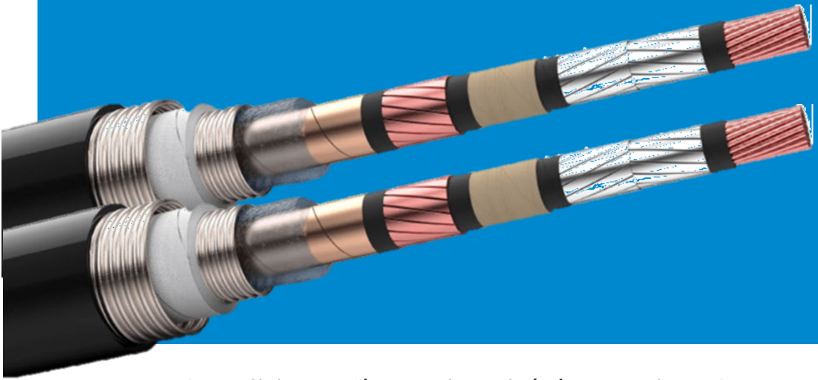
IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 56, March, 2024. Invited presentation given at ISS 2023, Nov. 2023, Wellington, New Zealand

SUPERRAIL

Current status and future prospects of the SuperRail project in France

Kévin Berger – Université de Lorraine, GREEN



G. Hajiri, Y. Laïb – Université de Lorraine, GREEN
L. Quéval , L. Ferreira, Y. Baazizi – CentraleSupelec, GEEPS
H. Caron, D. Ferandelle, S. Villagra – SNCF
A. Allais, J.M. Saugrain, L. Gervaise – NEXANS
L. Terrien, G. Bouvier, J. Roudaut – Absolut System

FRANCE 2030
This project is supported by France 2030.

CentraleSupélec · Université de Lorraine · Nexans · Absolut System (Innovative cryogenic solutions) · SNCF Réseau

SUPERRAIL

INCREASE IN RAIL TRAFFIC

Need to increase the traffic on the railway network in densely populated areas with high constraint to comply with 2030 carbon reduction objectives

Solutions must be in line with SNCF's strategy

- To reduce the losses
- To participate to the low carbon national strategy
- To optimize capital and operating expenditure to meet these needs

Practical case = 10 MW reinforcement of the power supply from the Vouillé substation to the tracks at Montparnasse station

This project is supported by France 2030.

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CONTEXT

High constraints on the Montparnasse station

In 2025 SNCF should deliver an electrical installation able to transmit more energy to the tracks in order to improve the robustness of the electricity supply of Montparnasse station (50 Millions of passengers in 2020, 90 Millions in 2030).

- **Conventional solution:** to reinforce with **copper cables** **=> not possible here due to restrictions on rights of way and limited available space**
- **Innovative solution => Superconducting cable system**

The SNCF roadmap 2025-2035 is in progress to reinforce the railway network on the left riverbank of Paris. This roadmap will identify other sites where superconducting technologies can be of interest.

This project is supported by France 2030.

SUPERRAIL

CONSORTIUM

Network operator

SNCF RÉSEAU

Industry

Nexans

ABSOLUT SYSTEM
INNOVATIVE CRYOGENIC SOLUTIONS

Research labs

CentraleSupélec

UNIVERSITÉ DE LORRAINE

SuperRail
Superconductivity for Railway

FRANCE 2030
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PROJECT OBJECTIVES

To increase the energy density in a highly constraint area **where conventional technologies,** based on reinforcement by resistive cables**, are not applicable.**
To increase **the commercial offer** by increasing the **public transport capacity and reliability**.

To develop industry and education related to the superconducting technologies (R&D, design, production, installation and test labs), particularly in France.

To deploy the world 1st demonstrator of superconducting cable permanently in exploitation in a railway network.

To validate the superconducting technology in Montparnasse-Vouillé.
To qualify this technology for future projects to reinforce and secure the national railway network.

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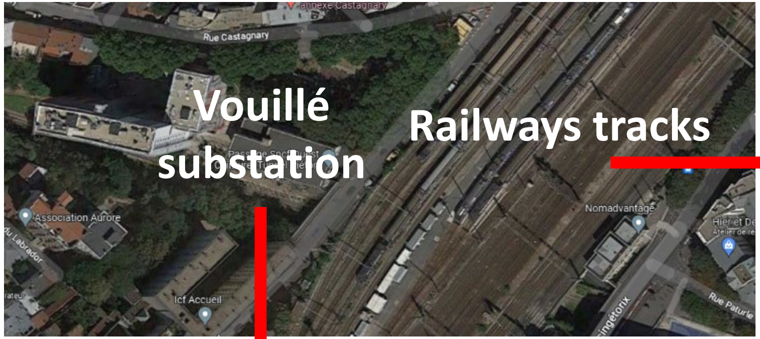
SUPERRAIL

LOCALIZATION



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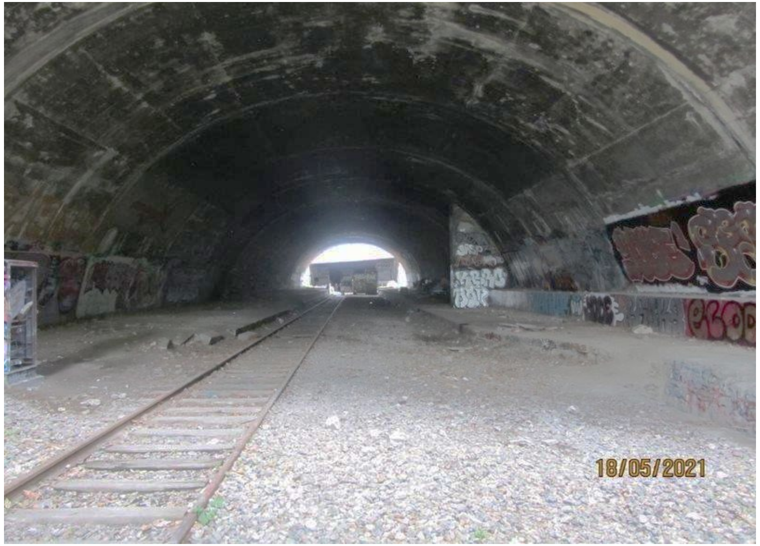
LOCALIZATION - RETROFIT

Existing rights of way saturated with only few conduits left (100 mm in diameter)
400 mm² copper cable ≅ 500 A



Very risky to build new rights of way with one century old constructions and presence of a lot of other networks (water, gas, telecom)

