

Progress of the SuperRail Project in Paris and Qualification Results of the 35 m Prototype HTS Cable System

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Content

- I. Motivation of the SuperRail project
- II. Qualification of the SuperRail HTS cable system
 - Type test loop
 - Type test results
- III. Conclusion

I. Motivation

Motivation

Need to increase rail traffic in densely populated areas
to meet carbon emission reduction targets by 2030

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Need to increase the electric power



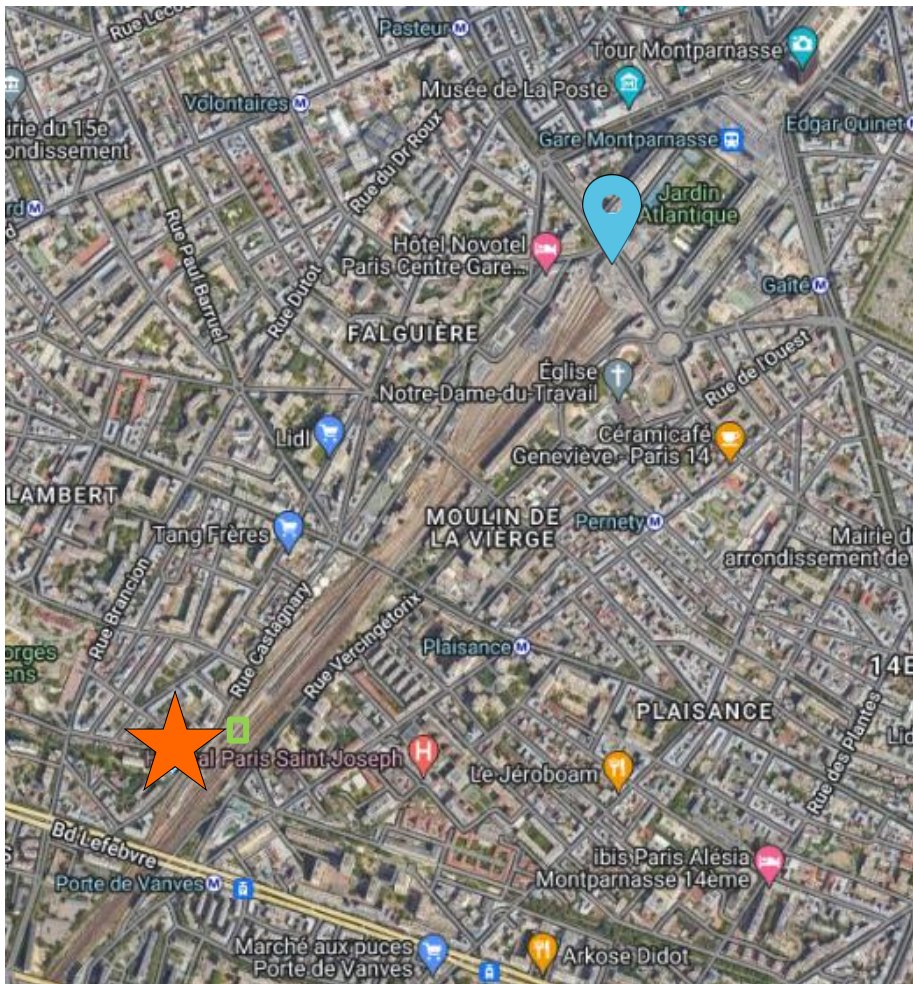
Practical case

Reinforcement of Paris Montparnasse train station (4th in France)
 28 tracks, 200 000 passengers/day on 750 trains
 50 Millions of passengers in 2020, 90 Millions in 2030



4.5 MW of nominal power (3000 A @1500 VDC)
 10.5 MW of inrush power (7000 A repetitive peaks)
 Fault current of 67 kA during 100 ms

Practical case



Paris Montparnasse



Substation



Tracks

Practical case



Existing rights of way saturated
 only $2 \times \Phi 100$ mm conduit left
 = 2×400 mm² copper cable
 = 2×500 A reinforcement

Instead of the required 3000 A



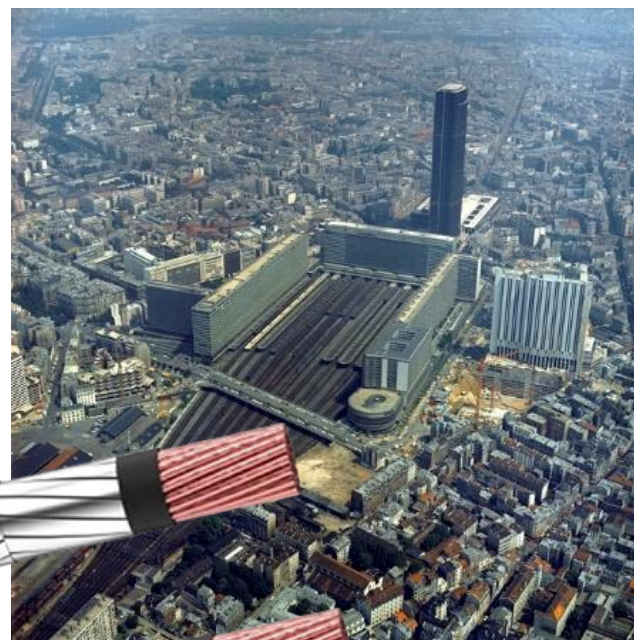
Limited available space
 & other networks (water, gas, telecom)
 & century-old civil engineering structures

Very risky, expensive and time-consuming
 to build new rights of way

18/05/2021

SuperRail (2022-2025)

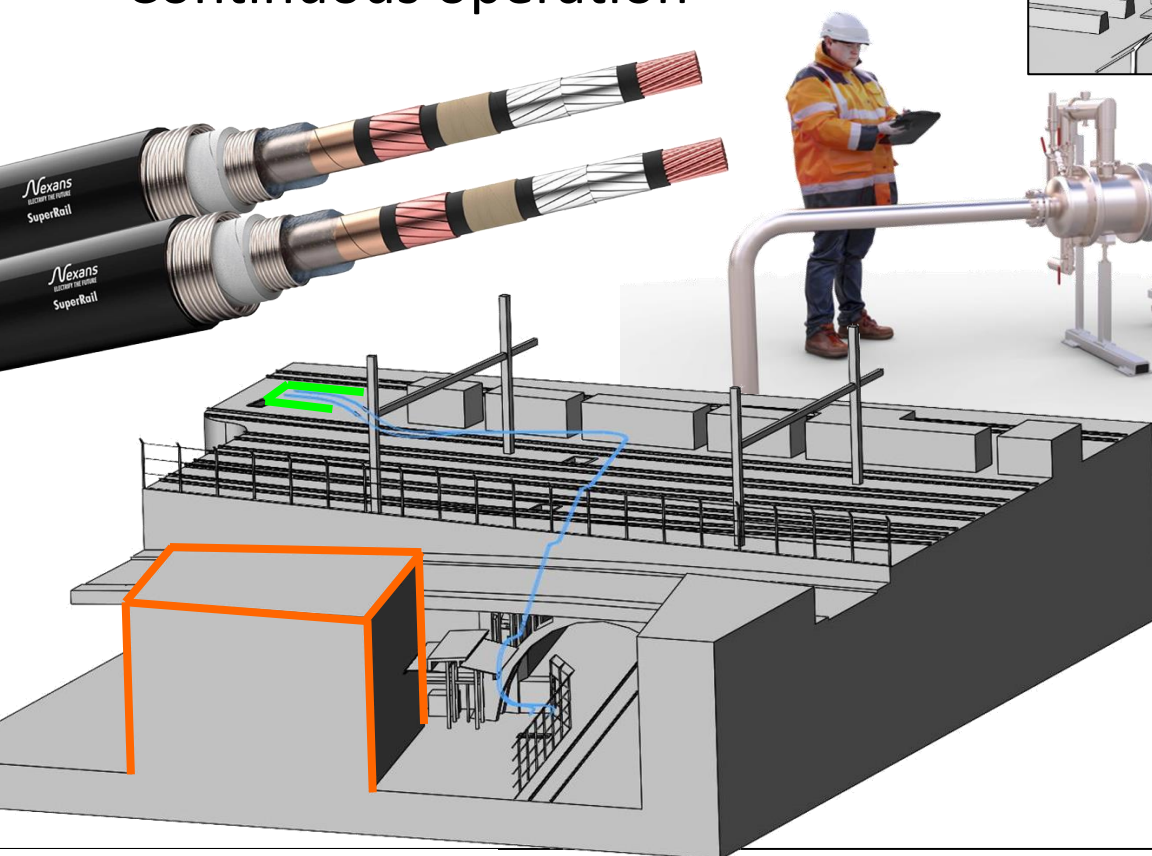
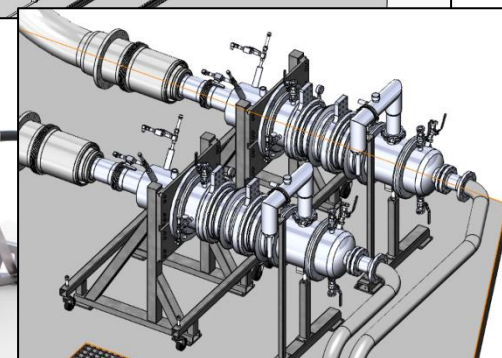
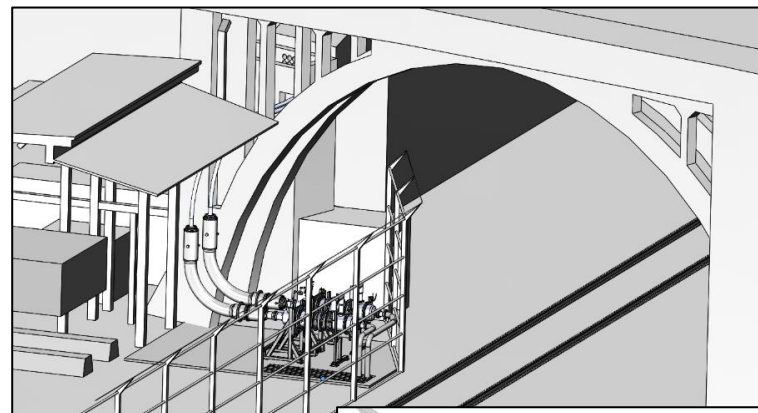
Paris, France



