DSO Innovation Briefing: Superconductors

2 September 2026
Gabriel Hajiri, Nexans

CurrENT
Enabling Network Technology throughout Europe

Summary

I. Straight to the Core
II. Removing Electrical Resistance: Changing the Rules of the Game
III. From superconducting Tape to Grid Integration
IV. Superconducting cable to the Grid
V. Data Center Power Context
VI. Conventional vs. Superconducting: Case Study
VII. Conventional vs. Superconducting: Case Study (MV)
VIII. Conventional vs. Superconducting: Case Study (LV)
IX. Key Benefits
X. Q&A

CURRENT
Enabling Network Technology throughout Europe

Straight to the Core

Challenges Driving the Evolution of Electrical Infrastructure

Infrastructure Complexity and Grid Modernization

→

Increasing Power Demand and Growing Electricity Consumption

High Urban Density

Environmental Constraints

Compactness

→

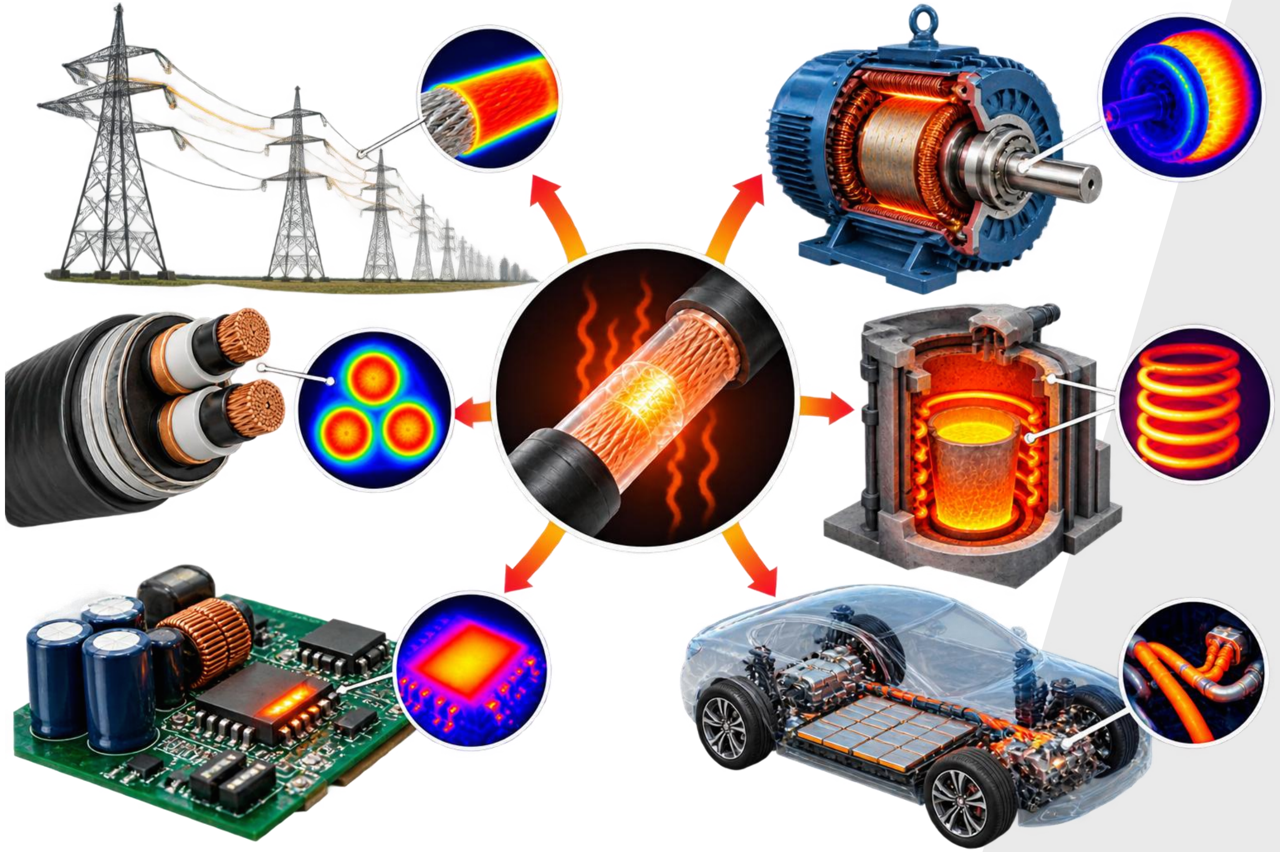
Optimization of Electrical Components

CurrENT
Enabling Network Technology throughout Europe

Electrical Resistance: A Key Driver of System Performance

Across all electrical systems, the same objectives are constantly pursued:

- **Higher efficiency**
- **Lower energy losses**
- **Reduced carbon footprint**
- **More compact systems**
- **Higher power density**
- **Improved thermal management**



Behind these improvements lies a fundamental engineering challenge:

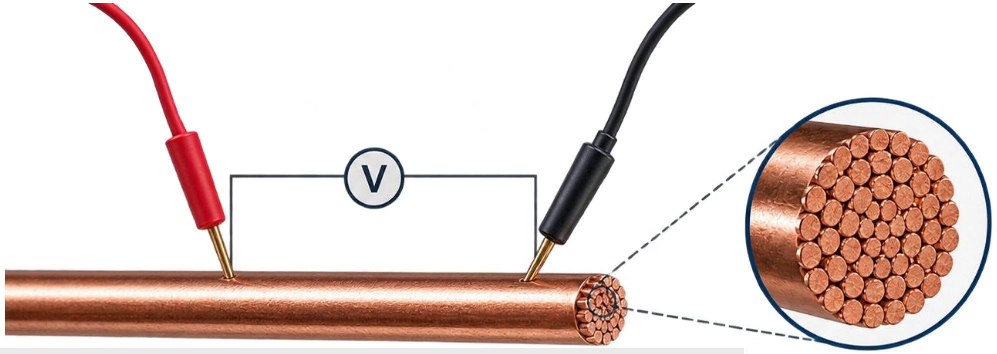
Optimizing the design and minimizing the electrical resistance of conductors.

Removing Electrical Resistance: Changing the Rules of the Game

Welcome to the Superconducting State

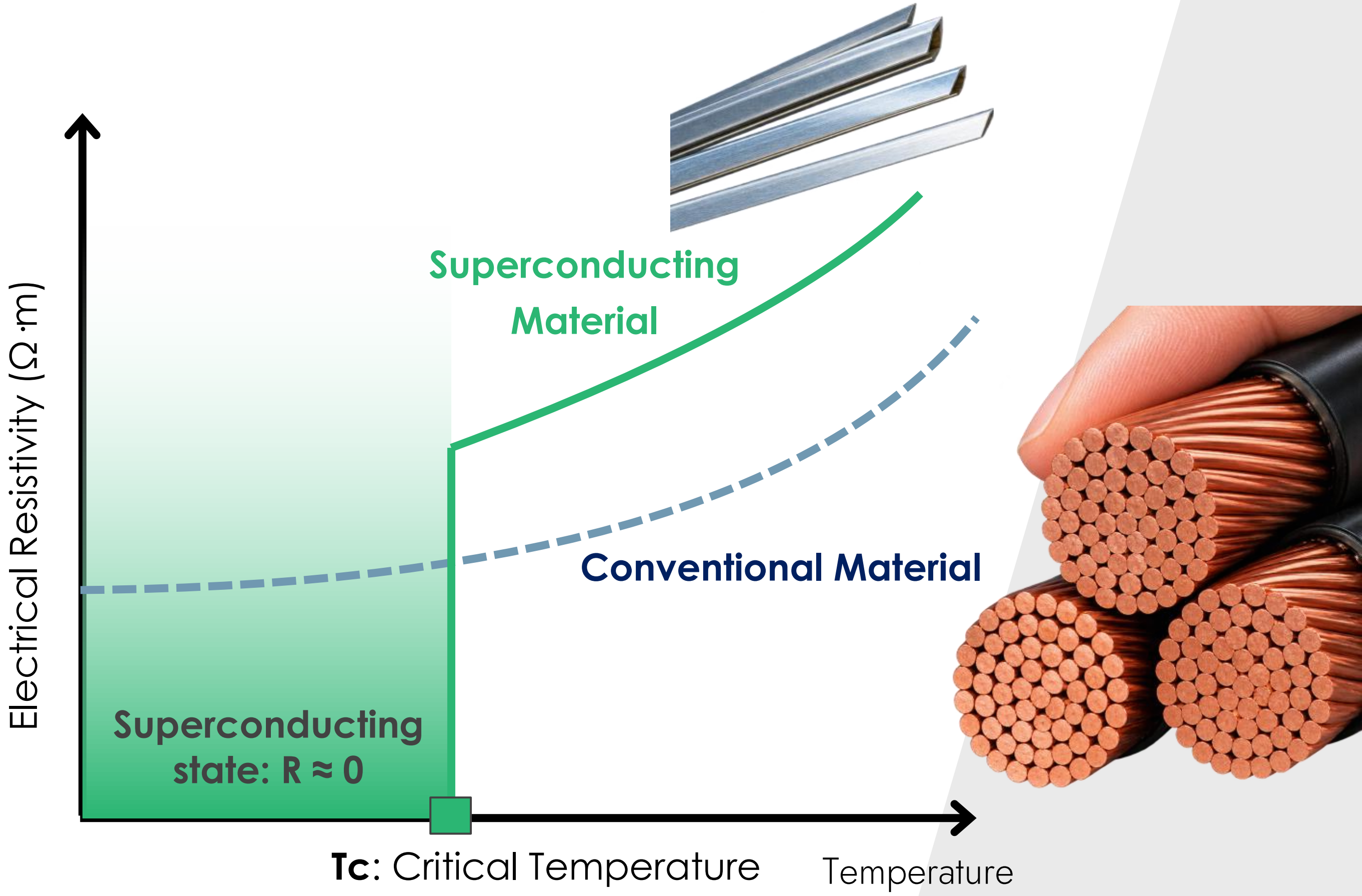
CURRENT
Enabling Network Technology throughout Europe