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SUPERRAIL

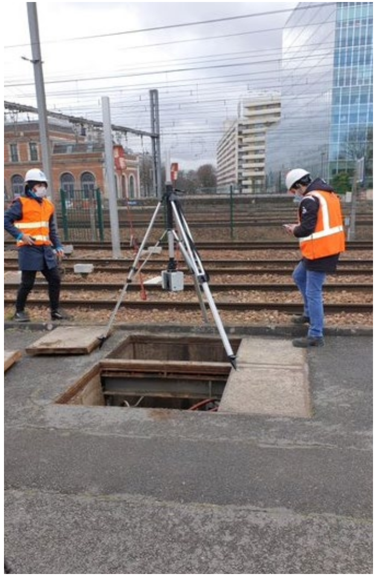
CHALLENGING SPECIFICATIONS

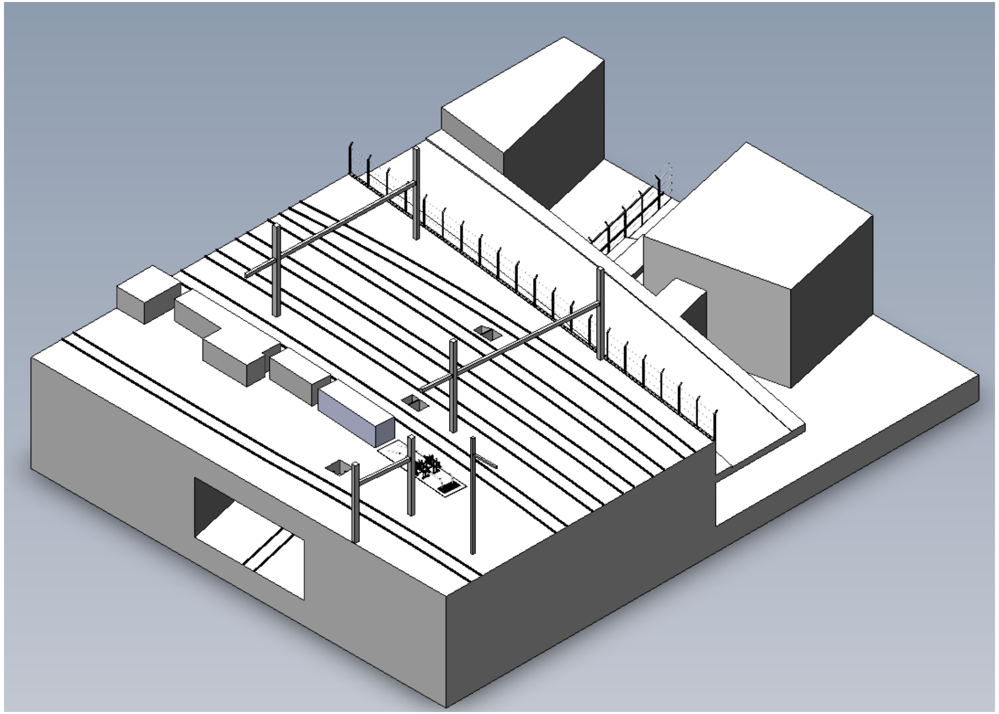
- **2 electrically independent cables to supply each**
  - 1500 A @ 1500 VDC in rated conditions (max 3% of harmonics below 5 kHz)
  - 3500 A @ 1500 VDC current inrush (trains acceleration to reach traffic speed)
- **Return currents through the rails (connected to the negative (0) pole of the DC supplies)**
- **Substation directly connected to the RTE transmission network at 63 kV**
  - Fault power of 100 MVA
  - Fault current of 67 kA during 200 ms
- **Cooling system**
  - High reliability, high efficiency, variable cooling capacity
  - Available cooling power of up to t 1.2 kW @ 67 K

This project is supported by France 2030.

SUPERRAIL

3D DIGITAL TWIN





- LiDAR scan of the area
- Building a 3D digital twin for the virtual integration of equipment to anticipate issues and confirm designs of different components

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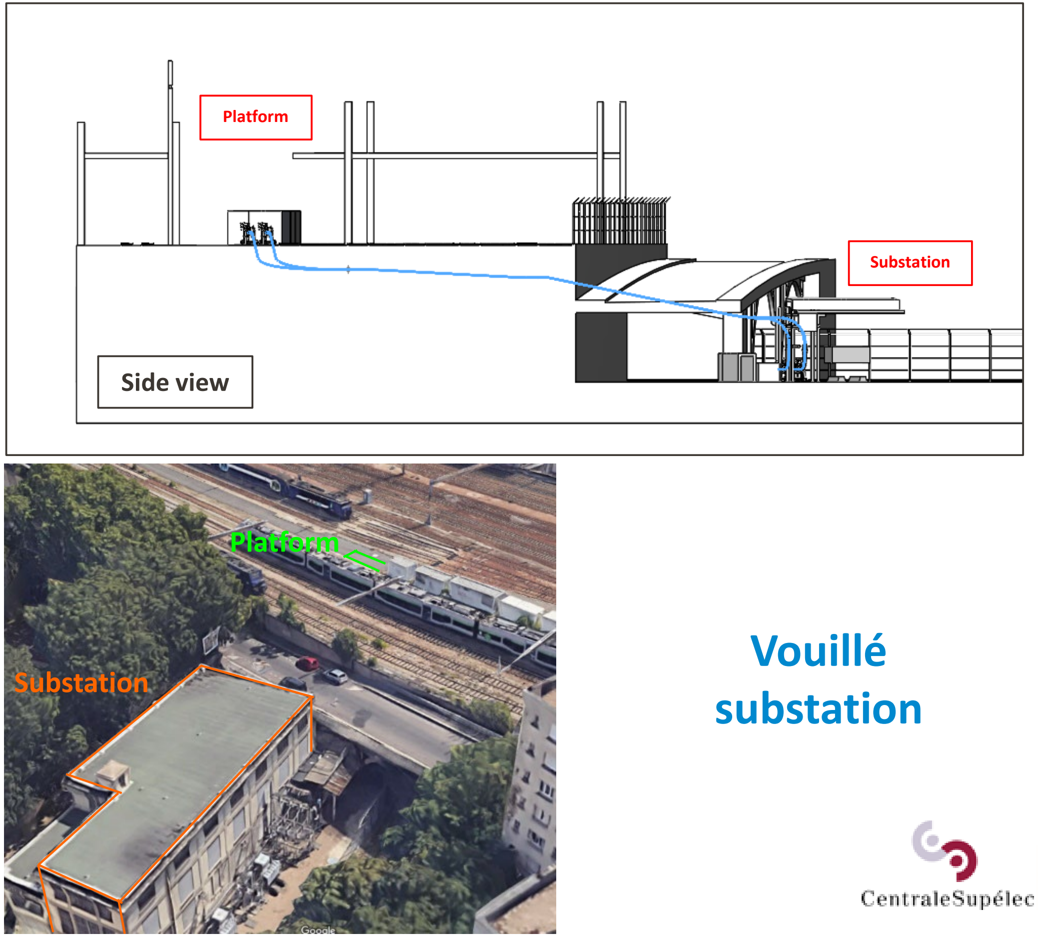
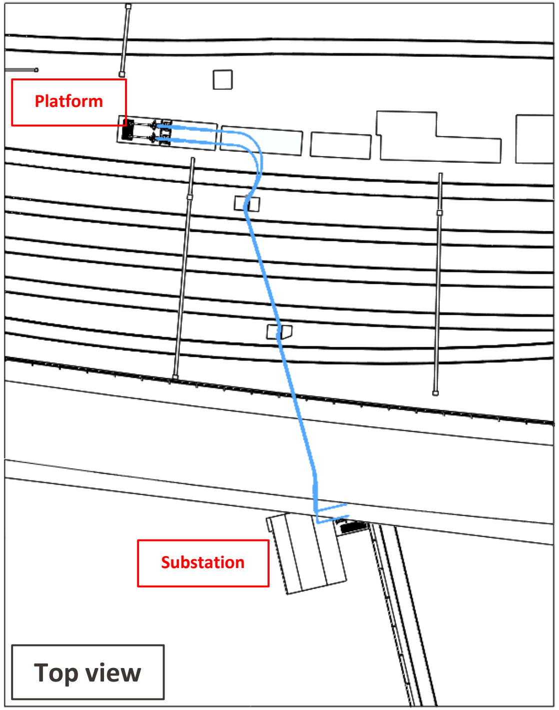
SUPERCONDUCTING CABLE ROUTE





Vouillé substation

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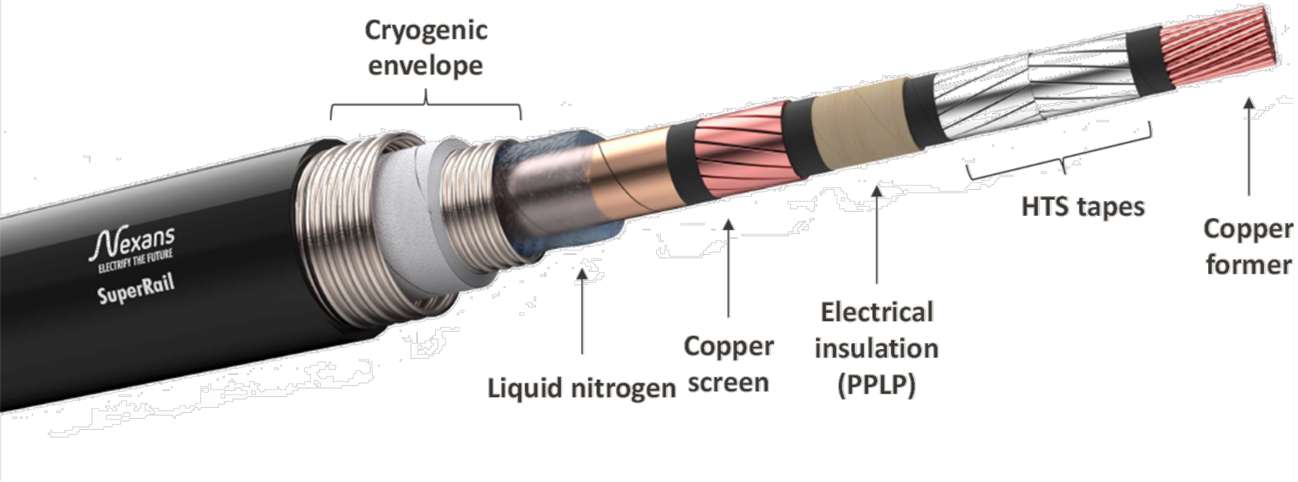
CABLE DESIGN