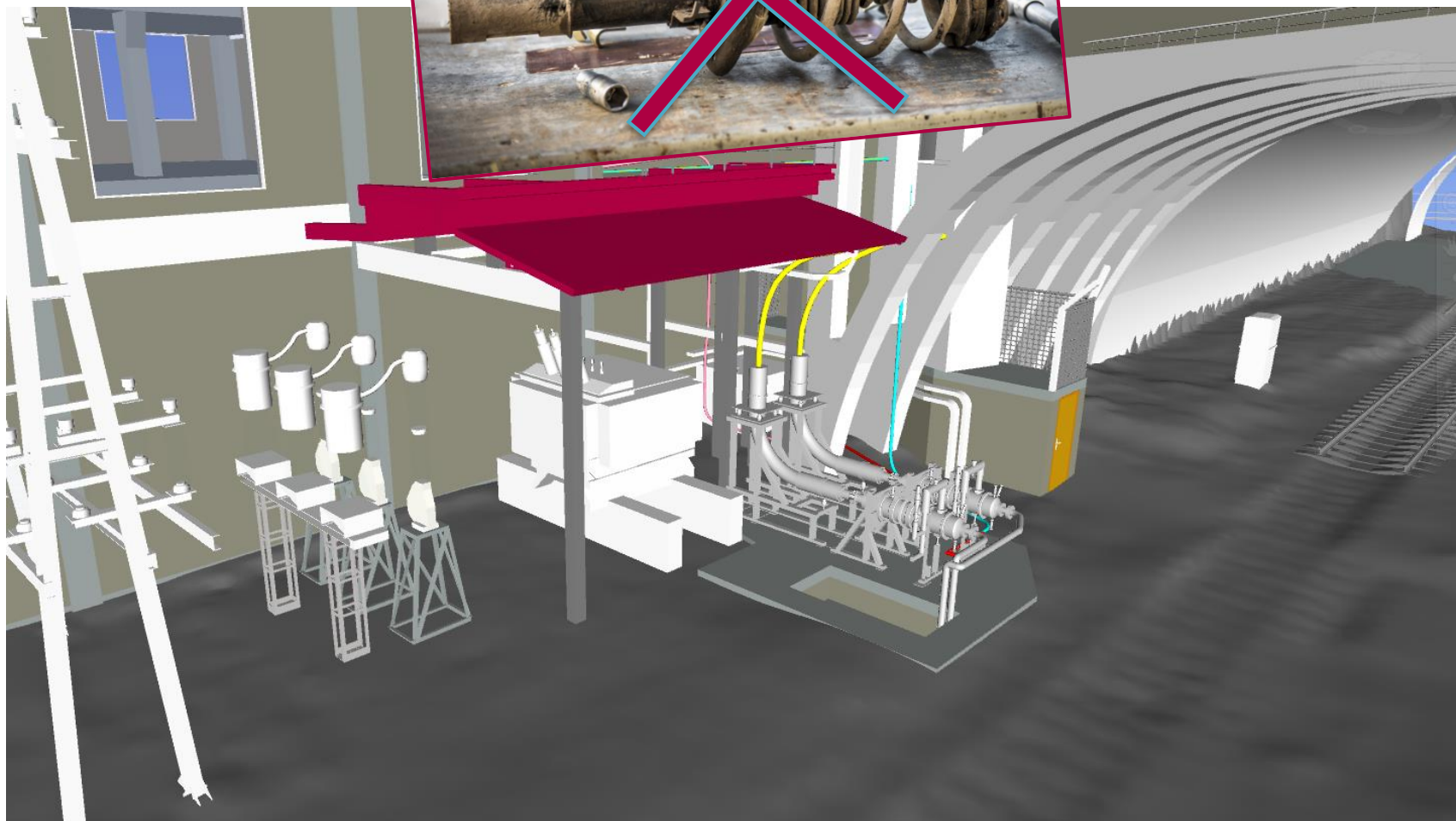
Integration

- Installation in existing conduits
- Sharp gradient and turns
- Continuous operation

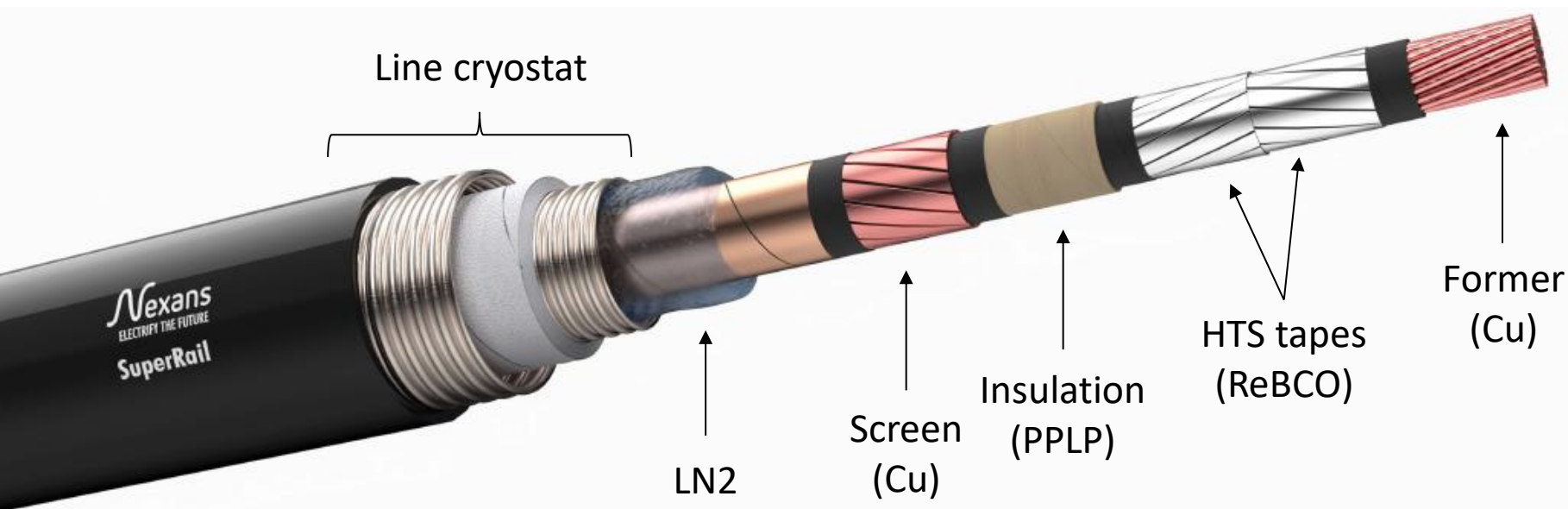
Substation side



Urban life...



Superconducting cable



| Electric parameters | |
|---------------------|----------------|
| Nominal voltage | 1500 V |
| Nominal current | 1500 A |
| Inrush current | 3500 A |
| Critical current | > 4000 A |
| Fault current | 67 kA - 100 ms |

| Geometric parameters | |
|-------------------------|---------|
| Cryostat outer diameter | 74 mm |
| Minimum bending radius | 1.5 m |
| Length | 2x 60 m |

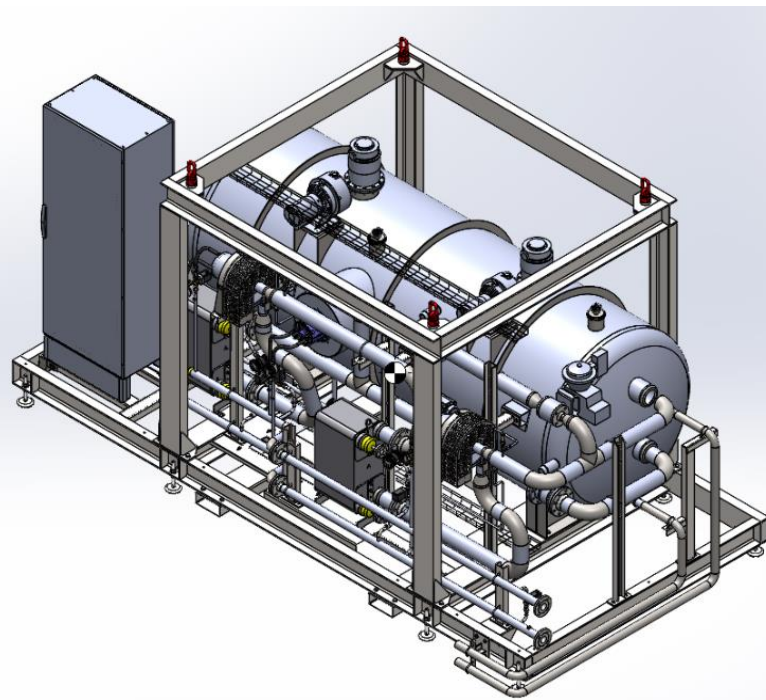
Cooling system



Cryogenic skid

- ▶ For type test & for final installation
- ▶ LN2 circulation & pressurization
- ▶ Cool down and warm up management (requires a LN2 tank)

+



Reverse Turbo Brayton (RTB)

- ▶ Newly developed cooling system with high efficiency and low maintenance
- ▶ 30% to 100% of cooling power
- ▶ 1.7 kW @ 67 K