Electric résistance



Copper Conductor (Conventional)

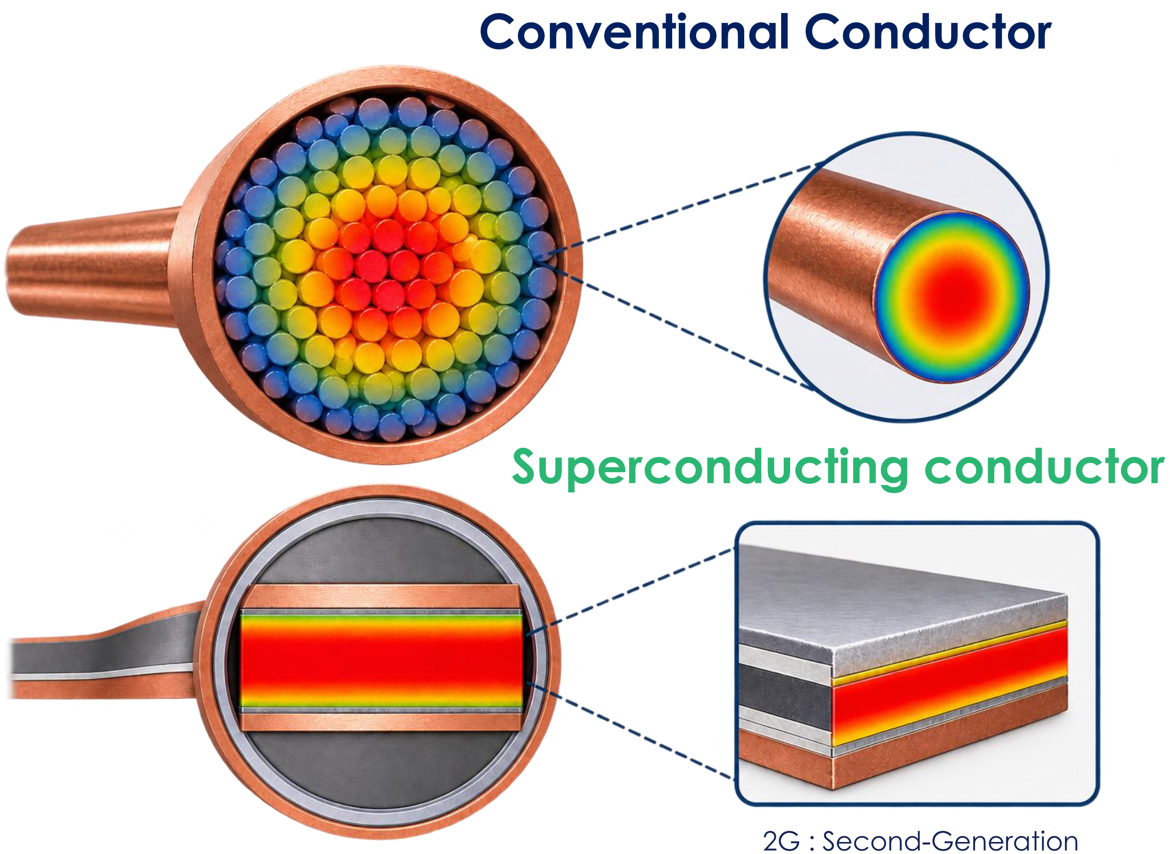
Superconducting conductor



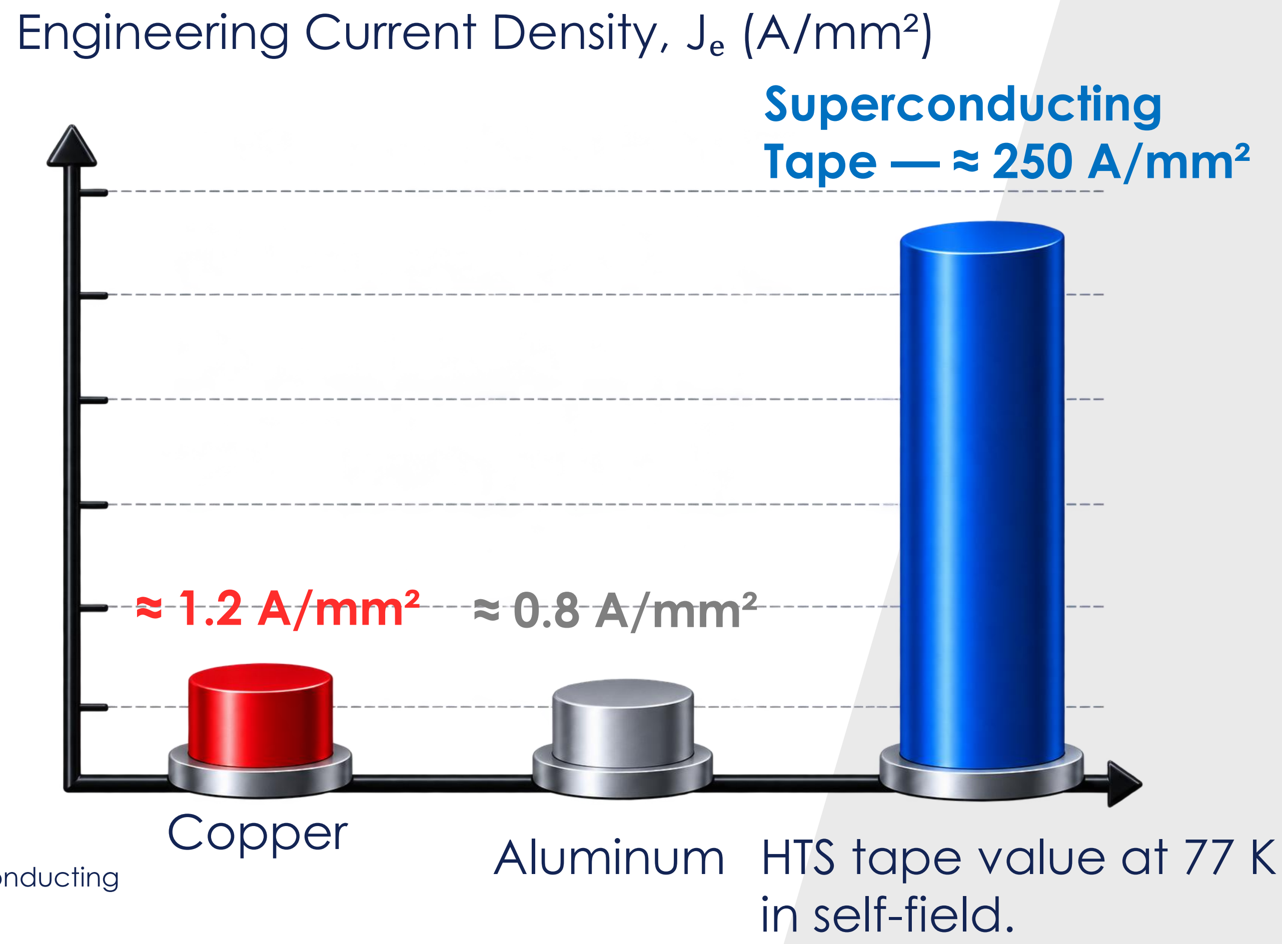
- Below **the critical temperature (Tc)**, the material enters the **superconducting state.**
- Electrical resistance drops to nearly zero **(R ≈ 0).**
- Conventional conductors always exhibit electrical resistance.