Electrical parameters	
Nominal voltage	1500 V
Inrush current	3500 A
Nominal current	1500 A
Critical current	4000 A
Fault current	67 kA - 200 ms
Tape parameters	
Tape manufacturers	SuNAM & AMSC
Tape width	4.4
Geometric parameters	
Copper core	18 mm
Number of layers	2
Number of tapes	25 (12+13)
PPLP thickness	1 mm
Copper screen thickness	1.8 mm
Cryostat outer diameter	74 mm
Length	60 m
Min. bending radius	1.5 m

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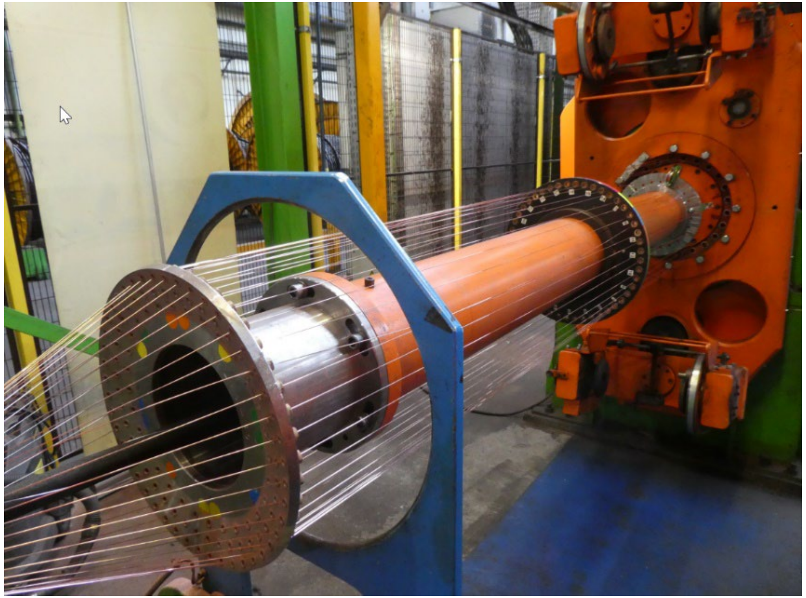
SUPERRAIL

PRODUCTION OF THE SUPERCONDUCTING CABLE

Upgrade of standard cabling line in Bourg-en-Bresse (France) to produce superconducting cables



Before

After integration of a paper lapping unit

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SUPERCONDUCTING CABLE TERMINATION

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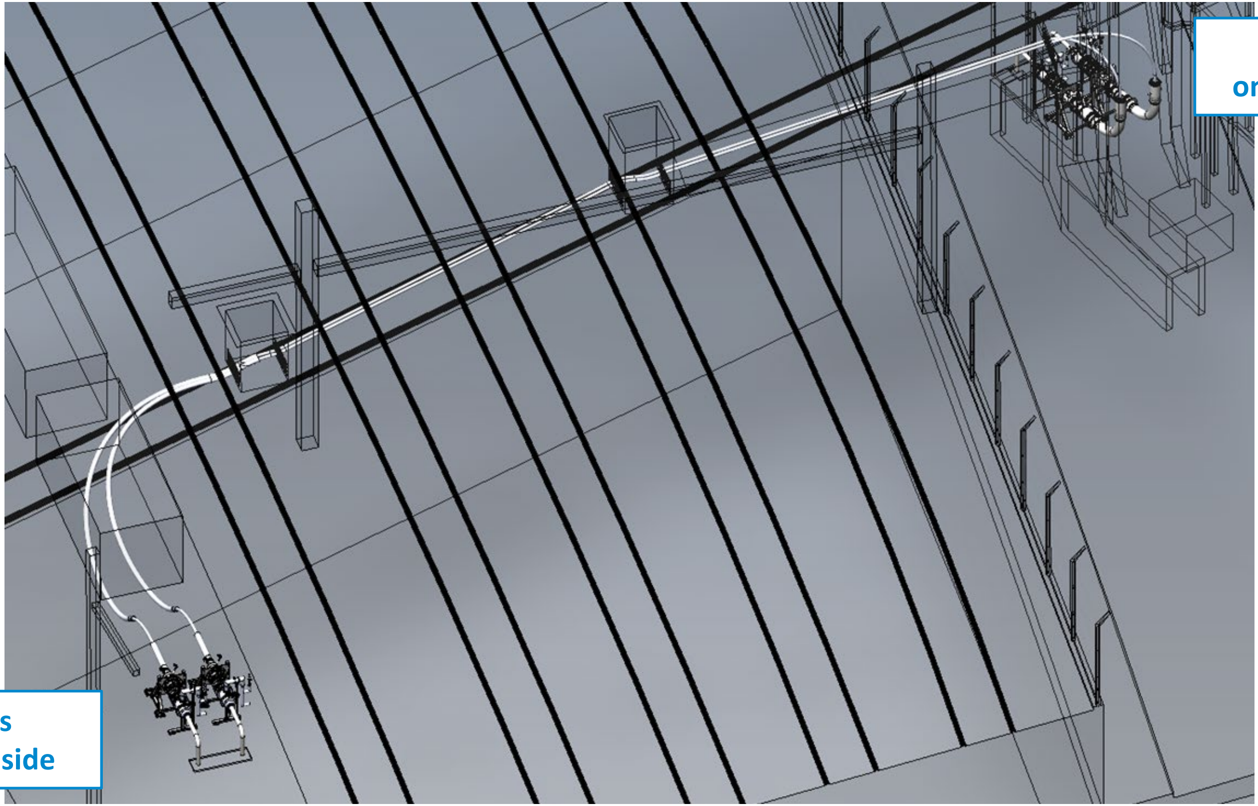
SUPERRAIL