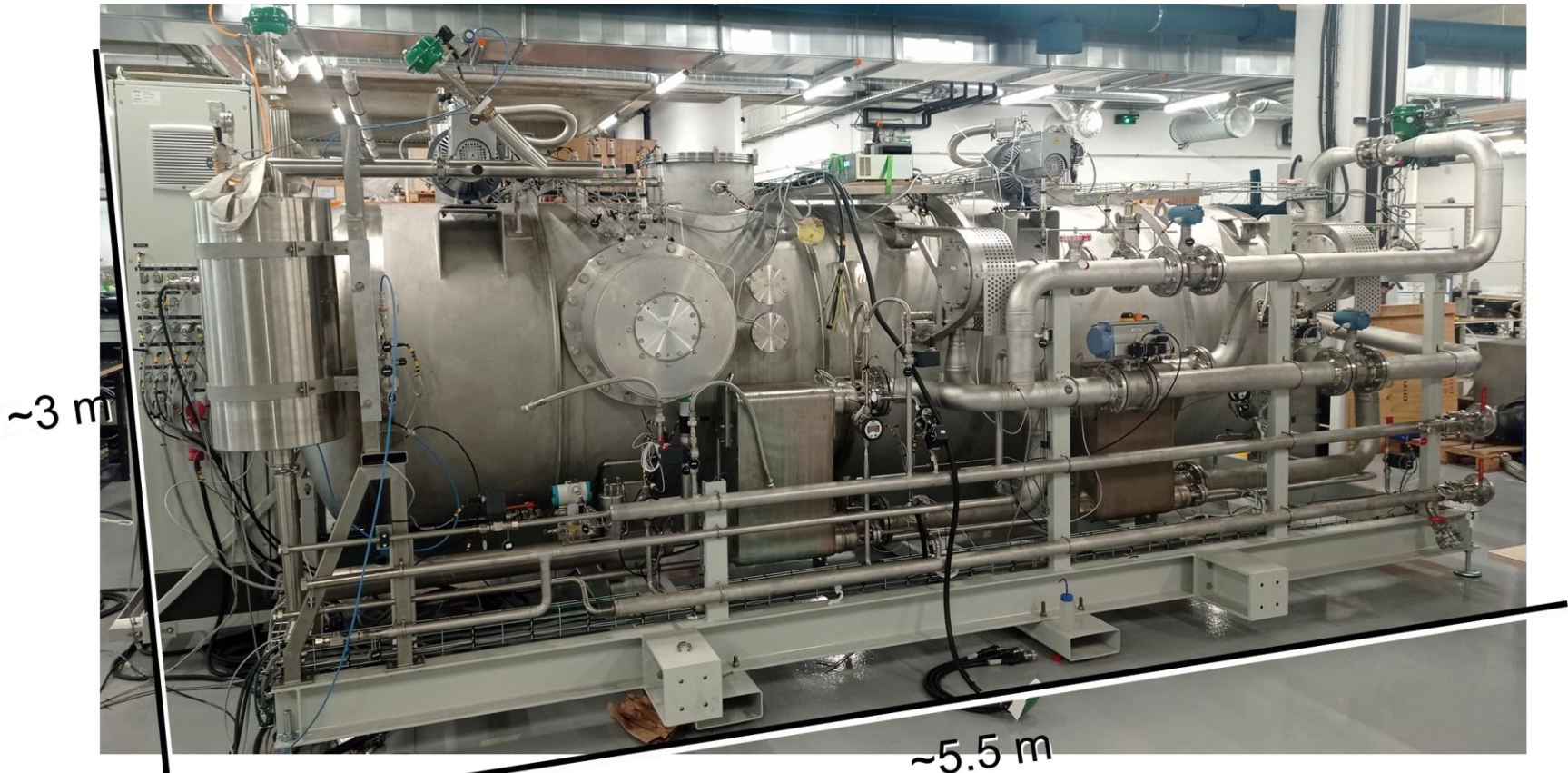
Reverse Turbo Brayton (RTB)

- ▶ RTB cold box: finalized / wired / unit tests OK
- ▶ Awaiting turbo-machines integration

**ABSOLUT
SYSTEM**

INNOVATIVE CRYOGENIC SOLUTIONS

Cryo Cool 1000



- Absolut System SAS - All rights reserved

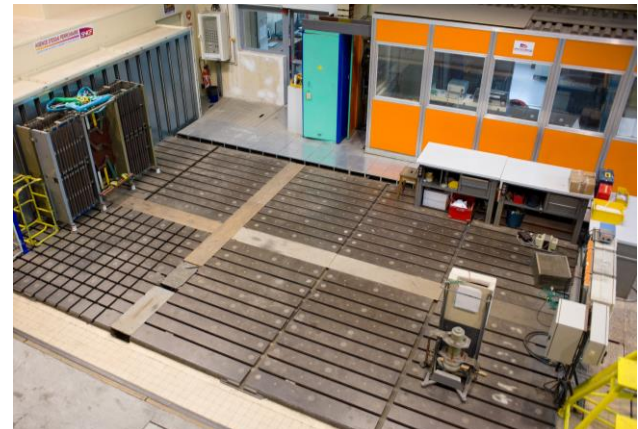
II. Qualification of the SuperRail cable system

Type test loop

SNCF Railway Test Agency (SNCF-AEF)



SNCF-AEF Traction substation



SNCF-AEF Electrotechnics laboratory

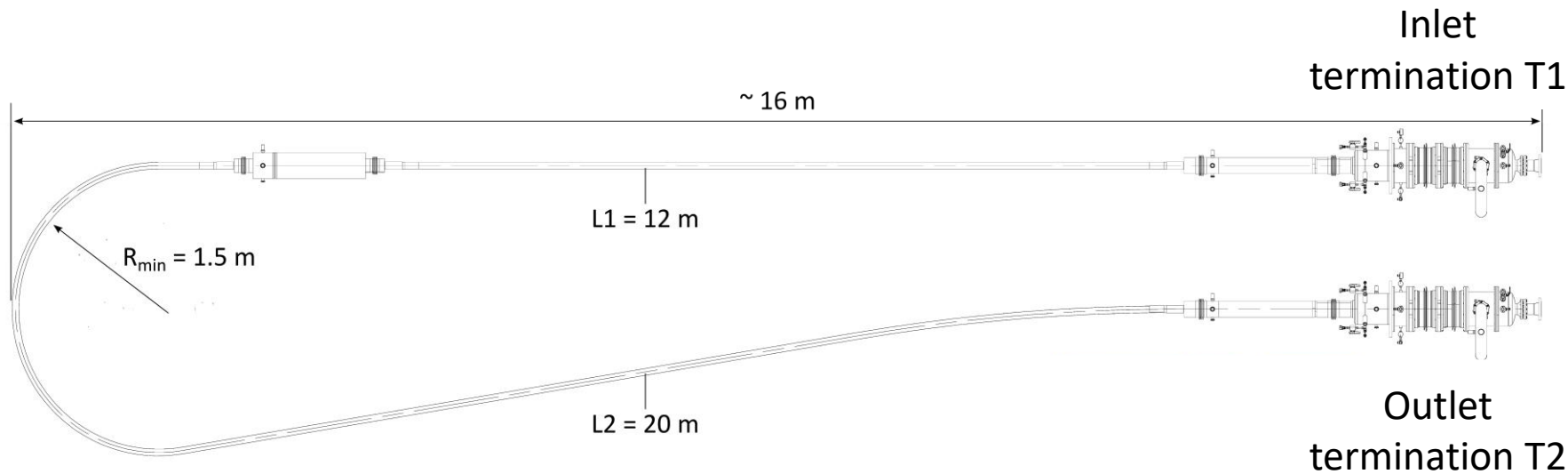
Type test loop

- ▶ 35 m test loop
 - ▶ 2 terminations
 - ▶ 1 joint
 - ▶ 2 cable pieces

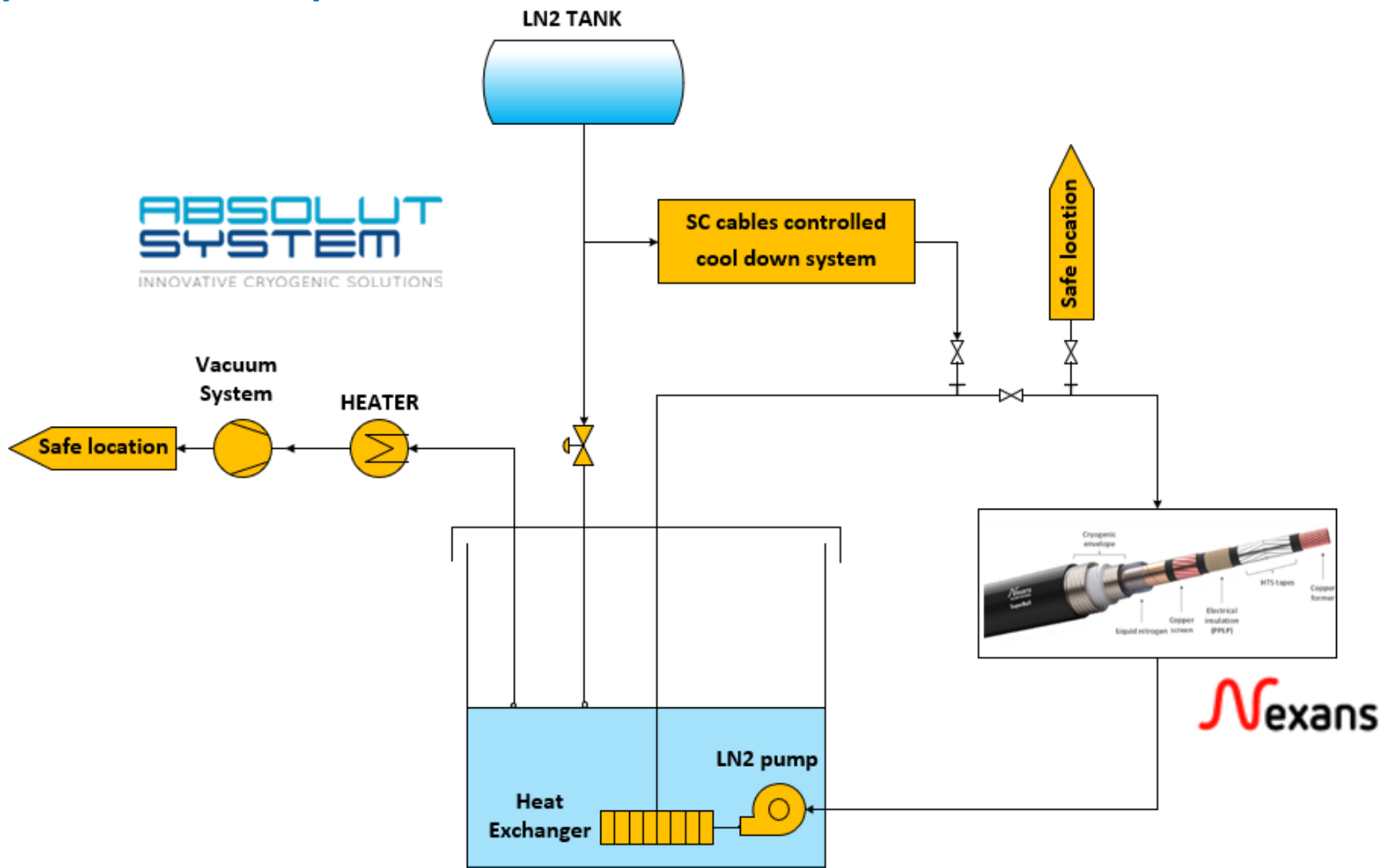
- ▶ LN2 tank
- ▶ LN2 circulation SKID
- ▶ Controlled cool down system