CURRENT
Enabling Network Technology throughout Europe

Engineering Current Density



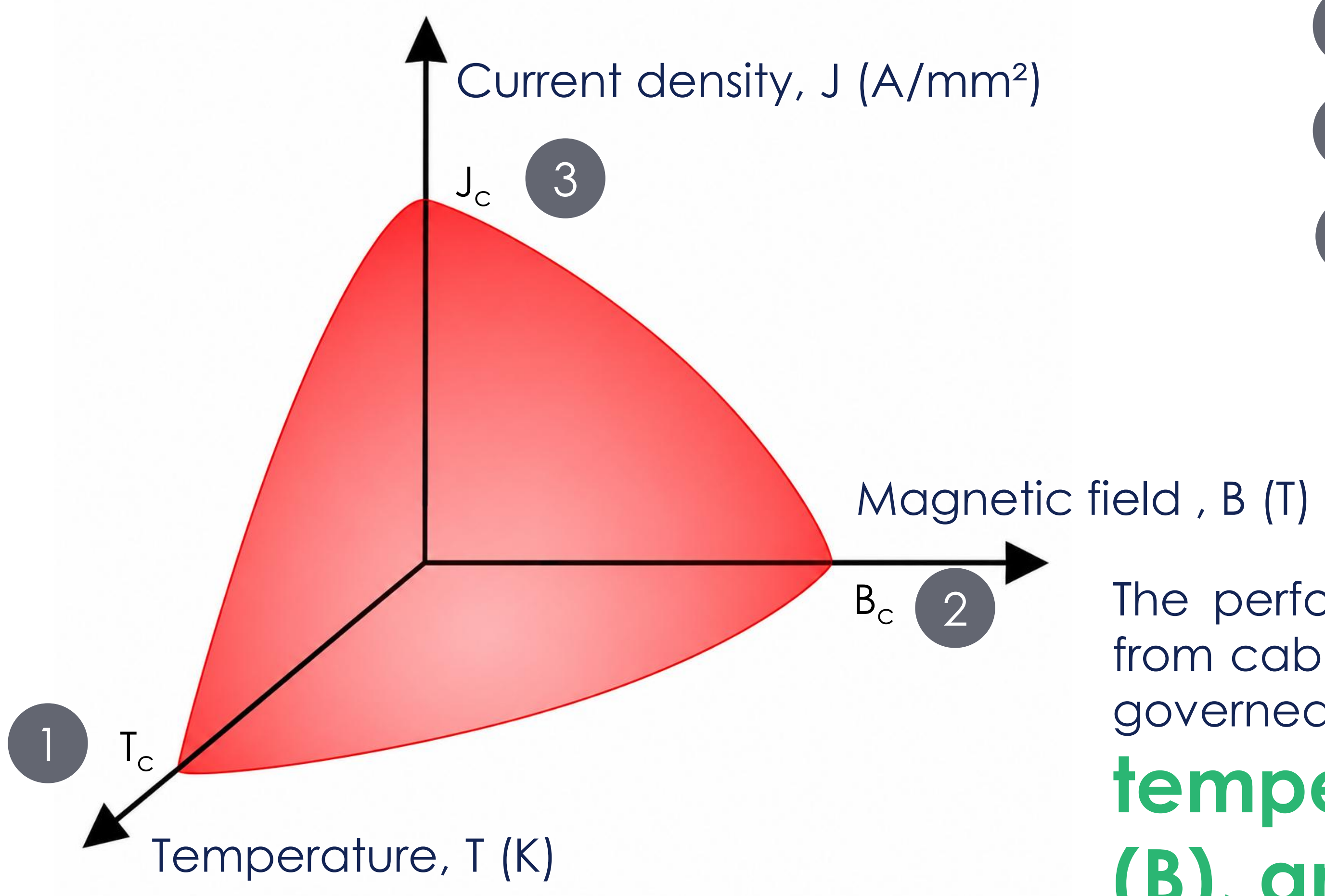
2G : Second-Generation
HTS : **H**igh-**T**emperature **S**uperconducting



On average, the current density of a superconductor is approximately 250 times higher than that of a conventional conductor.

CURRENT
Enabling Network Technology throughout Europe

Critical Surface



KEY FACTORS

1. A critical temperature (Tc)
2. A critical magnetic field (Bc)
3. A critical current density (Jc)

The performance of any superconducting system, from cables to electrical machines and magnets, is governed by **three fundamental parameters**:

temperature (T), magnetic field (B), and current density (J).

Need for cooling to cryogenic temperatures.

CURRENT
Enabling Network Technology throughout Europe

Overview of Superconducting Wires and Cryogenics

❑ Superconductors – Critical Temperature

Superconductor	Full Name / Family	Tc (K)	Tc (°C)
Nb-Ti	Niobium–Titanium	~9	~−264
Nb_3Sn	Niobium–Tin	~18	~−255
BSCCO-2212	Bismuth Strontium Calcium Copper Oxide	~85–90	~−188 to −183
BSCCO-2223	Bismuth Strontium Calcium Copper Oxide	~110	~−163
2G-**HTS** Tape **REBCO**	Rare-Earth Barium Copper Oxide	~90–93	~−183 to −180

2G : Second-Generation
HTS : High-**T**emperature **S**uperconducting

❑ Cryogens – Boiling Temperature

Cryogen	Symbol	Boiling Temperature (K)	Boiling Temperature (°C)
Helium	He	4.2 K	−269°C
Hydrogen	H_2	20.3 K	−253°C
Neon	Ne	27.1 K	−246°C
Nitrogen	N_2	77.4 K	−196°C
Argon	Ar	87.3 K	−186°C
Oxygen	O_2	90.2 K	−183°C
Methane	CH_4	111.7 K	−162°C

CurrENT
Enabling Network Technology throughout Europe

Optimal Combination for HTS Power Cables

Why REBCO + Liquid Nitrogen?

Second-Generation (2G) **H**igh-**T**emperature **S**uperconducting (**HTS**) Tape (**REBCO)**

Tc ≈ **90–93 K**

High critical temperature

High critical current density

High-field performance

Mechanically robust tape

+

Liquid Nitrogen (LN_2)

Boiling point ≈ **77 K @ 1 atm**

Economical

Non-flammable

Widely available

Industrially mature

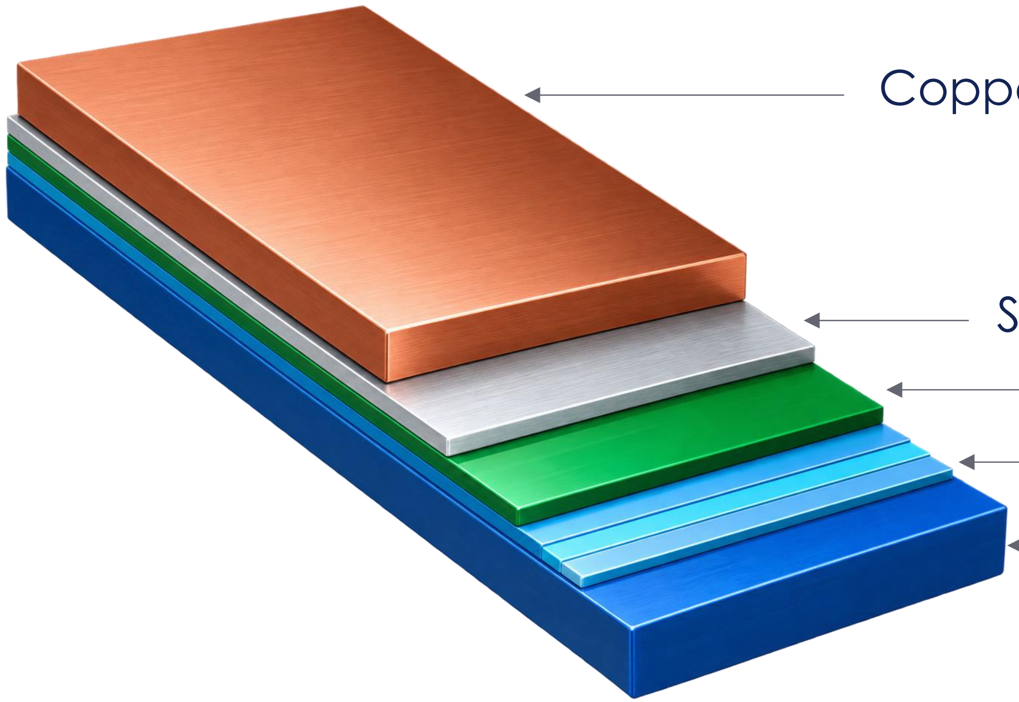
REBCO + LN_2 = Optimal Combination for HTS Power Cables

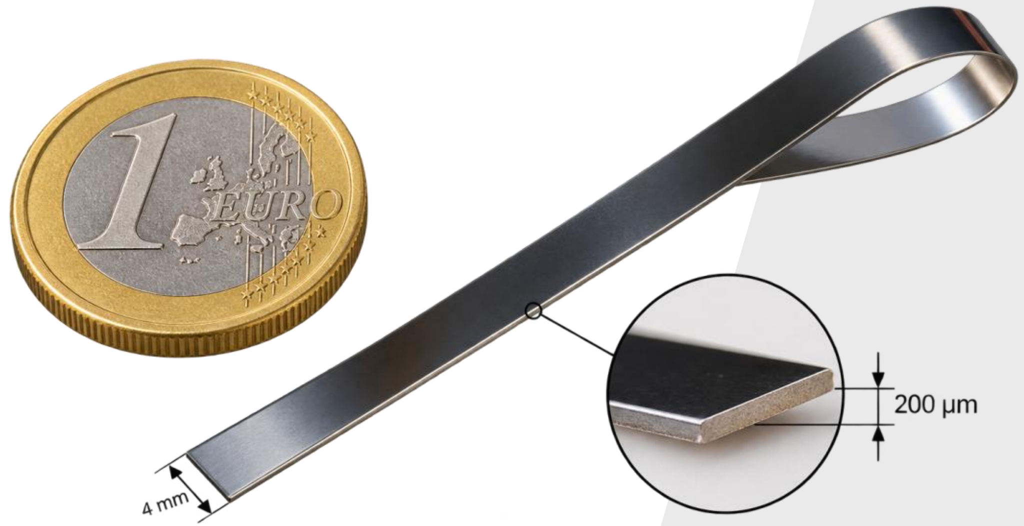
High Tc + High Current Density + Economical & Mature Cryogen = Practical High-Power Cable System