POSITIONING OF THE TERMINATIONS



2 Terminations
on the substation side

2 Terminations
on the platforms side

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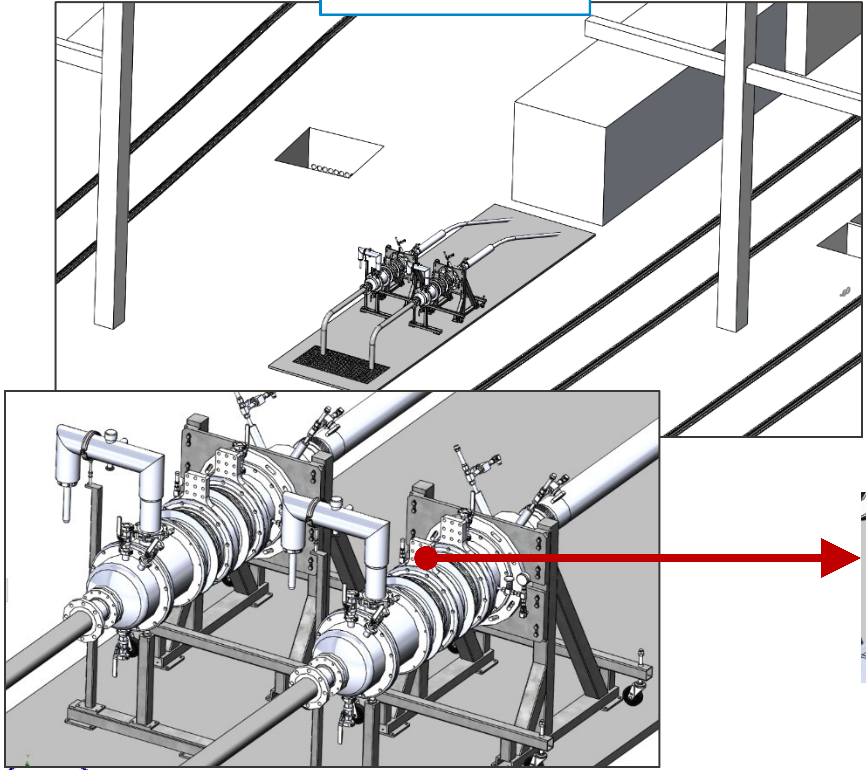
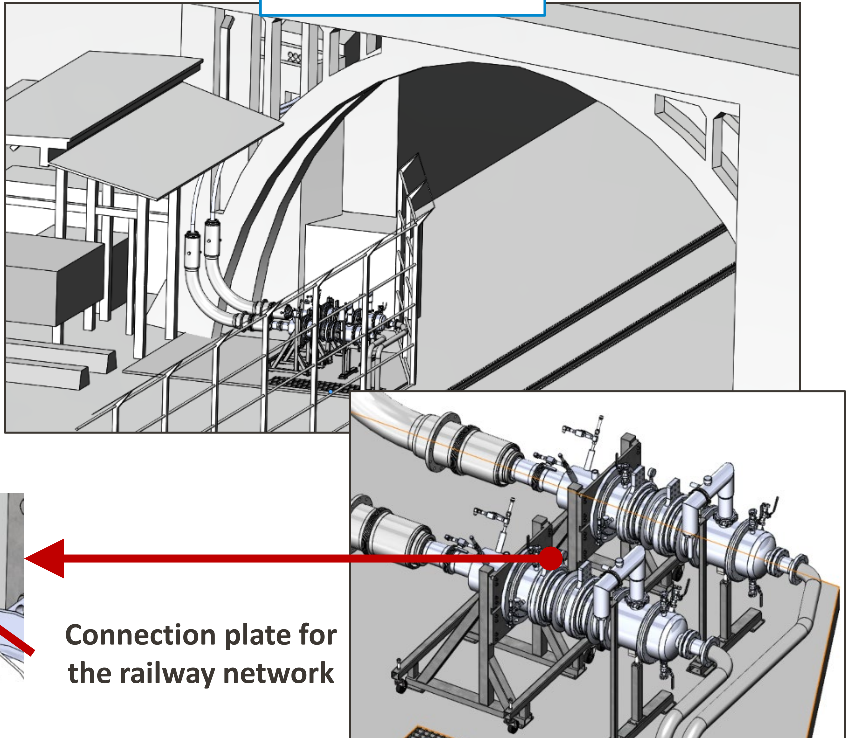
SUPERRAIL

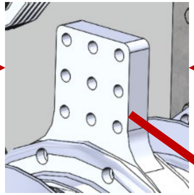
TERMINATIONS INTEGRATION

PLATFORM SIDE



SUBSTATION SIDE





Connection plate for the railway network

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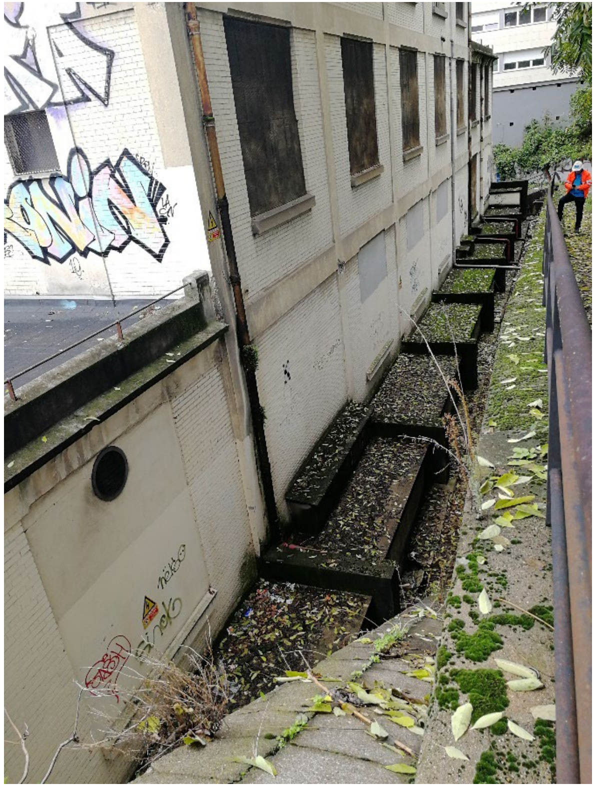
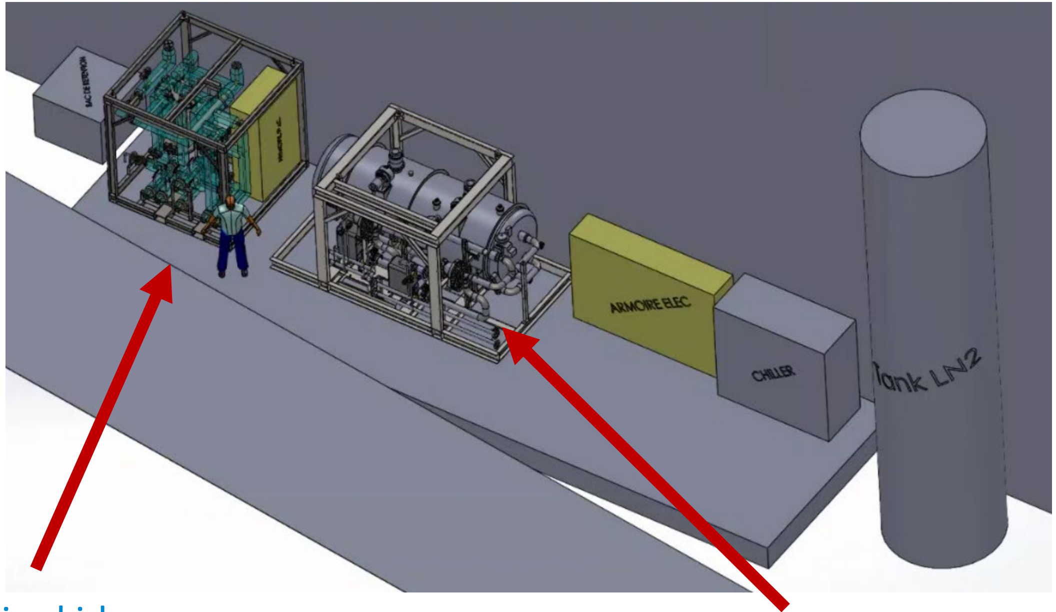
SUPERRAIL

INTEGRATION OF THE COOLING SYSTEM



Civil work in progress



Cryogenic skid

- LN2 Circulation and pressurisation
- Cool down management

Cooling system

(Turbo Brayton - RTB)

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COOLING SYSTEM: CRYOGENIC SKID

SKID for CIRCULATION COOLING DOWN and SUBCOOLING

- To be used during type test and final installation
  - Liquid Nitrogen circulation
  - Pressurization
  - Cool down management (requires a LN_2 tank)
- Based on a bath of LN_2 pumped into a cryostat with a heat exchanger to cool the cable.
- A cryocooler can be connected in place of the pumped LN_2 cryostat to produce sub-cooled liquid nitrogen.