Type test loop



Type test loop



Type test loop



Type test loop



LN2
circulation
SKID

Controlled
cool down
system

Inlet
termination
T1

Outlet
termination
T2



II. Qualification of the SuperRail cable system

Type test results

Timeline

August 2023
Tests at SNCF AEF #1

- Thermal cycles
- Pressure
- Dielectric & lightning impulse
- Nominal current

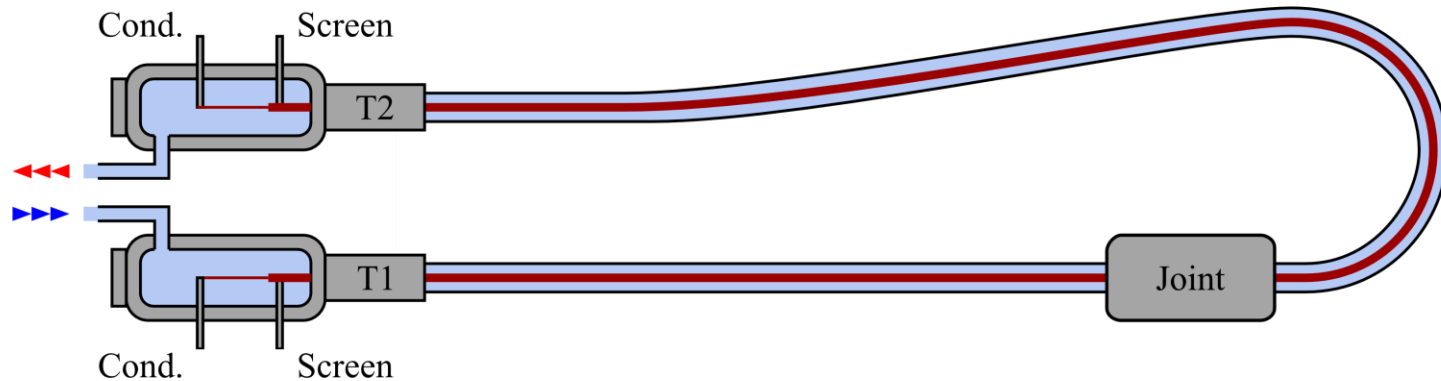
April 2024
Tests at SNCF AEF #2

- Nominal current
- System losses & pressure drop
- Fault current & recovery time
- V-I characterization

Applicable standards:

- IEC 63075:2019 specifies test methods and requirements for HTS AC power cable systems (cables and their accessories) for fixed installations, for rated voltages from 6 kV up to 500 kV.
- EN 50124-1, EN 60664-1, EN 50124-1 are electrical standards specific to railway grids.