CURRENT
Enabling Network Technology throughout Europe

Second-Generation (2G) **H**igh-**T**emperature **S**uperconducting (**HTS**) Tape

Structure of a Second-Generation (2G) **H**igh-**T**emperature **S**uperconducting (**HTS**) Tape





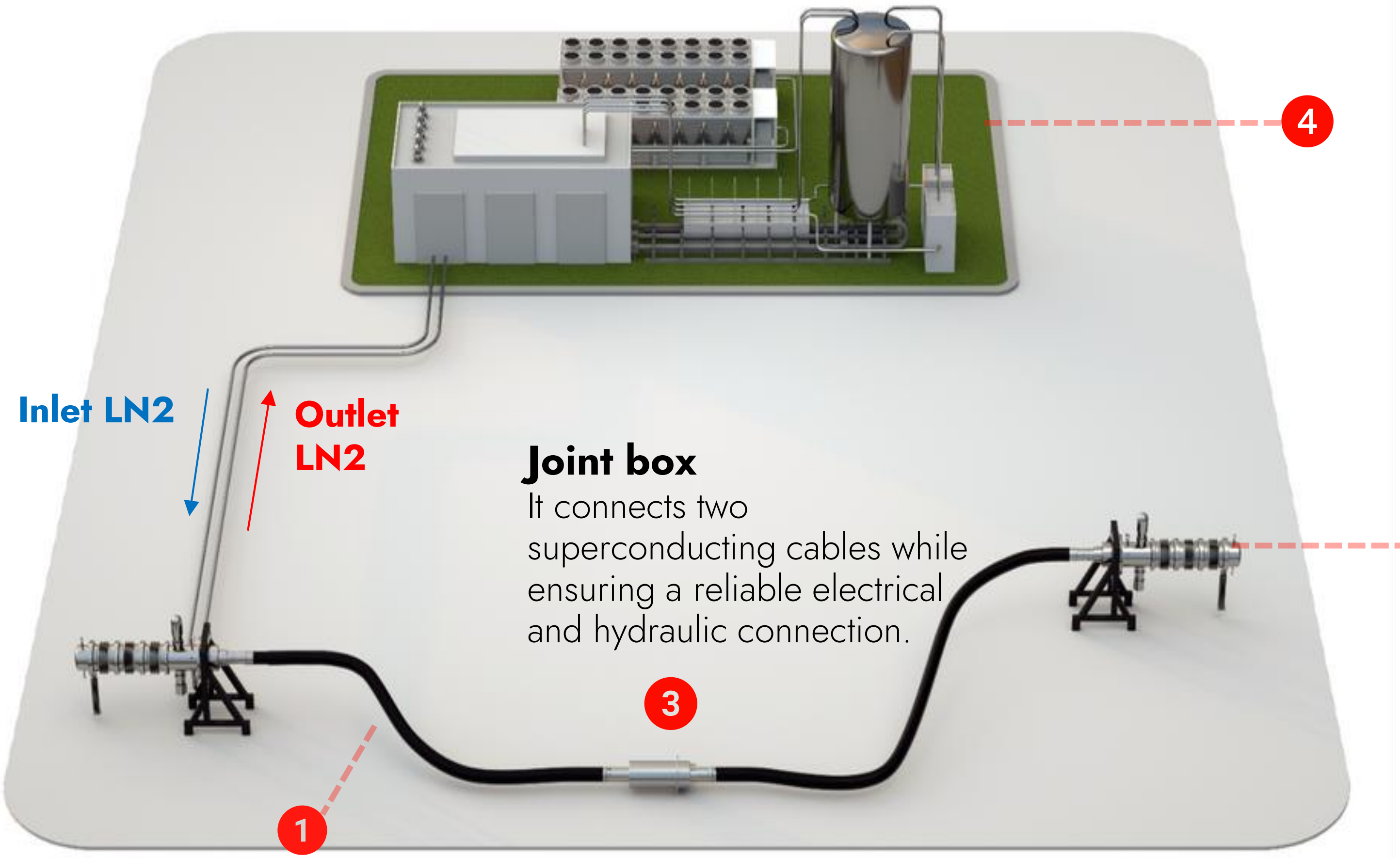
Game Changer: ~200 A in a single 4 mm-wide HTS tape at 77 K.

From superconducting Tape to Grid Integration

Superconducting Systems for Next-Generation Power Grids

CurrENT
Enabling Network Technology throughout Europe

Overview of Superconducting Systems



4 **Cryogenic Cooling**
Maintains about -200°C. Operates open or closed loop. The liquid is cooled and pumped through the cable, linked with vacuum-insulated pipes.

2 **Terminations**
They connect the superconducting cable properly to the electrical grid.

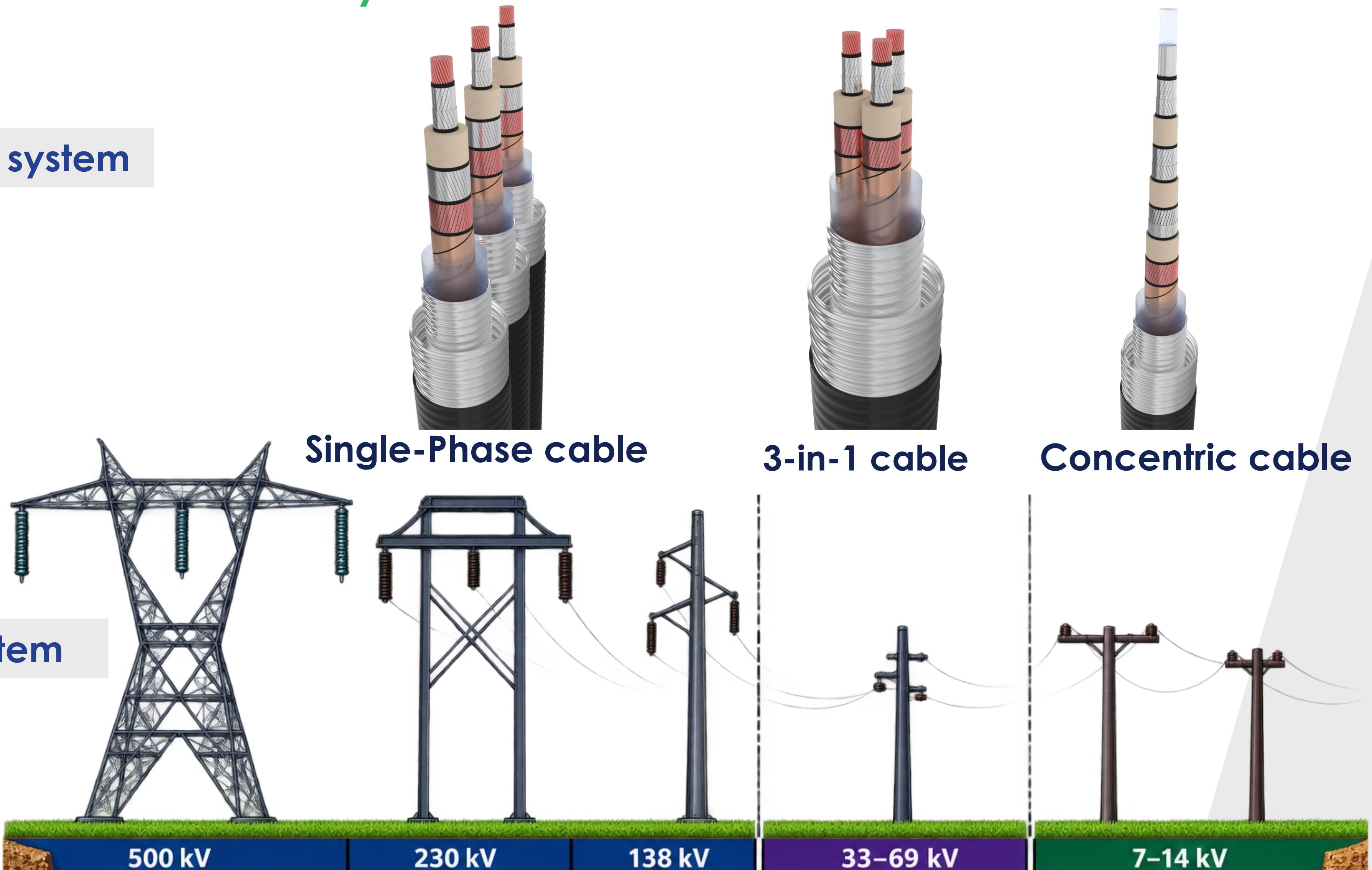
Superconducting Cable
Transmits power with zero electrical resistance, maximizing efficiency.