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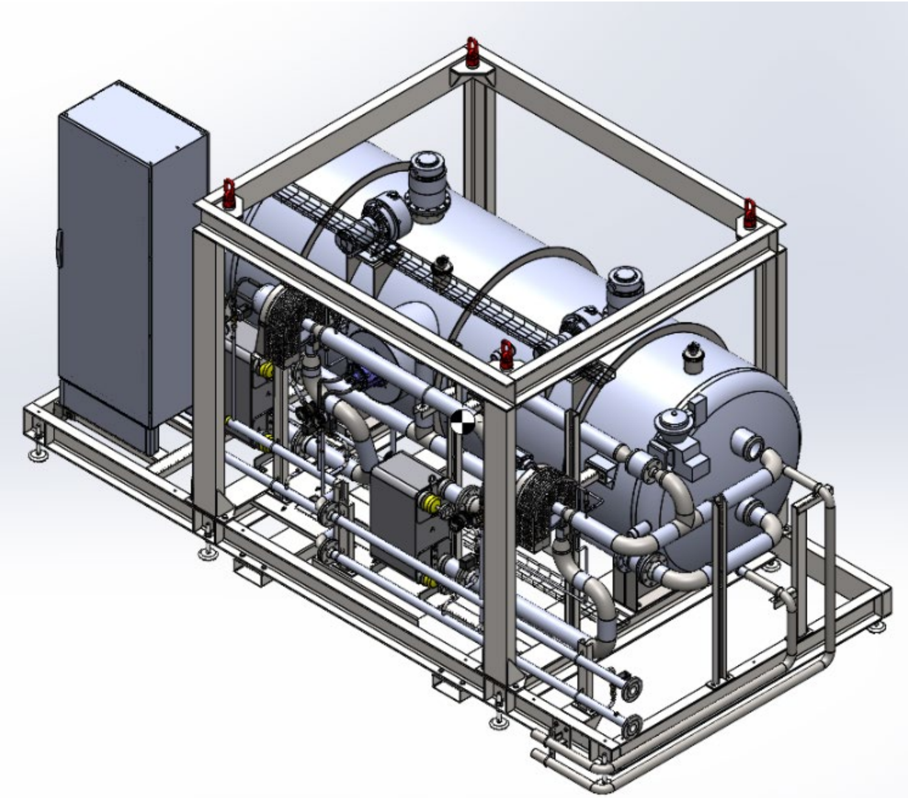
COOLING SYSTEM: TURBO BRAYTON (RTB)



- A new family of cooling system is developed to cover, with a higher efficiency and low maintenance requirement, a range of cooling power of few kW@ LN_2 needed for urban superconducting systems.
- RTB allows the cooling capacity to be controlled from 30% to 100% of the maximum power.
- A 1.7 kW@ 67 K RTB will be connected to the SKID for long-term commissioning.

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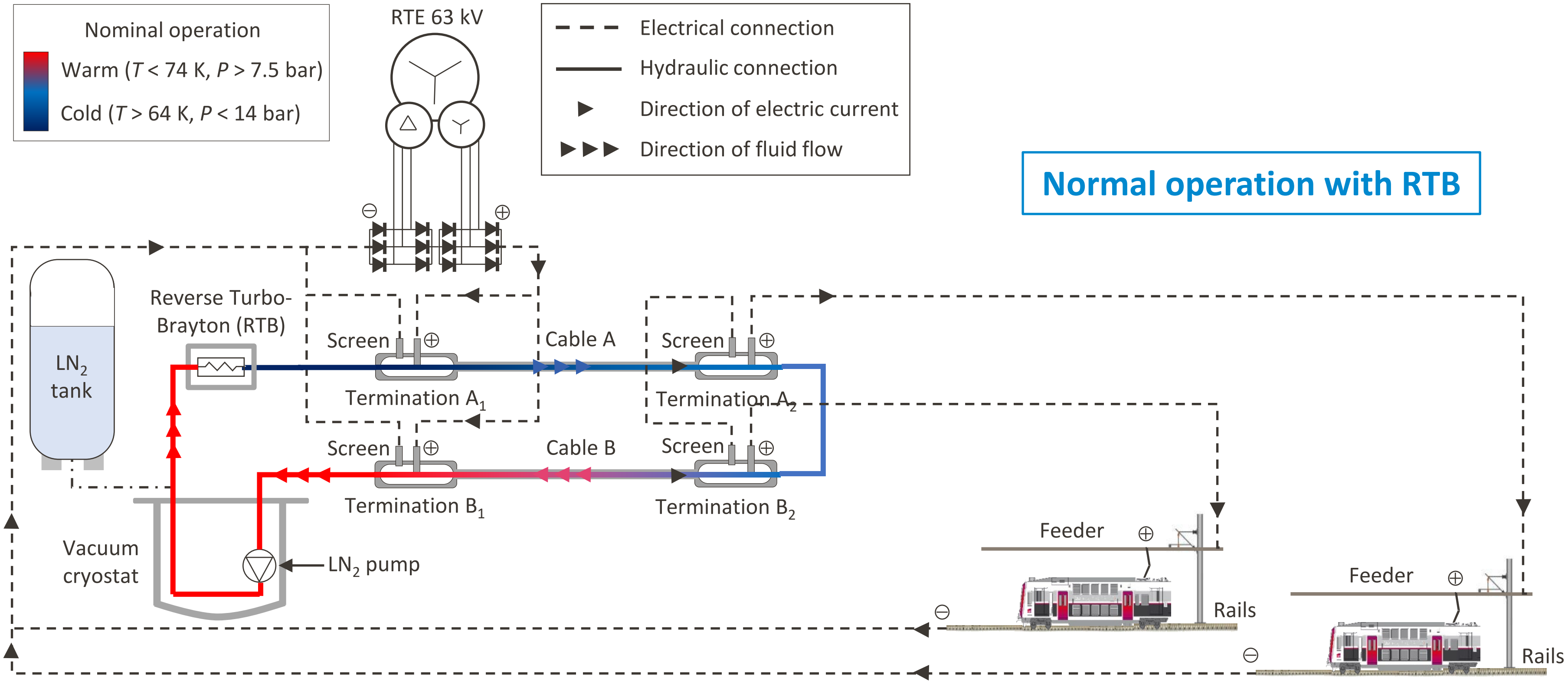
SUPERRAIL

CABLE AND COOLING SYSTEM

Normal operation with RTB



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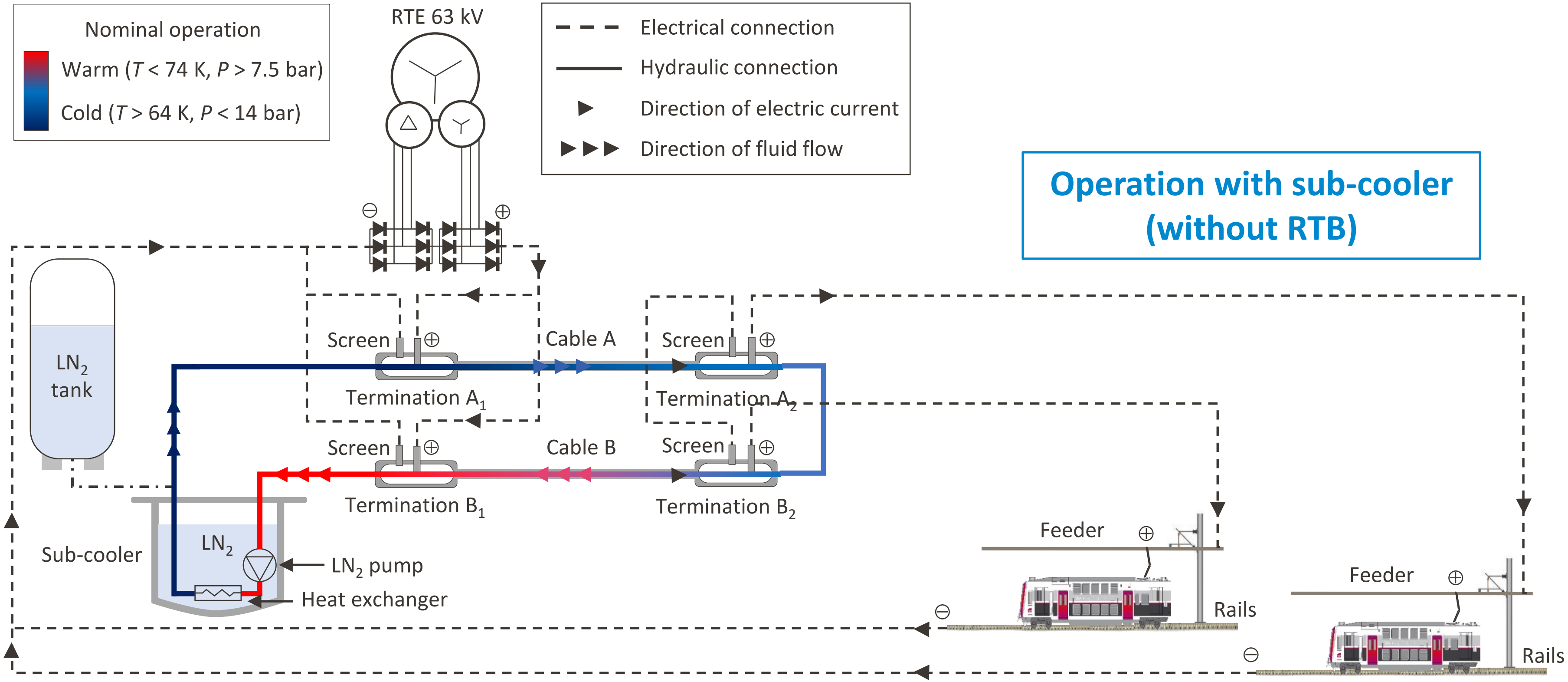
CABLE AND COOLING SYSTEM



