisms of the polymeric insulated cable system:
 1. Electrical discharges at insulation material interfaces
 2. Discharges in voids
 3. Mechanical/Ambient stresses
 4. Intrinsic aging
 5. Thermal/Chemical mechanism (Arrhenius law)

Electrical insulation system

- Failure rate of the components



Single-stress aging Weibull distribution:

$$F(t) = 1 - \exp\left(-\left(t/\alpha\right)^\beta\right)$$

R. Ross et. al. "Insulation Reliability of Superconductive Cables",
ICEMPE 2017, 1st International Conference on Electrical Materials and
Power Equipment, 14-17 May, 2017, Xi' an, China

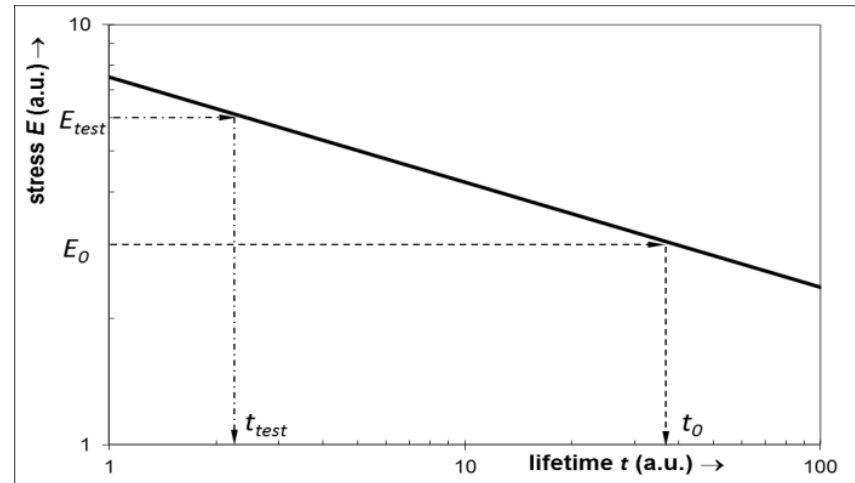
Electrical insulation system

- (Inverse) Power Law (IPL)

$$(E_{\text{test}})^n \times t_{\text{test}} = (E_0)^n \times t_0 = \text{const.}$$

The IPL is extensively used in the conventional cable system:

- i. water treeing: $2 \leq n \leq 4$
- ii. partial-discharge induced degradation: $n \sim 4$
- iii. contaminant effects in polymer insulation in real cable under dry conditions: $8 \leq n \leq 10$ (often $n \sim 9$ is taken as average)



- Cable length effect

$$t_{0,\text{cable}} = t_{0,\text{sample}} \left(L_{\text{sample}} / L_{\text{cable}} \right)^{1/\beta}.$$

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Cooling System

The cooling system includes at least:

- Thermal insulation system (MLI + Vacuum)
- Cooler subsystem
- Liquid/gaseous coolant circulation subsystem

Concerns on cooling system:

- Cost and efficiency
- Minimum cooling down / heating up process time
- Regular maintenance (redundancy in moving parts is needed)
- Reliability and Lifetime of the cryostat
- Acoustic noise

Cooling System

- Preferred cooling system for Supernet NL project
 1. High efficiency and low cost
 2. Fast cooling down / heating up
 3. Robustness and reliability
 4. Acoustically insulated
- Other
 1. Preferably one-sided cooling system
 2. Integrated liquefier
 3. Possible small reservoir for emergency
- Testing
 1. Pressure and vacuum tests
 2. Tests on subsystems (i.e. cooling and circulating S.S.)
 3. Full scale combined test

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Monitoring

- Monitoring system should be able to measure:
 1. Distribution of the temperature in the cable (DTS);
 2. Pressure and mass flow rate of the coolant;
 3. Vacuum; and
 4. Partial discharge (PD)
- Monitoring system should
 1. support the cable system operation
 2. provide information regarding the reliability, availability, maintainability, and possible remaining lifetime
 3. determine the system performance (losses, insulation condition)
 4. communicate with the SCADA system of the power grid

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Recommendations

- Efficient and cheap cooling system
- Investigating the aging phenomena of the electrical insulation
- Investigating the thermal contraction/expansion effect on the electrical insulation system
- Investigating the n -value of the HTS cable system
- Investigating the length effect
- Increasing the lifetime of the cryostat and cooling system (maintainability of cryostat)
- Lab scale repair time investigation
- Long-term grid application
- Cheaper tape production for cable system

Thank you for your attention

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