CURRENT
Enabling Network Technology throughout Europe

Grid Overview: Superconducting vs. Conventional Systems

Superconducting system

Conventional system



CURRENT
Enabling Network Technology throughout Europe

Superconducting cable to the Grid

Design of a Superconducting and termination Cable

CURRENT
Enabling Network Technology throughout Europe

Concentric cable

USAGE

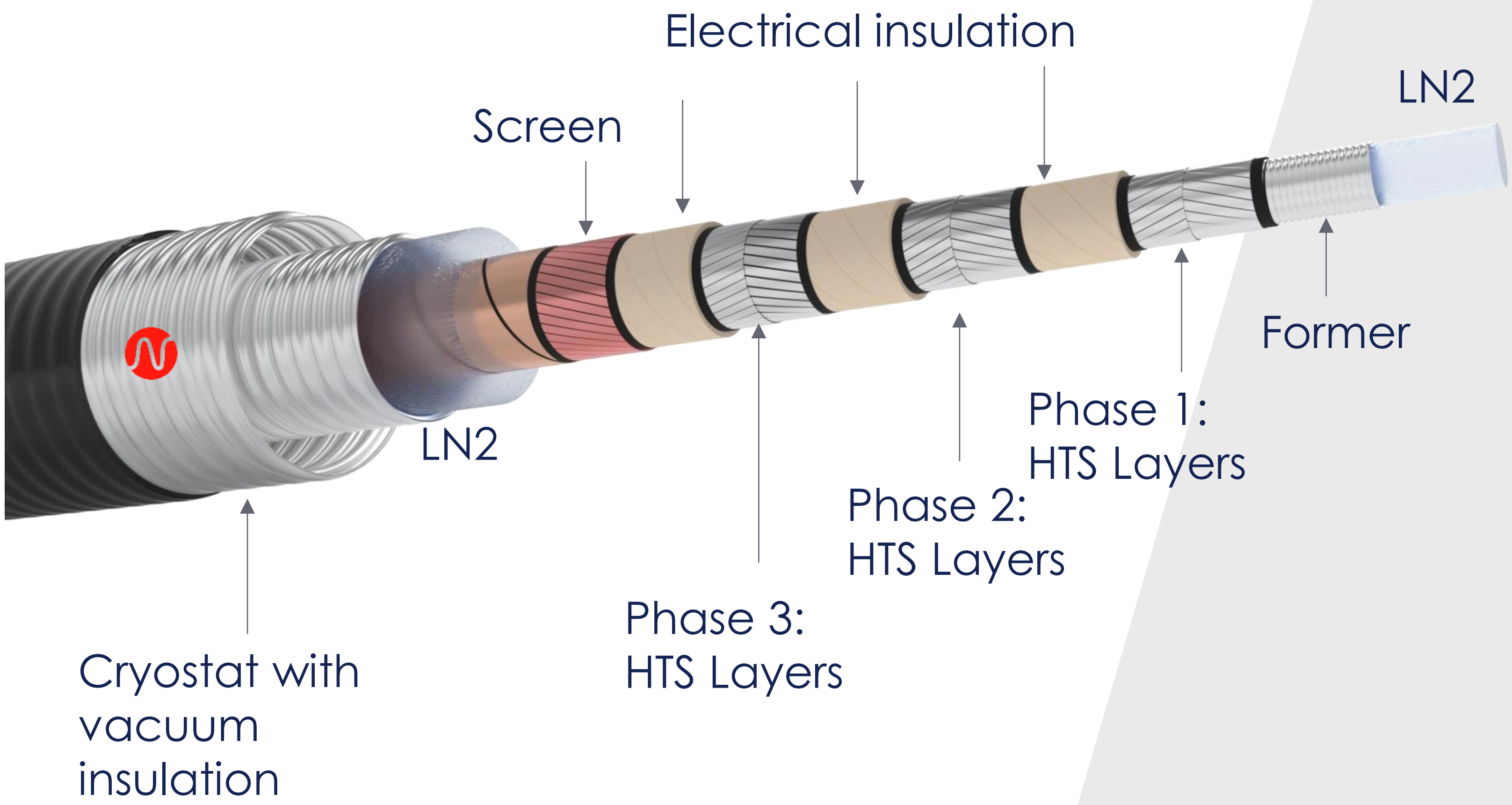
Designed for constrained LV and MV installations, this cable delivers high power density in a compact footprint.

Ideal for urban substations, retrofits and brownfield upgrades where space is limited.

TECHNICAL INFO

- phase-specific HTS design
- capacity: 25–100 MVA
- suitable for LV & MV applications

25 – 100 MVA



3-in-1 cable

USAGE

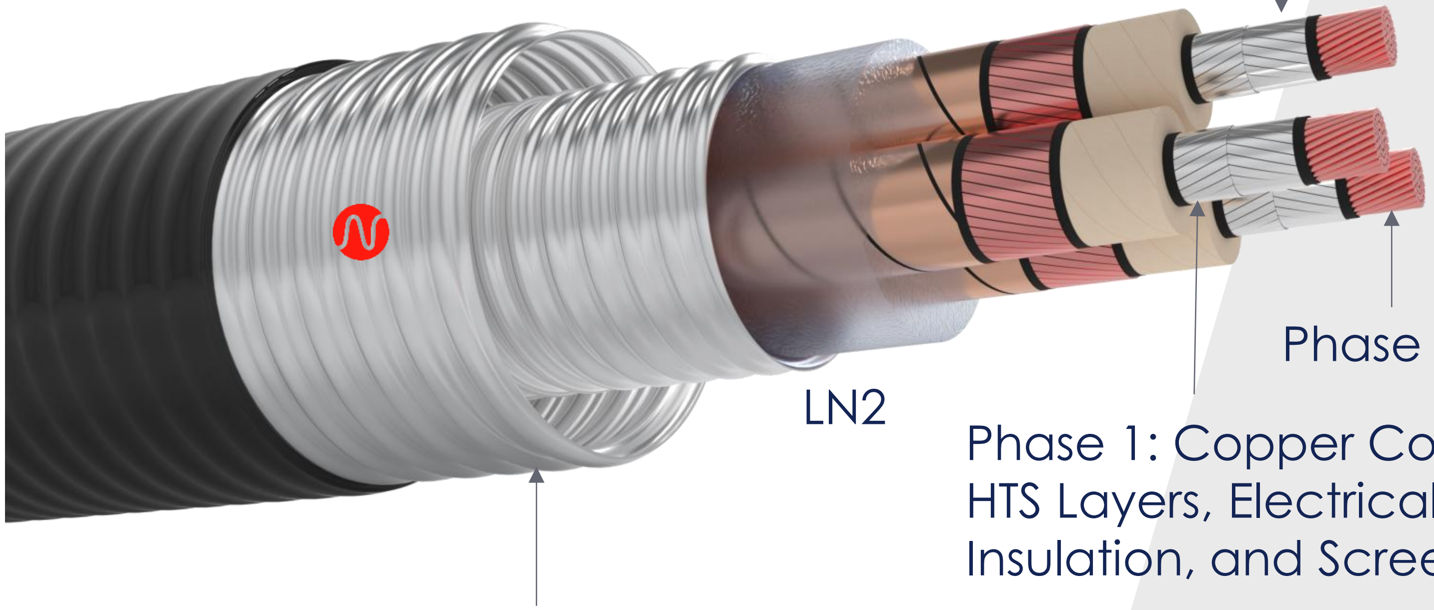
The three-phase-in-one cable combines all phases in one cryostat, maximizing transmission capacity in limited space.

It's designed for high power transmission and sub-transmission in compact environments.