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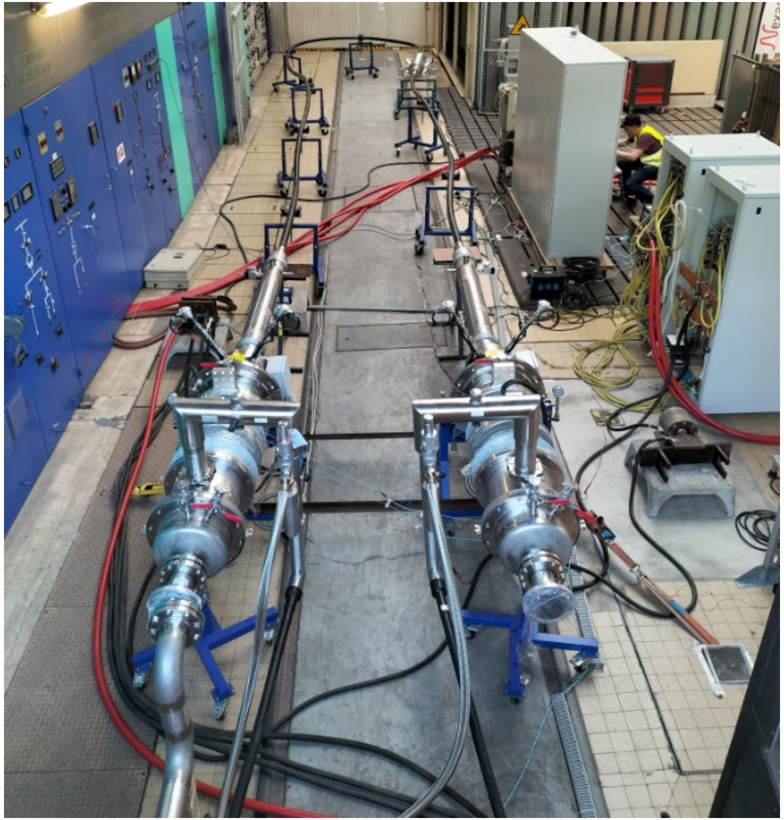
SUPERRAIL

TESTS IN SNCF RAILWAY TEST AGENCY (SNCF-AEF)

- 30 m test loop with a junction
  - Tests in accordance with IEC 63075
    Bending test, Pressure test, Thermal test, Critical current test
  - Tests in accordance with EN 50124-1
    Lightning impulse, Dielectric test
  - Fault current
    Equivalent energy to 67 kA during 200 ms since only 40 kA @ 1500 V is possible at the test agency



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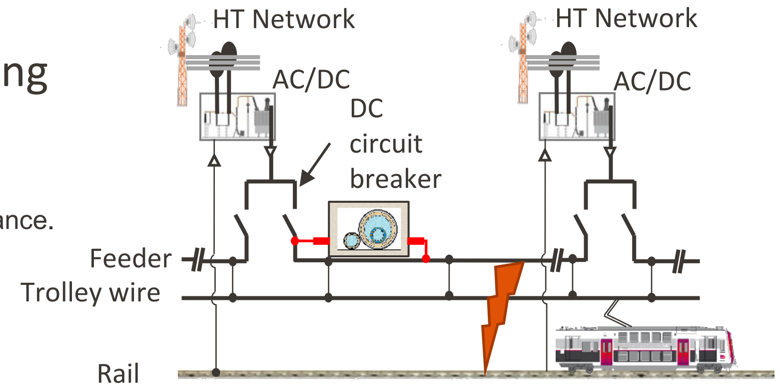
SUPERRAIL

BEHAVIOR OF SUPERCONDUCTING CABLES

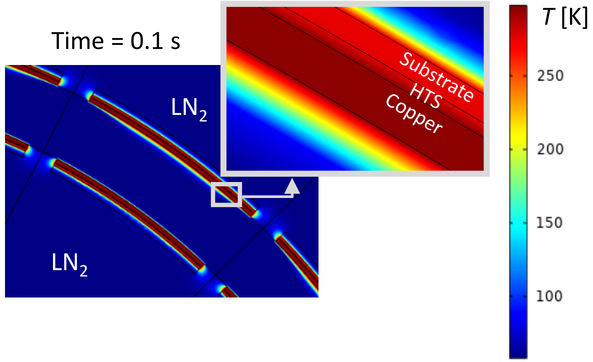
- Development of simulation tools for superconducting cables **operating under railway conditions**

  Hajiri, G., Berger, K., Dorget, R., Lévêque, J., Caron, H. (2022). Design and modelling tools for DC HTS cables for the future railway network in France. *Supercond. Sci. Technol.*, 35(2), 024003.



- Transient electrothermal FEM simulations coupled **with an electrical network circuit model**

- Feasibility study and integration of **new functionalities** such as limitation



- **Development of a test platform** to validate the models and carry out high current tests on cables prototypes

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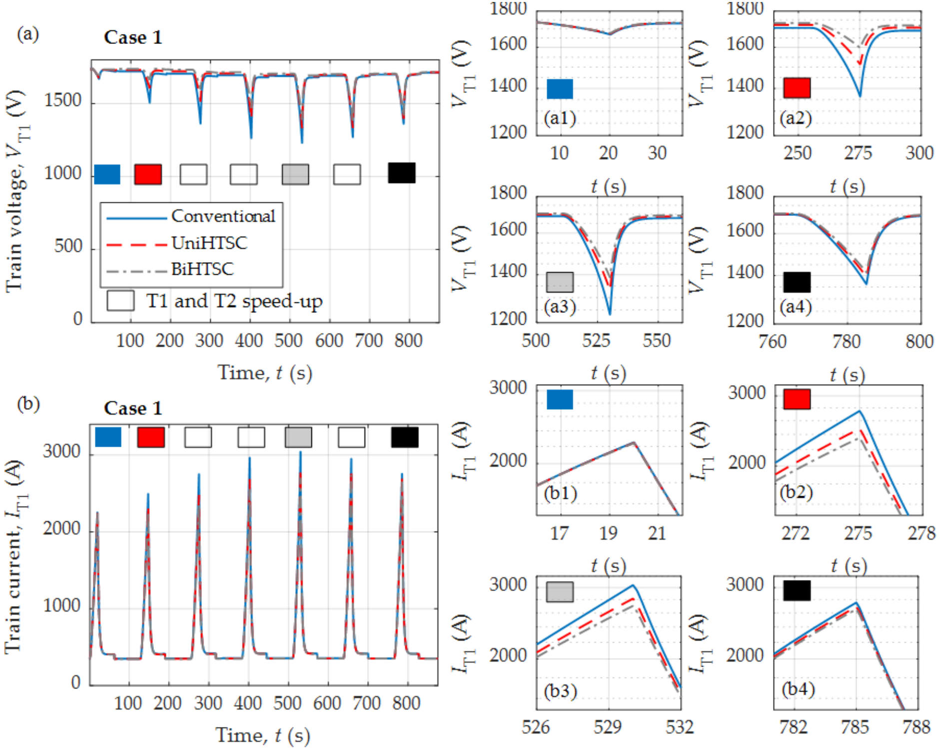
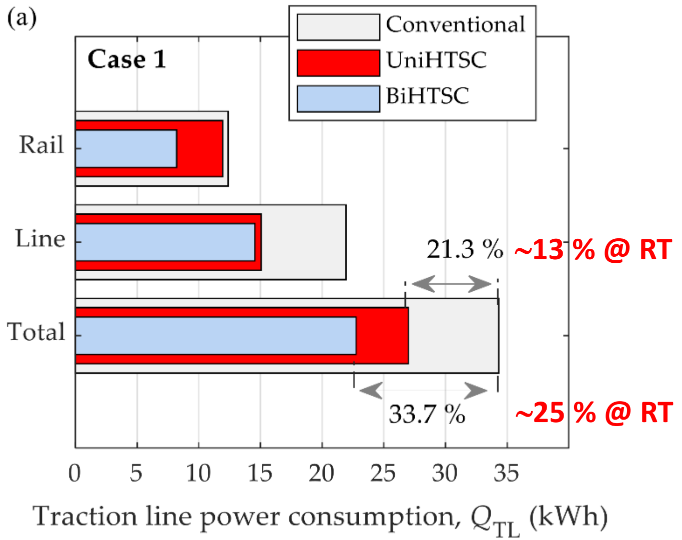
IMPACT OF SUPERCONDUCTING CABLE ON A RAILWAY NETWORK