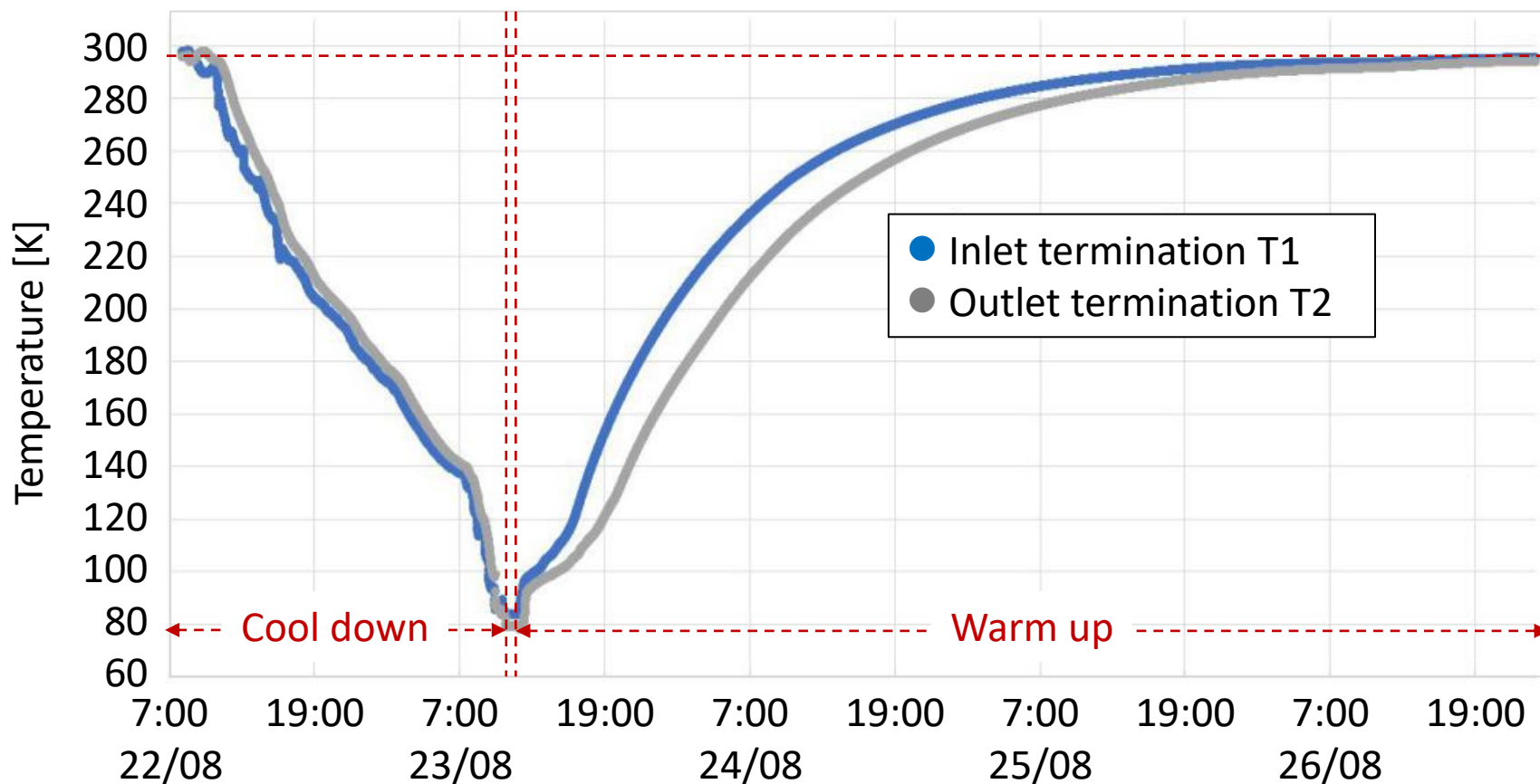
Thermal cycles



- 5 cycles of cooling down and warming up

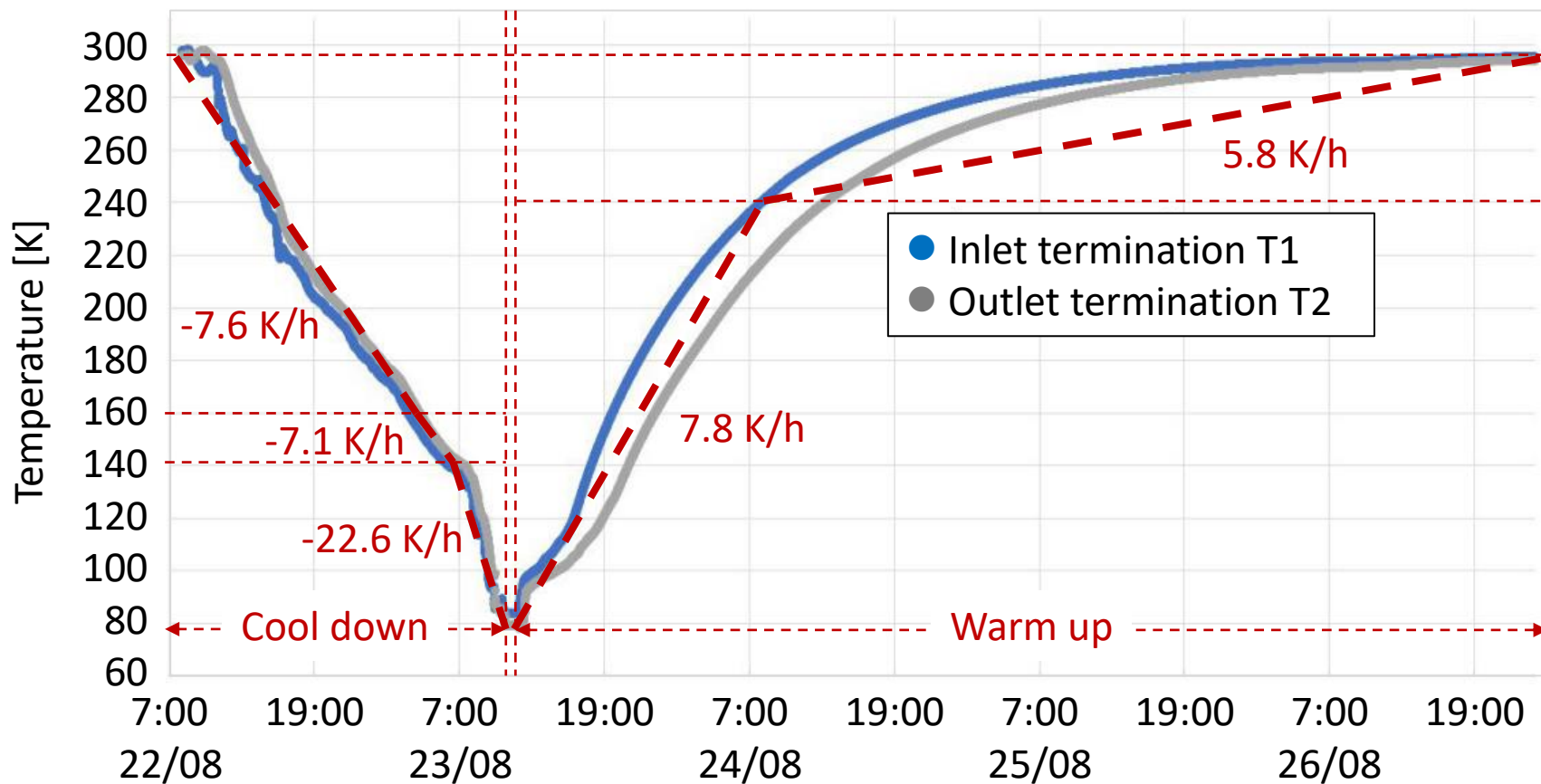
Thermal cycles

Manual cooling down and warming up: thermal cycle 4



Thermal cycles

Manual cooling down and warming up: thermal cycle 4

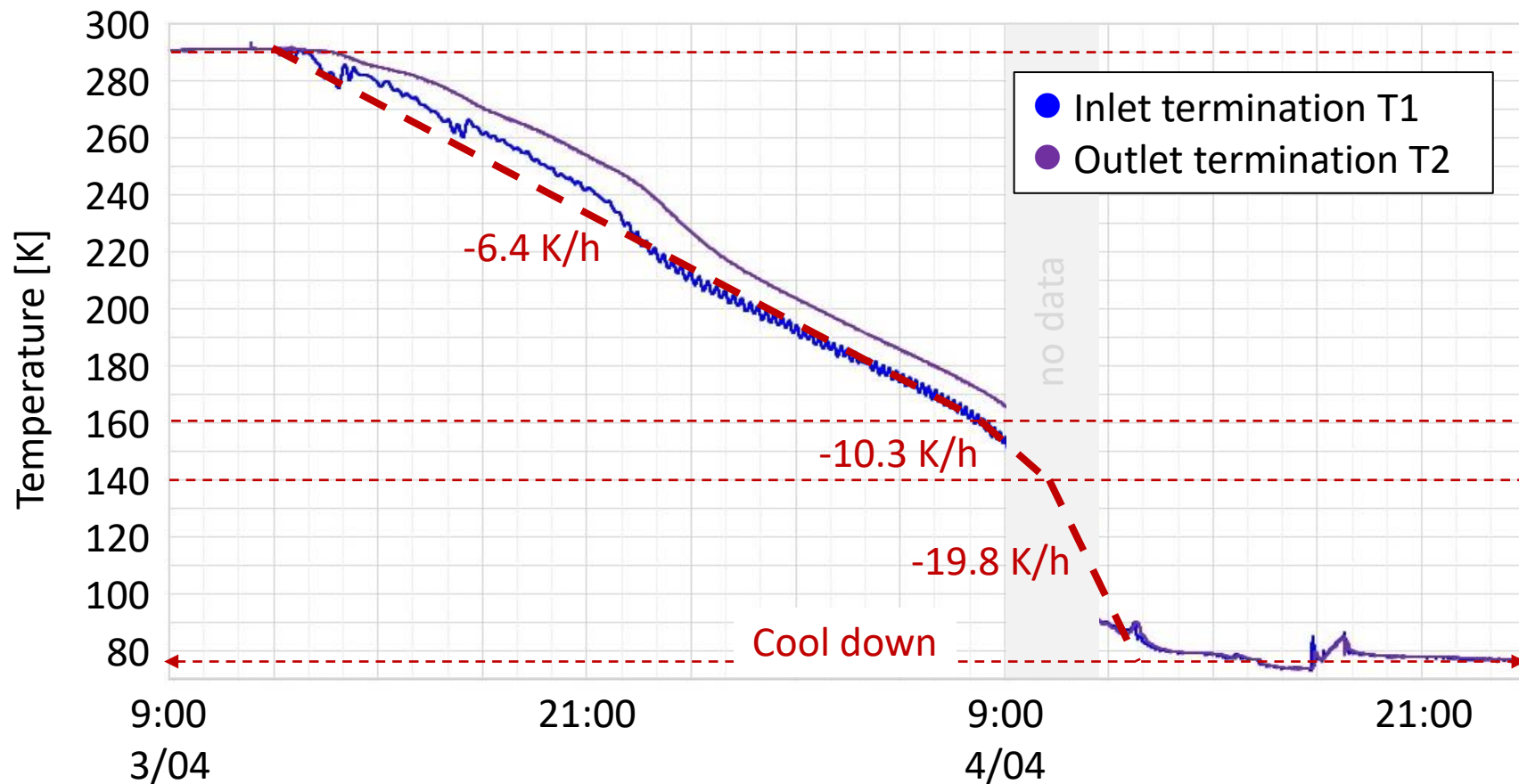


● Inlet termination T1
● Outlet termination T2

- Thermo-mechanical robustness of the system fully validated ✓

Thermal cycles

Automatic cooling down: thermal cycle 6



- Automatic cool down validated
- No risk for Montparnasse Vouillé system (cooling rate < 10 K/h) ✓

Pressure

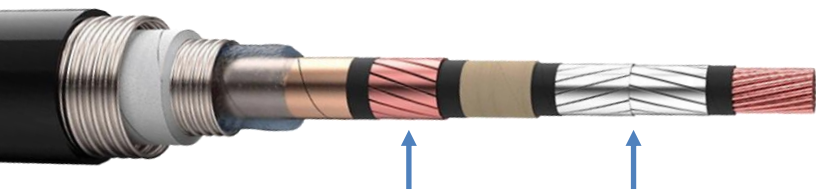
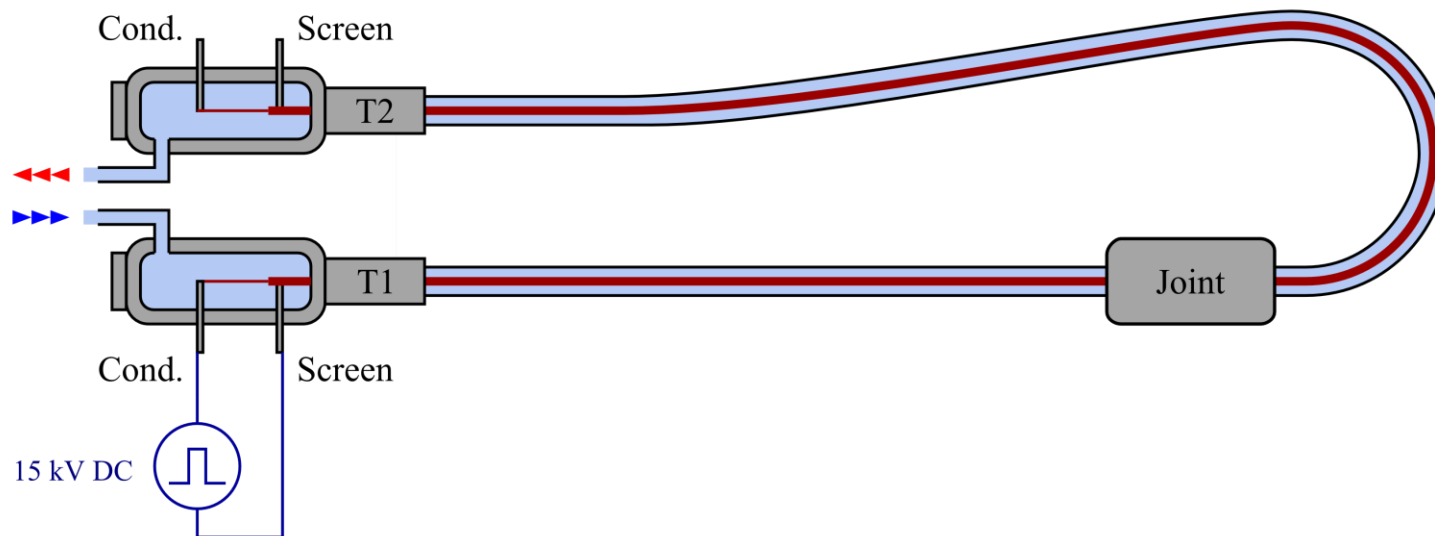
Immediately after assembly: successful pressure test up to 18.5 bar to validate the system's safety devices.