TECHNICAL INFO

- three-phase-in-one architecture
- capacity: 100–1000 MVA
- suitable for transmission and sub-transmission networks

100 – 1000 MVA



CurrENT
Enabling Network Technology throughout Europe

Single-Phase cable

USAGE

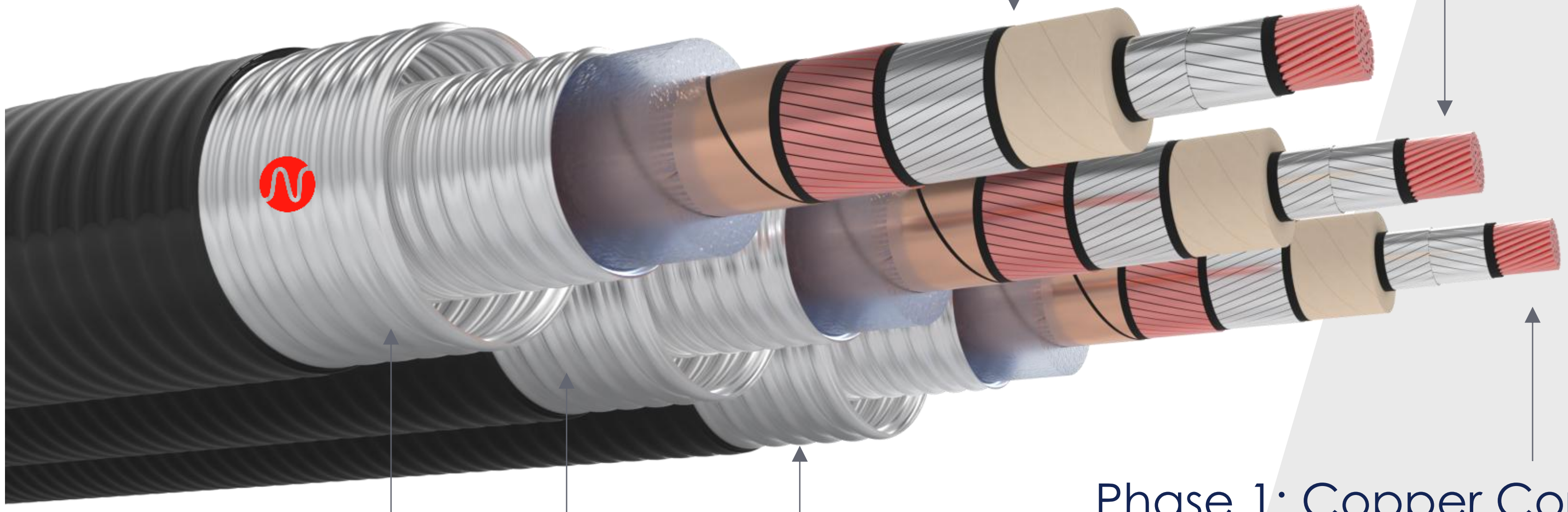
This cable system is designed for constrained LV and MV installations, offering high power density in a compact design.

It's ideal for urban substations, retrofits, and brownfield upgrades with space limitations.

TECHNICAL INFO

- phase-specific HTS design
- capacity: 25–100 MVA
- suitable for LV & MV applications

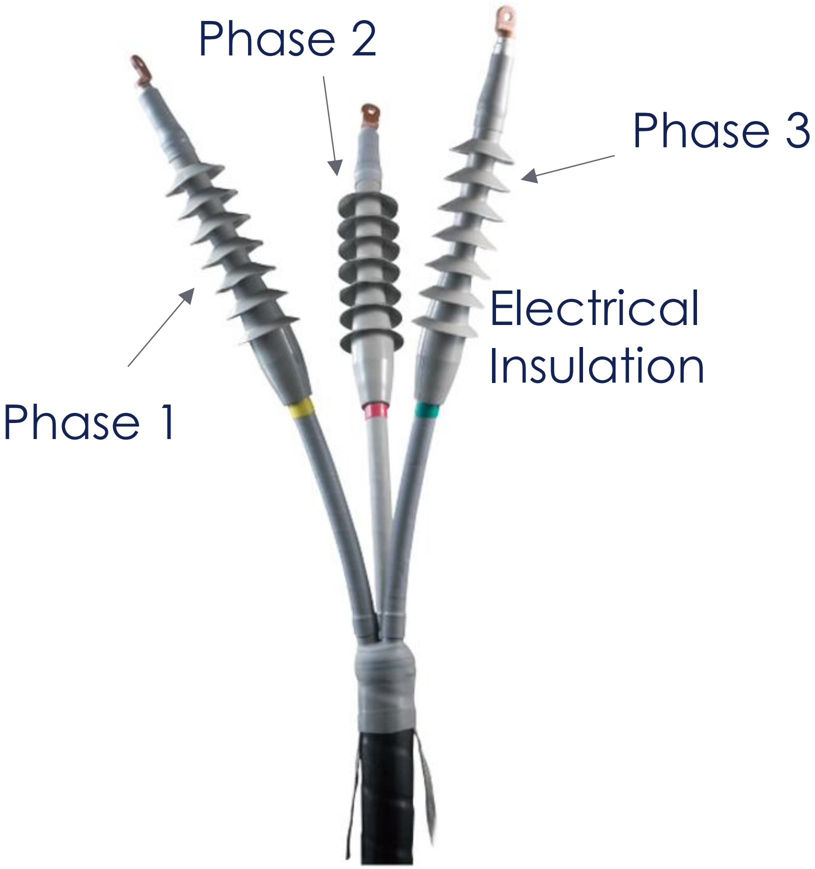
> 1 GVA



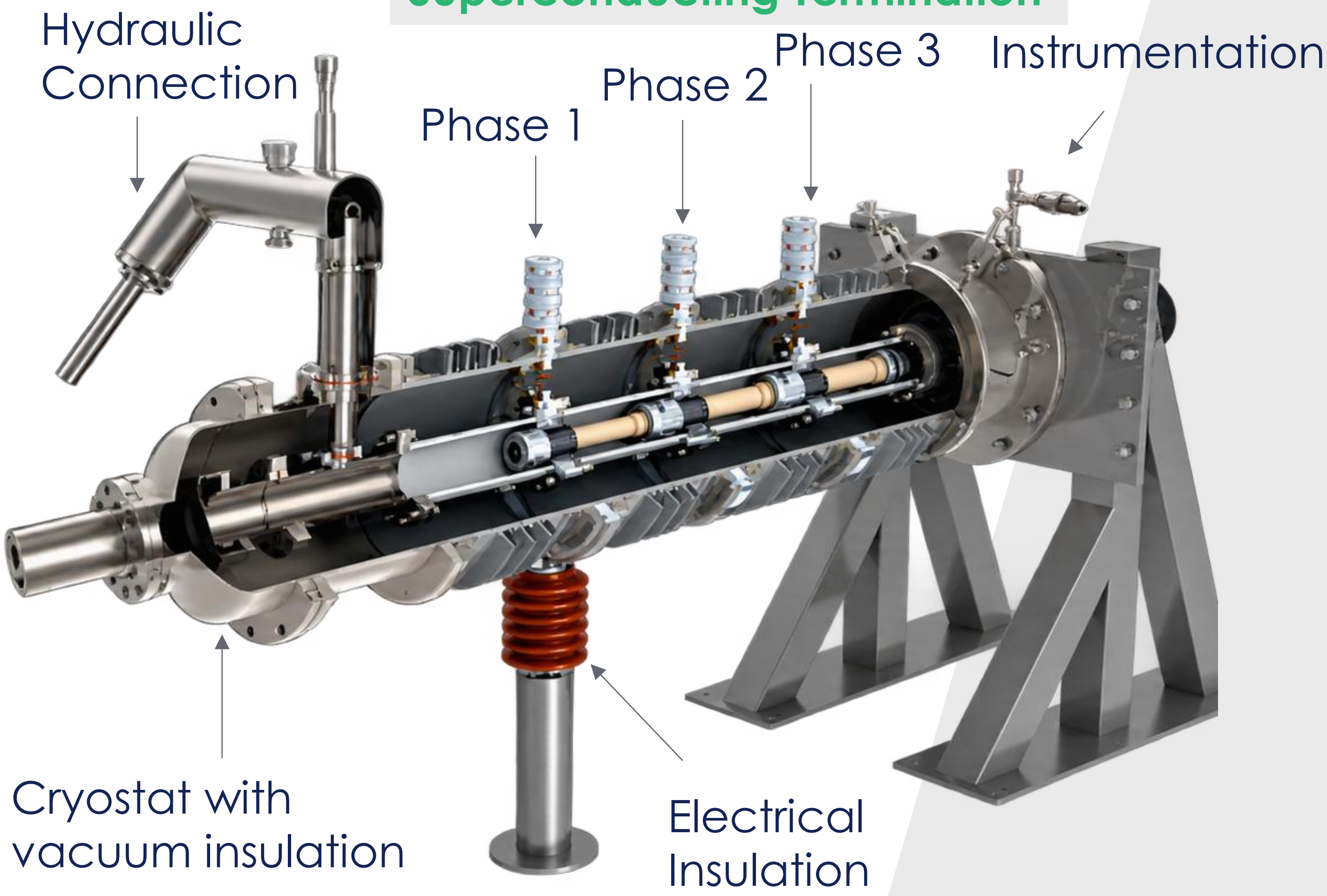
CurrENT
Enabling Network Technology throughout Europe