Estimation of losses reduction



Hajiri, G., Berger, K., Trillaud, F., Lévêque, J., Caron, H. (2023). Impact of Superconducting Cables on a DC Railway Network. *Energies*, 16(2), 776.

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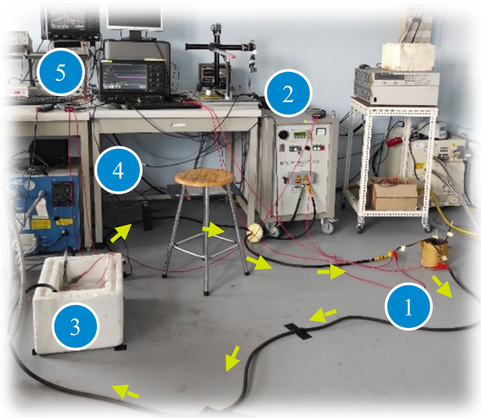
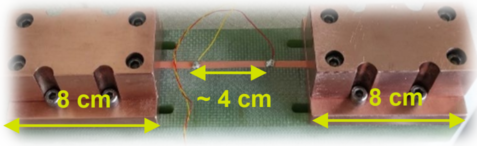
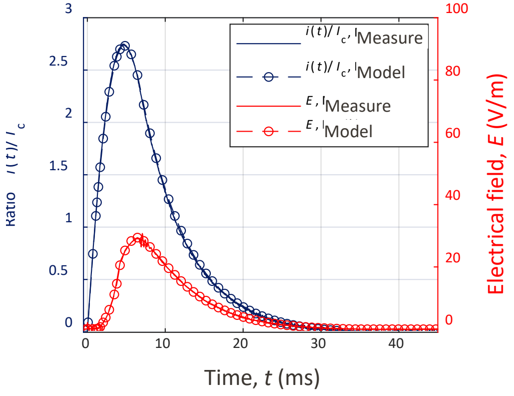
SUPERRAIL

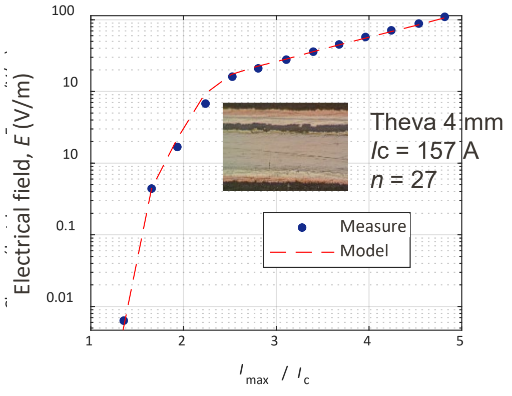
OVER CURRENT TESTS ON HTS TAPES

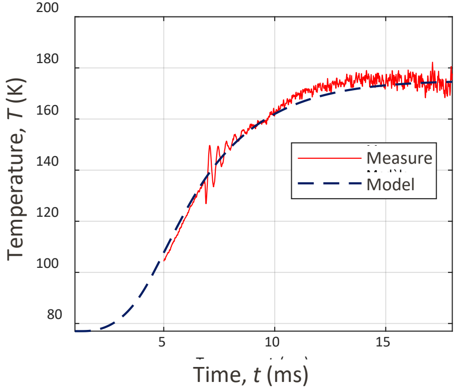


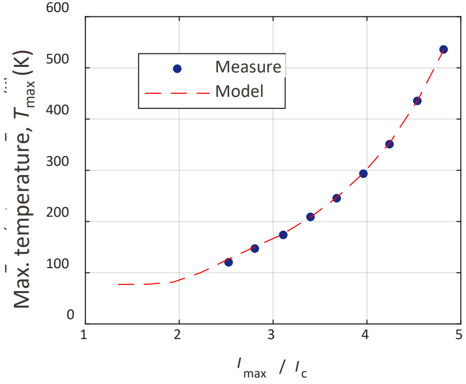
1 Coil
2 Capacitors bank
3 Sample + cryostat
4 Current measurement
5 Voltage measurement











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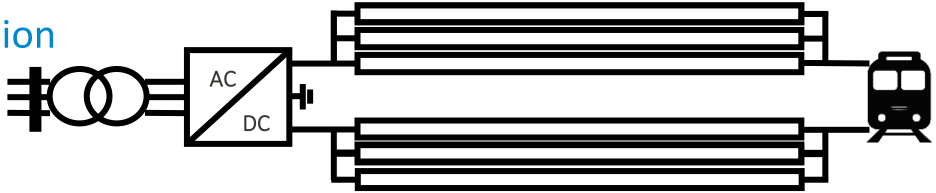
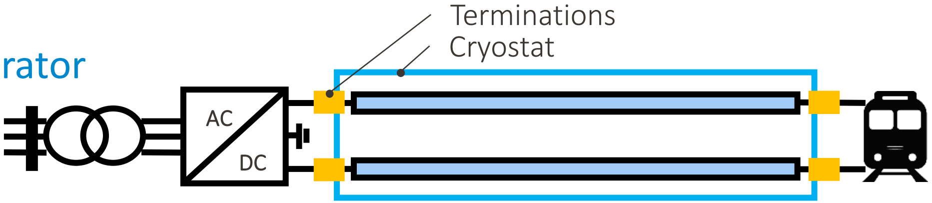
SUPERRAIL

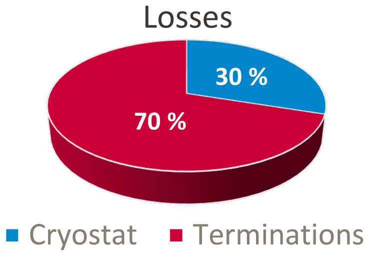
REDUCTION OF TERMINATIONS LOSSES

- Conventional solution

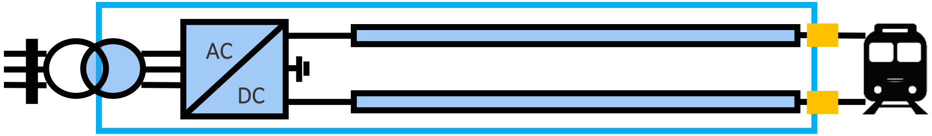


- SuperRail demonstrator (TRL 6-7)





- Lab demonstrator (TRL 4)
  - HTS transformer
  - Cryo-converter



- Half the number of term.
- Global efficiency?
- Power density?