During tests with LN2 pressurized loop:

- 12 bar operating pressure during several hours
- 15 bar max peak value (up to safety valves opening)
- In line with the operational pressure at Montparnasse Vouillé ✓

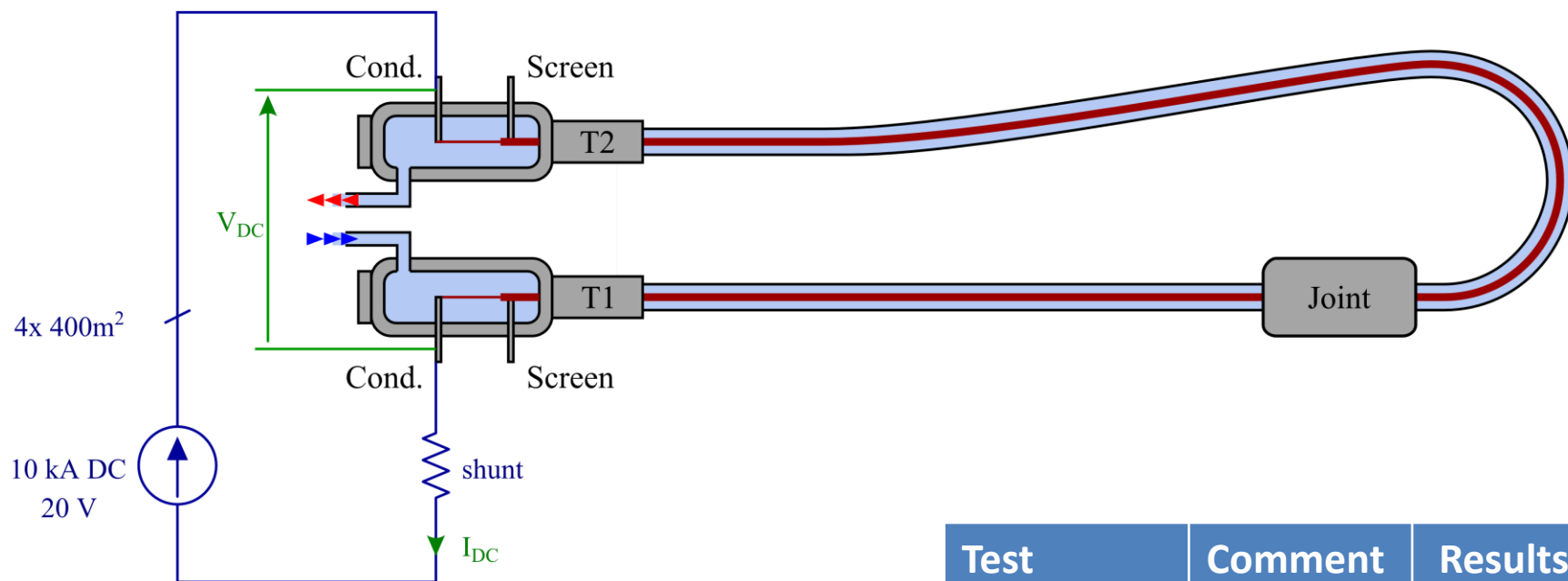


Dielectric & Lightning impulse



| Test | Comment | Results |
|-------------------|------------------------------------|---------|
| Dielectric | 1.5 kV DC class 10 kV DC / 10 s | ✓ |
| Lightning impulse | 1.5 kV DC class 3× ±15 kV shots | ✓ |

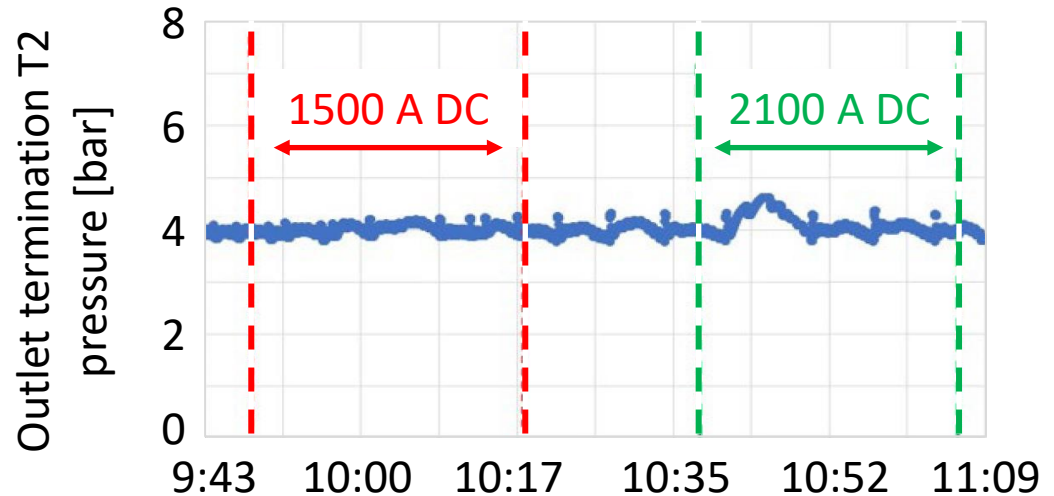
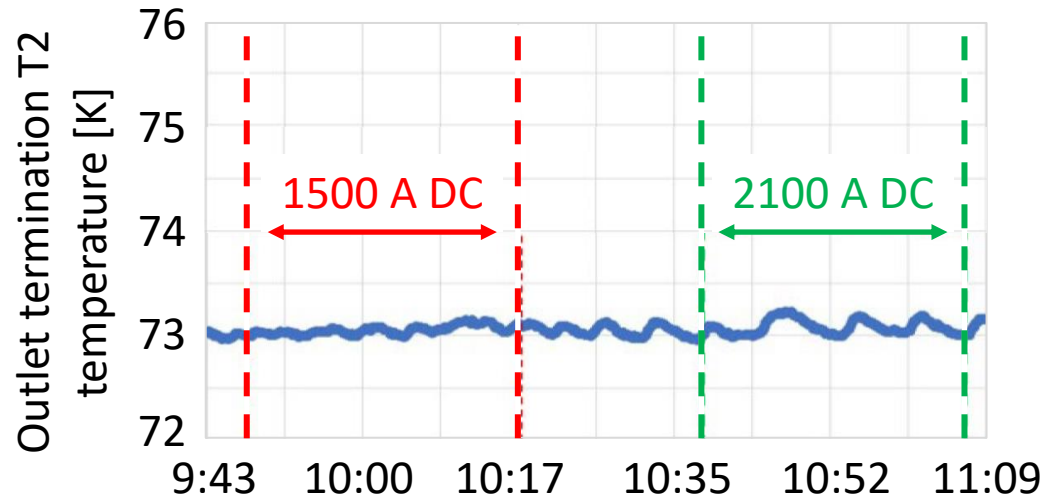
Nominal current



| Test | Comment | Results |
|-----------|---------|---------|
| 1500 A DC | 30 min | ✓ |
| 2100 A DC | 30 min | ✓ |

Nominal current

- No significant temperature or pressure increase
- Stabilization over time
- No resistance increase of the loop
- Integrity of the system unchanged after test
- Continuous current up to 2 kA is “transparent” for Montparnasse Vouillé operation ✓

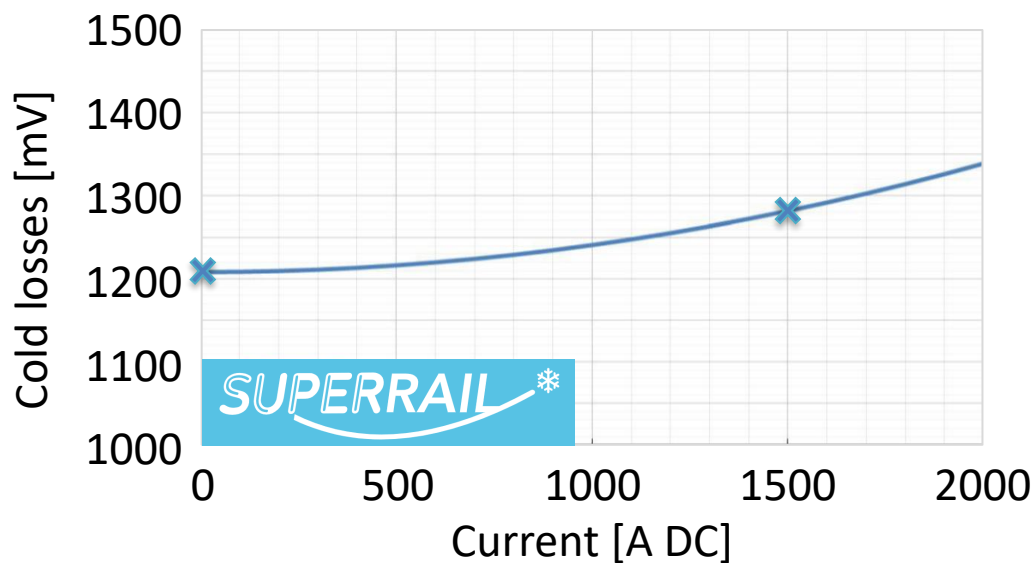


System losses & pressure drop

Measured cold losses : ~561 W without current (600 W expected)