Termination

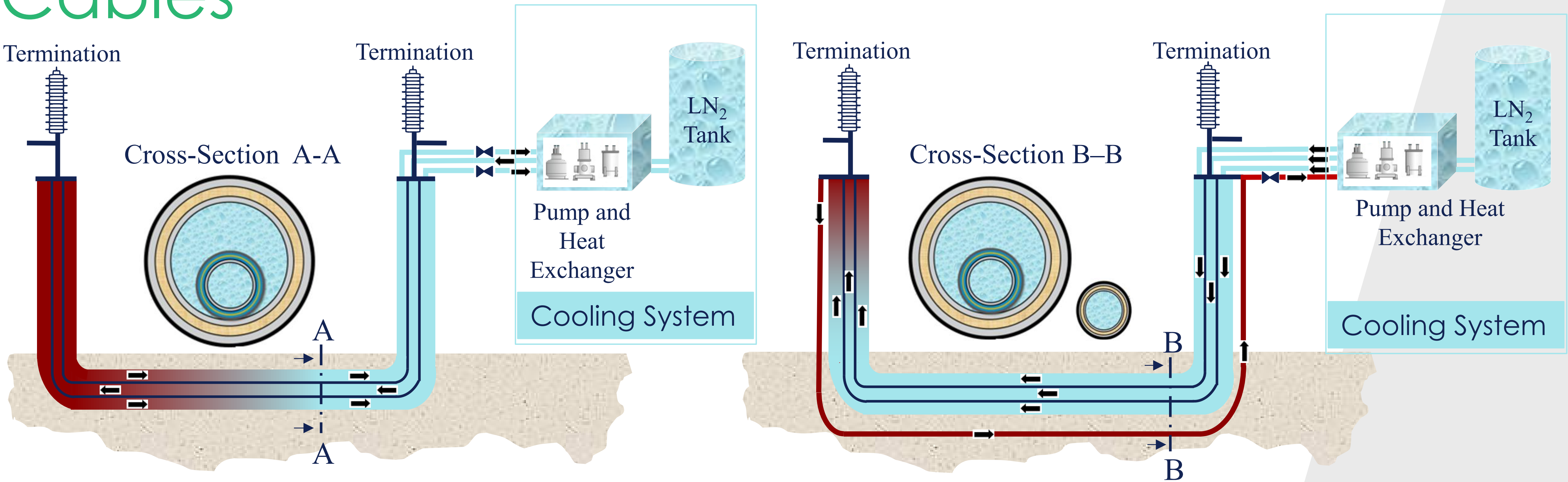
Conventional Termination



Superconducting Termination



Cooling Configuration for Superconducting Cables



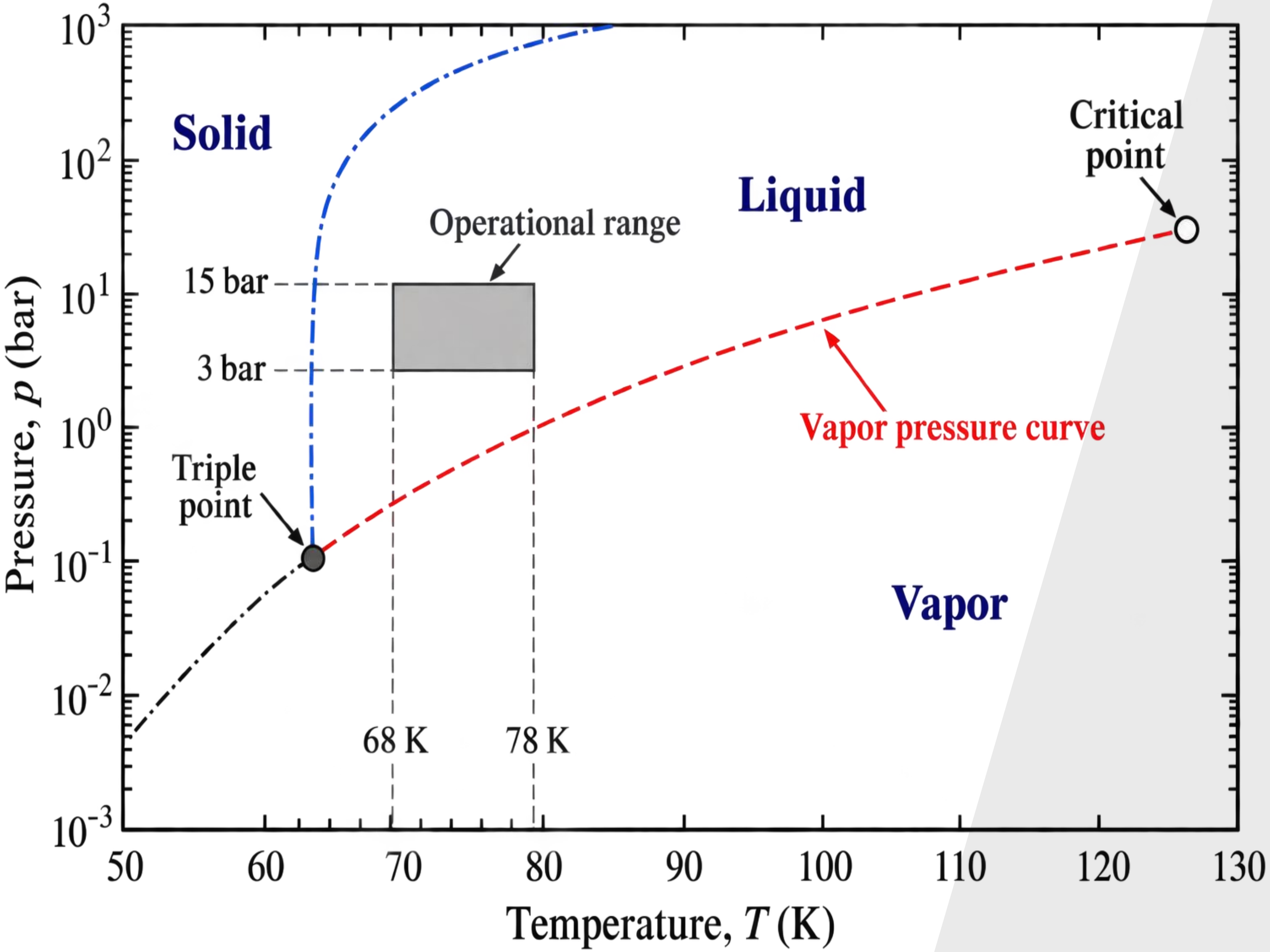
Several cooling configurations can be used. For more information: Gabriel Hajiri *et al* 2022 *Supercond. Sci. Technol.* **35** 024003

The cooling system operates in a closed loop to compensate for temperature and pressure variations within the cable.

What are the operating temperature and pressure?

Cryogenic LN2 Operating Conditions

Operating temperature between 68 K and 78 K, operating pressure between 3 bar and 15 bar, with single-phase liquid operation.



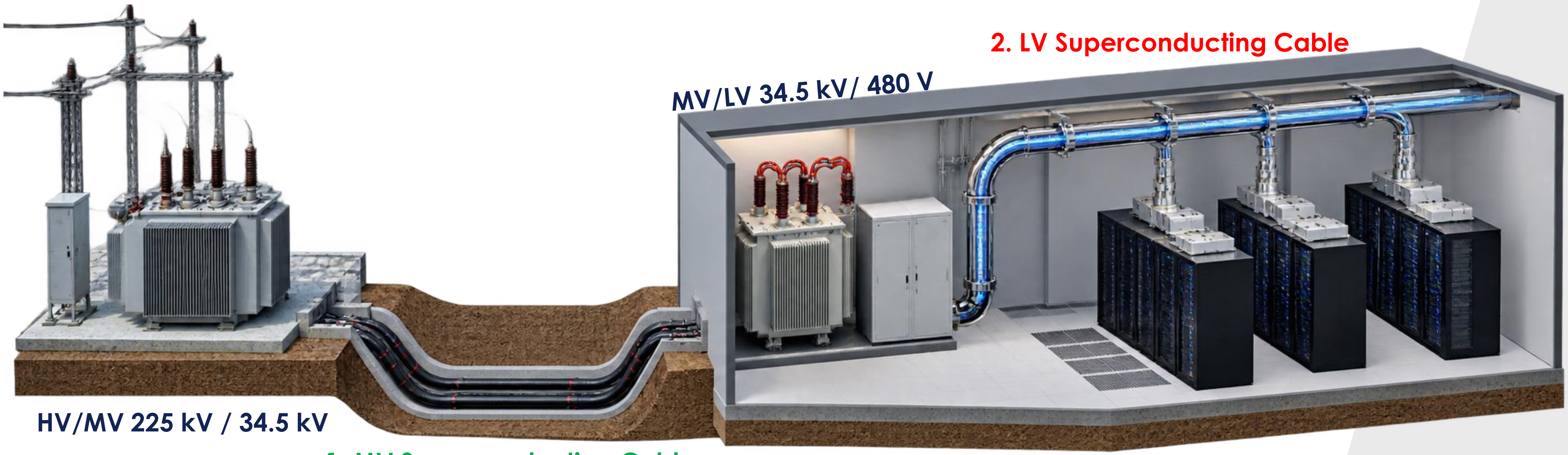
CurrENT
Enabling Network Technology throughout Europe

Data Center Power Context

Case Study

CURRENT
Enabling Network Technology throughout Europe

Typical Data Center Architecture



1. Medium Voltage (MV)

MV superconducting cable to connect the **HV/MV transformer** to the **MV/LV transformer**.

2. Low Voltage (LV)

LV superconducting cable to connect the **LV transformer directly to the racks**.

CURRENT
Enabling Network Technology throughout Europe

Conventional vs. Superconducting: Case Study

OPEX - How do we compare the two solutions?