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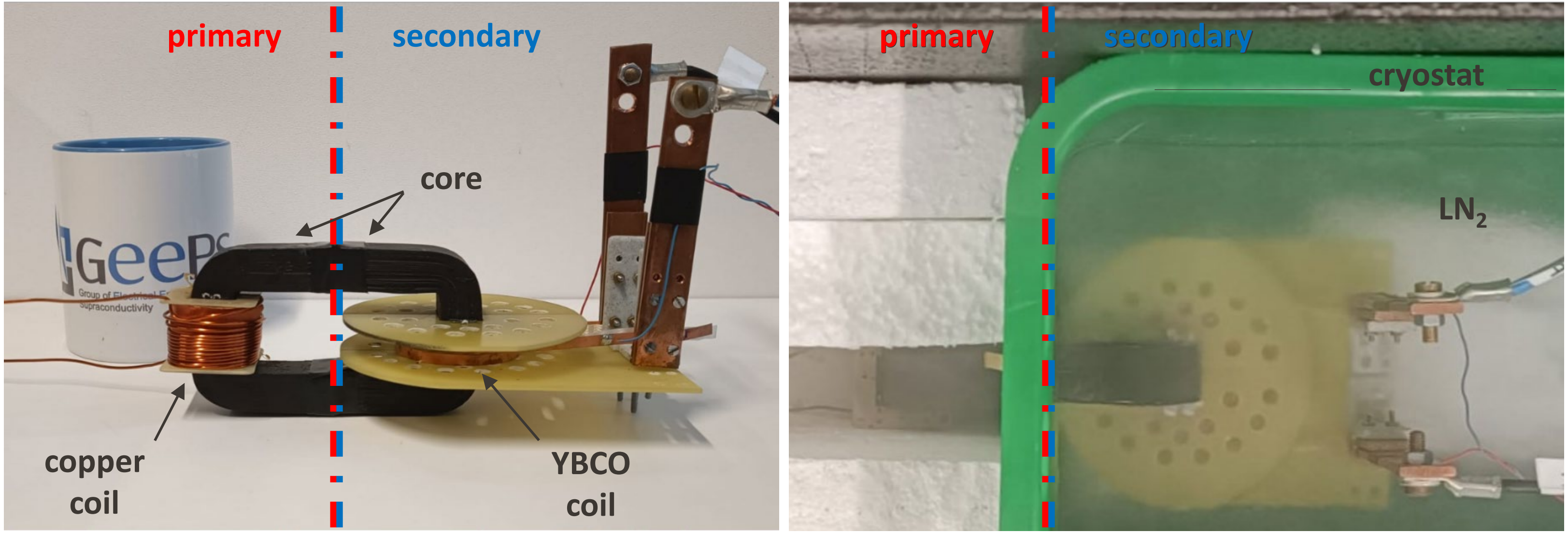
SUPERRAIL

SUPERCONDUCTING TRANSFORMER

- Manufacturing and testing of the first prototype
- Proof of concept: transfer power through the cryostat



L. Ferreira, Y. Baazizi, S. Meunier, T. Phulpin, R. Beljio, F. Trillaud, T.-Y. Gong, G. Henn, L. Quéval, “Étude expérimentale de l’alimentation d’un dispositif supraconducteur à courant continu,” Symposium de Génie Électrique (SGE 2023), id. 450881, Lille, France, Jul. 2023.

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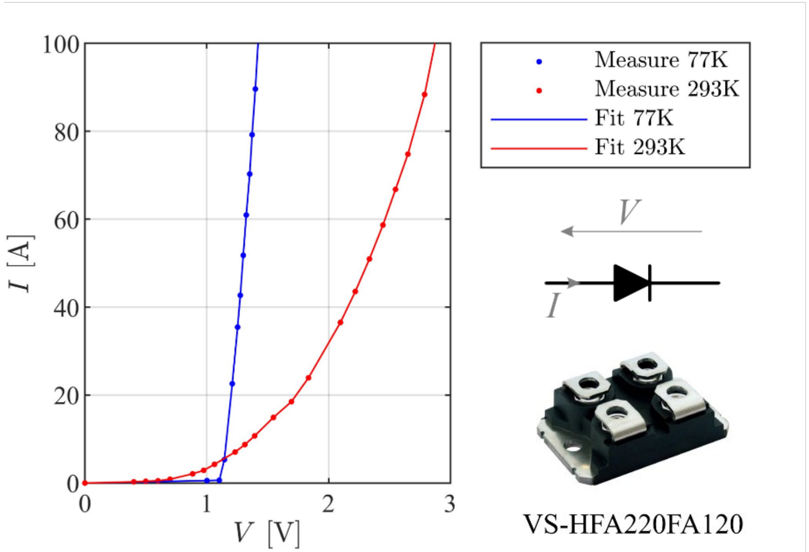
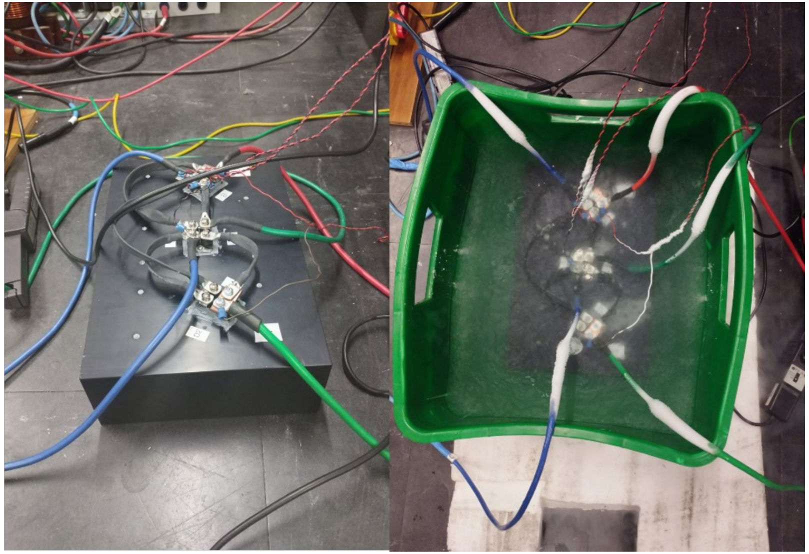
SUPERRAIL

CRYO-CONVERTER

- Manufacturing and testing of first prototype (3 kW 3-phase diode rectifier @77 K)
- Proof of concept: operate the full diode rectifier at cryogenic temperature





Y. Baazizi, L. Ferreira, S. Meunier, T. Phulpin, L. Quéval, "Operation of power diodes at cryogenic temperature," *3rd Momentom international congress energy at the crossroads: accelerating innovation in the age of disruption,* Gif-sur-Yvette, France, Mar. 2023.

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CONCLUSION

- **SuperRail** is an excellent example of **how a superconducting can unlock situations in power grids** where conventional technologies are not applicable or are too costly

- The superconductivity is **a way to increase the capacity of power supply to public transport** in dense areas, allowing **to meet national low carbon objectives**

- The validation of **the superconducting technology** during SuperRail will qualify superconducting cable **for future projects to reinforce and secure the national railway grid**

- **SuperRail** fosters **continuous improvement** of superconducting system through R&D approach **to reduce losses** and through **experiences in exploitation with SNCF teams** up to the end of the project and beyond

This project is supported by France 2030.

SOME KEY STAGES IN SUPERRAIL PROJECT

1. **February 2022** Project starts
2. **March 2023** Civil engineering for cable routes
3. **March 2023** Prototype cable is manufactured in France
4. **April 2023** Dummy cable pulling
5. **June 2023** 30 m test loop is installed at the SNCF test agency
6. **August 2023** Tests have been carried out at SNCF test agency
7. **October 2023** The HTS cables have been pulled into ducts
8. **April 2024** Final tests at the SNCF test agency
9. **July 2024** Installation of the 2 last terminations
10. **September 2024** Civil engineering work for the cooling system
11. **October 2024** Installation of the cooling system
12. **November 2024** Commissioning of the entire HTS cables system

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THANK YOU FOR YOUR ATTENTION

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NOTE: The presentation included several photos from the project; however, SNF is not able to include this upload.

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