Loss model validated ✓

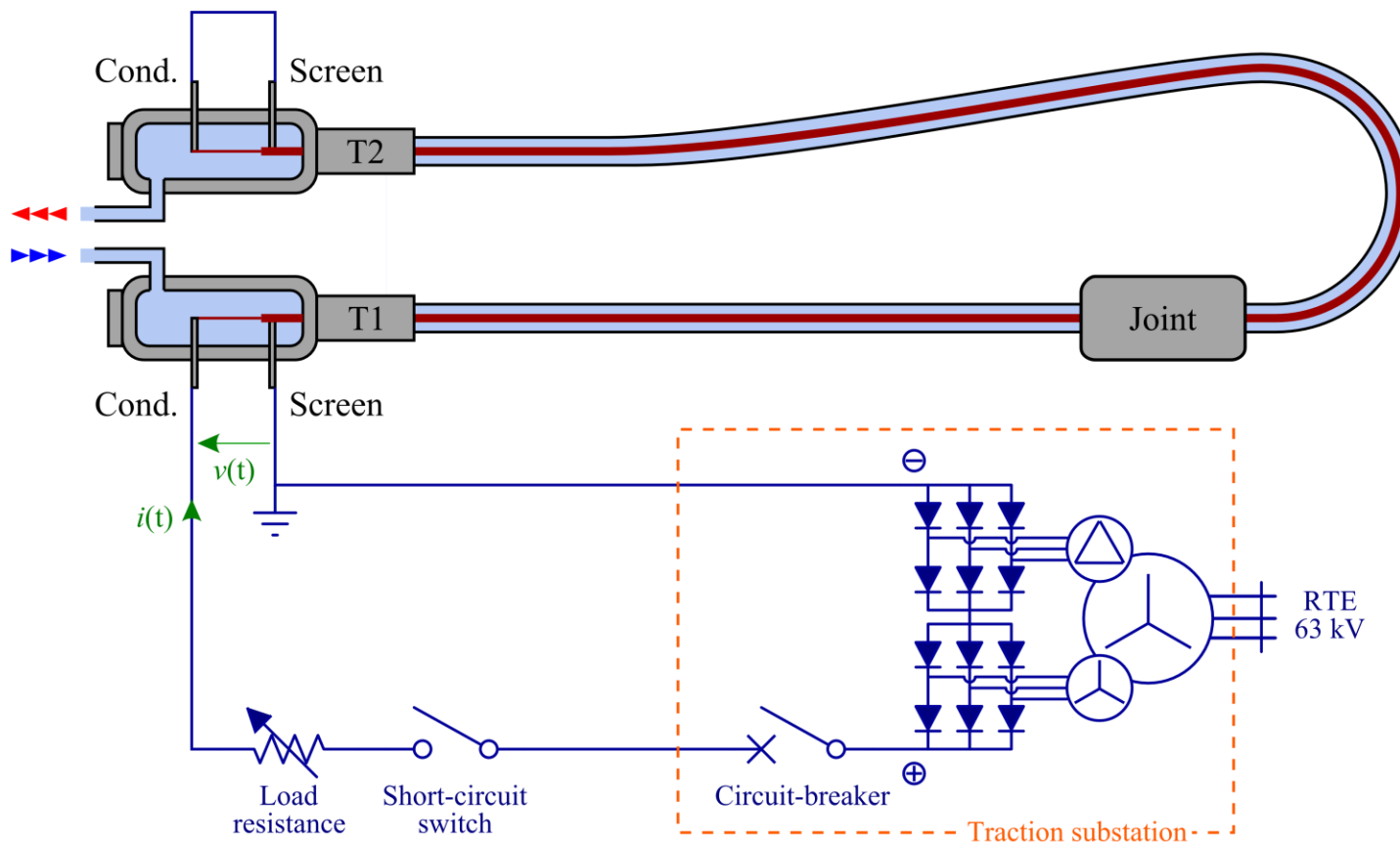
Update the estimated cold losses at Montparnasse Vouillé:



+
~500 W cooling
system losses

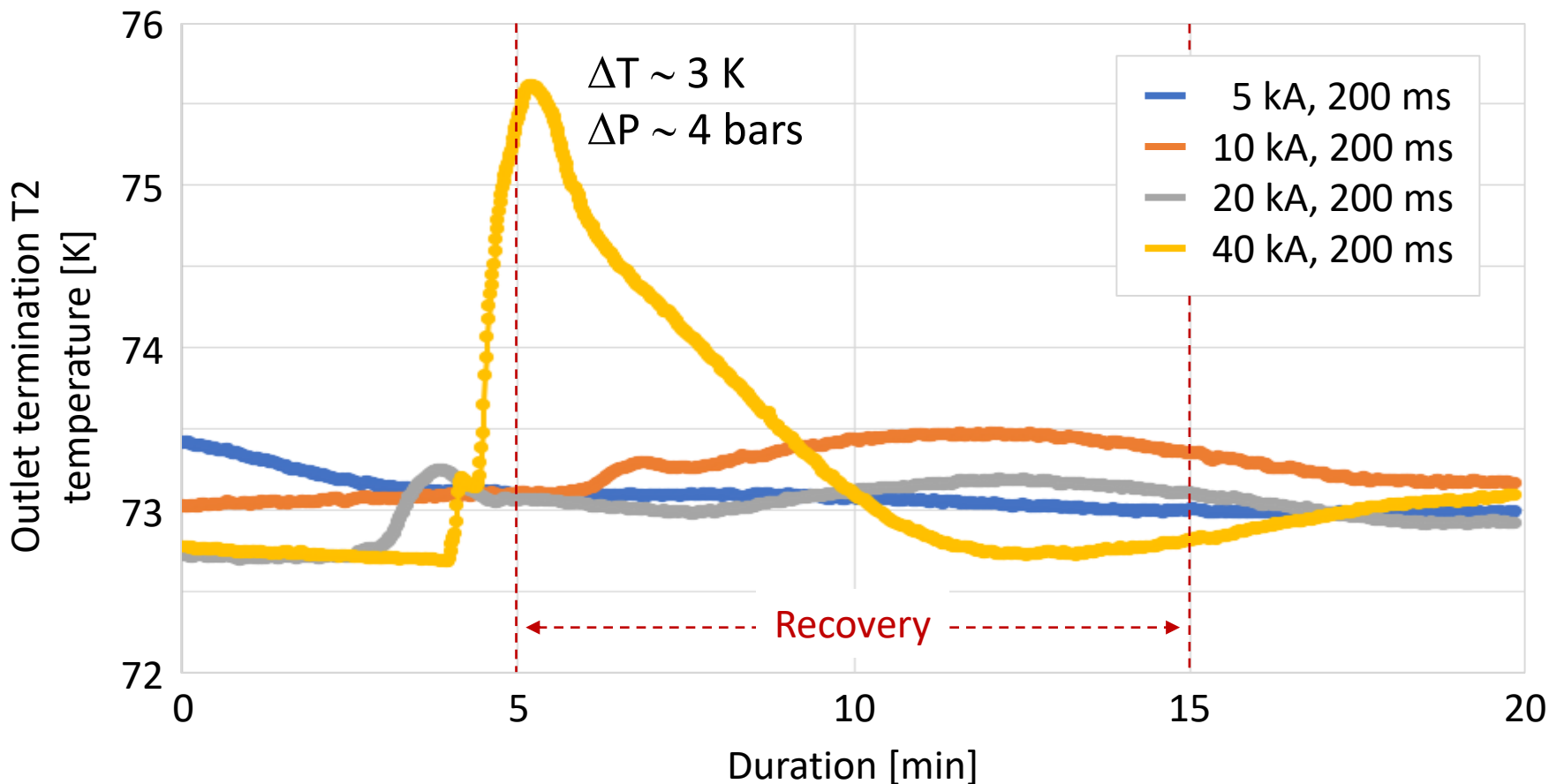
- In line with cooling capacity planned for Montparnasse Vouillé ✓

Fault current & recovery time

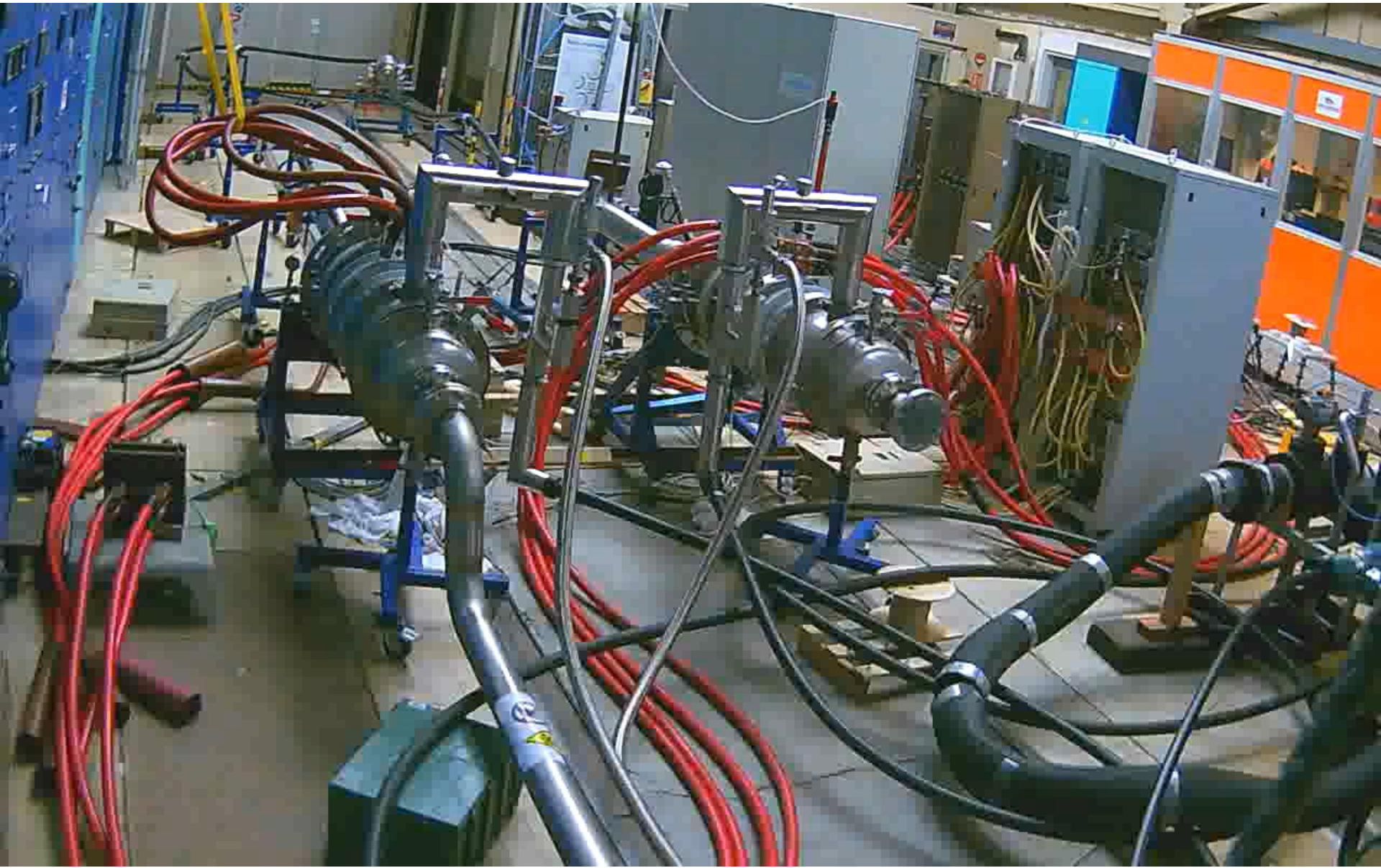


Fault current & recovery time

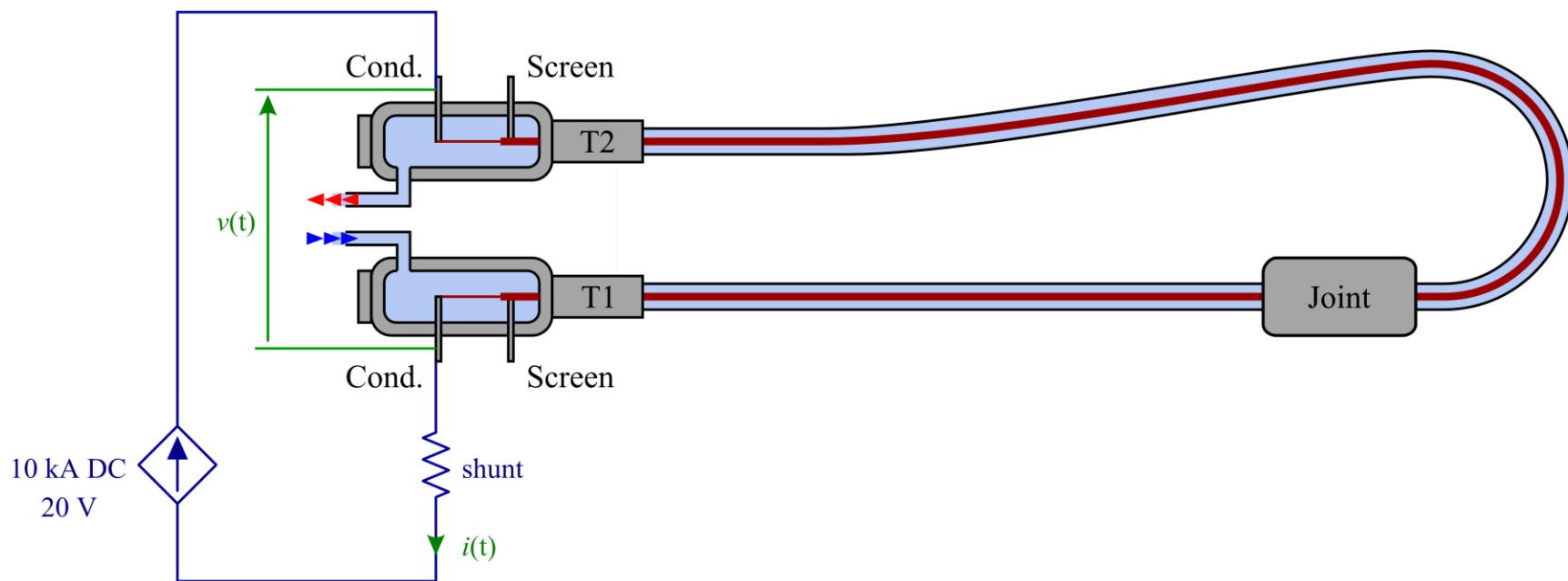
Energy ($I^2 \Delta t$)
 40 kA 200 ms \equiv 67 kA 100 ms



- No resistance increase of the loop
- Integrity of the system unchanged after test ✓

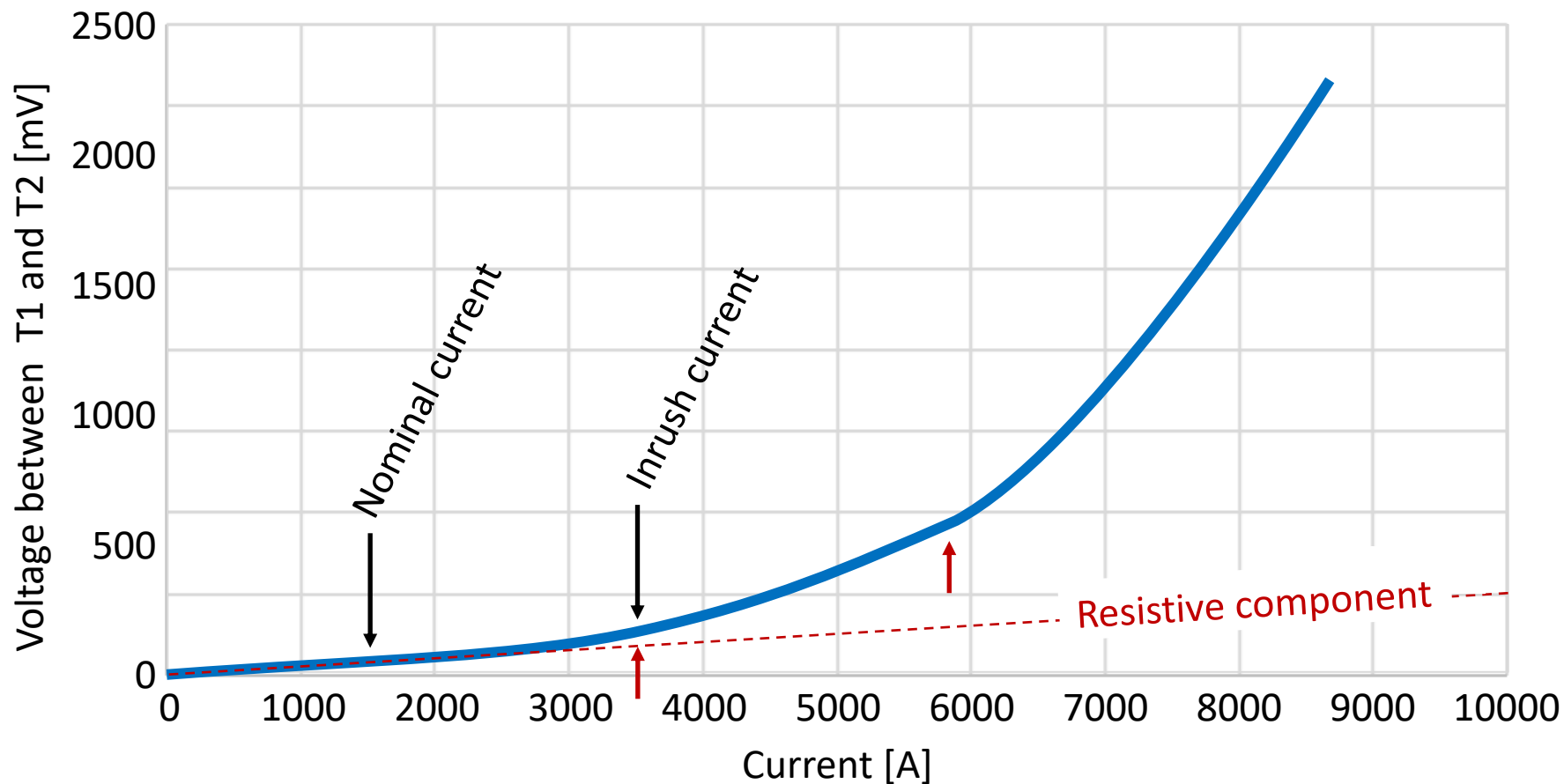


V-I characteristic



V-I characteristic

$I_c @ 67\text{ K} > 4000\text{ A}$ ✓



- No degradation of I_c after all the tests (including fault current!) ✓
- High robustness of the SuperRail cable system ✓

Conclusion

Summary of SuperRail cable type test at SNCF AEF



| Test | Results |
|-------------------------------|---------|
| Thermal cycles | ✓ |
| Pressure | ✓ |
| Dielectric | ✓ |
| Lightning impulse | ✓ |
| Nominal current | ✓ |
| System losses & pressure drop | ✓ |
| Fault current & recovery time | ✓ |
| V-I characteristic | ✓ |

Thank you for your attention

ご清聴ありがとうございました。

SUPERRAIL 



SuperRail project slideshow



References

- [1] A. Allais, J.-M. Saugrain, B. West, N. Lallouet, H. Caron, L. Terrien, G. Bouvier, K. Berger, L. Quéval, “SuperRail – World-first HTS cable to be installed on a commercial railway network in France,” *IEEE Transactions on Applied Superconductivity*, vol. 34, no. 3, pp. 1-7, May. 2024. ([DOI](#), [link](#))
- [2] NF EN 50124-1, “Applications ferroviaires – Coordination de l’isolement,” version de juin 2017.
- [3] NF EN 60664-1, “Coordination de l’isolement des matériels dans les systèmes (réseaux) à basse tension. Partie 1 : Principes, exigences et essais,” version de juillet 2020.
- [4] CEI 63075, “Câbles supraconducteurs d'alimentation en courant alternatif et leurs accessoires pour des tensions assignées de 6 kV à 500 kV. Méthodes d'essai et exigences,” Version de février 2019.