CURRENT
Enabling Network Technology throughout Europe

Opex comparaison

Conventional cables:
Electrical losses increase with the square of the current due to conductor resistance:

$$P_{JOULE} = R\,I^2$$

P_{Joule} : Joule losses / Pwer losses [W]
R : Electrical resistance [Ω]
I : Current [A]

Superconducting cables:
Electrical resistance is eliminated, but energy is required to maintain cryogenic operation:

$$Q_{Cooling} = \frac{P_{\text{HTS losses}}}{COP}$$

$Q_{Cooling}$: Electrical power consumed by the cooling system [W]
$P_{\text{HTS losses}}$:Thermal losses of the superconducting system [W]
COP : Coefficient of Performance [-]

CURRENT
Enabling Network Technology throughout Europe

The key comparison is therefore: resistive losses vs. cooling power consumption.

Conventional vs. Superconducting: Case Study (MV)

When does the superconducting solution become more advantageous?
What are the key benefits of superconductivity?

CURRENT
Enabling Network Technology throughout Europe

Conventional vs. Superconducting : Case Study

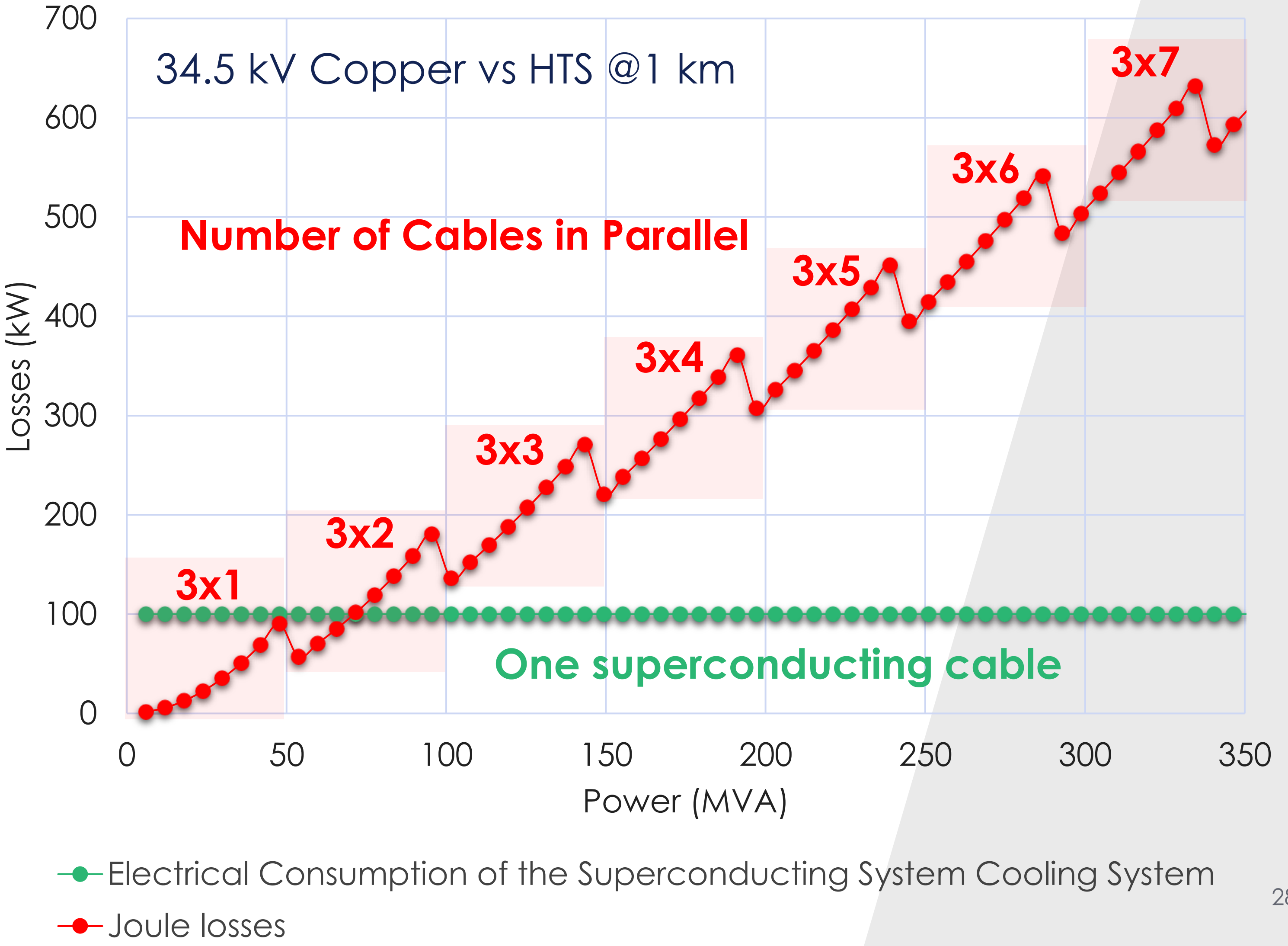
Conventional Copper Cable

Parameter	Value	Unit	Note
Copper Cross-Section	400	mm²	—
Maximum DC Resistance at 20°C	0.047	Ω/km	IEC 60228 – Class 2 Cu conductor

Superconducting Cable

Parameter	Value	Unit	Note
Total Thermal Losses*	10	W/m	Cable thermal losses
COP	0.1	—	Coefficient of Performance

*Worst-case scenario: under actual operating conditions, losses are expected to be approximately 50% lower.



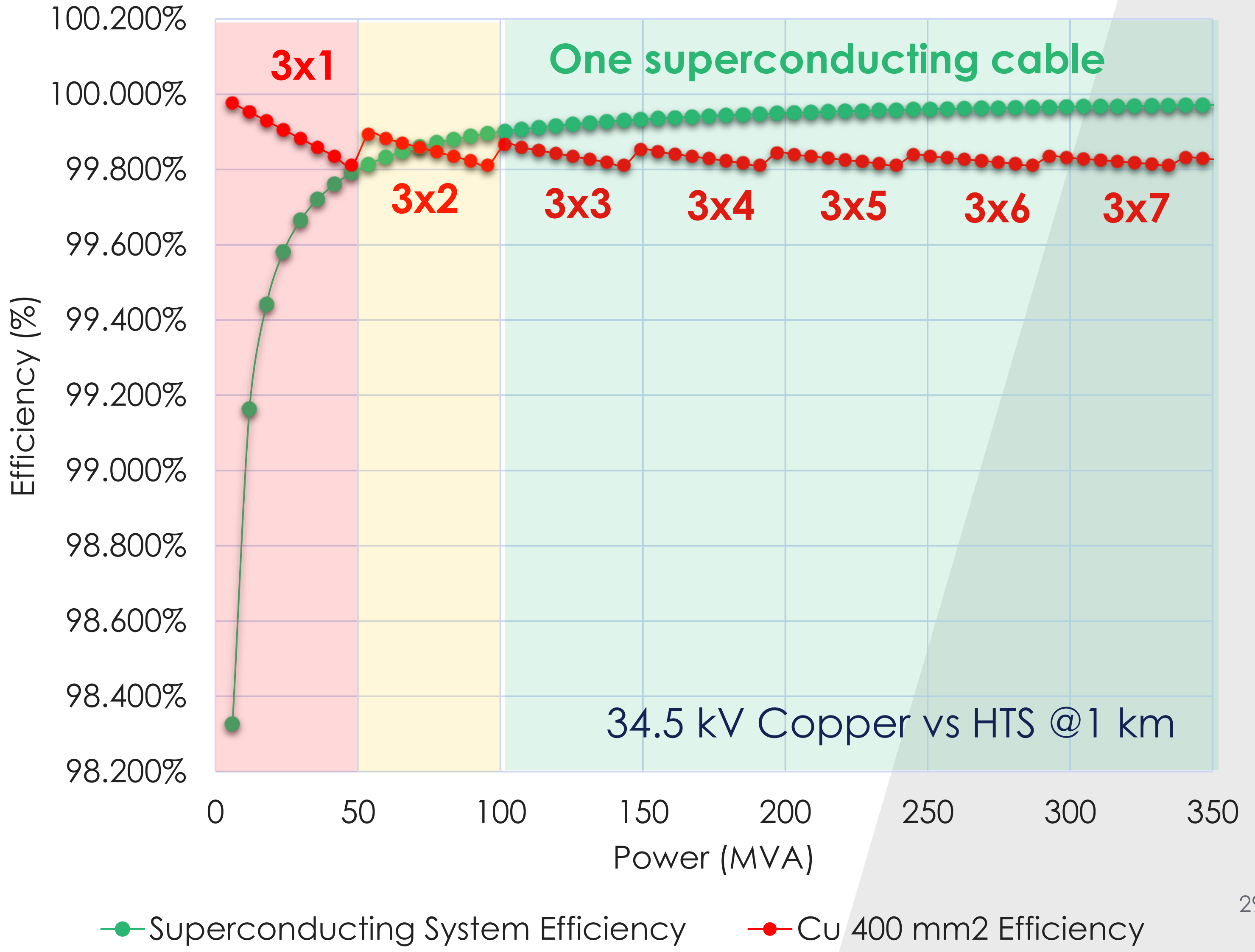
CURRENT Enabling Network Technology throughout Europe

Conventional vs. Superconducting: Energy Efficiency

Conventional Advantage

Comparable / Case-Dependent

Superconducting Advantage

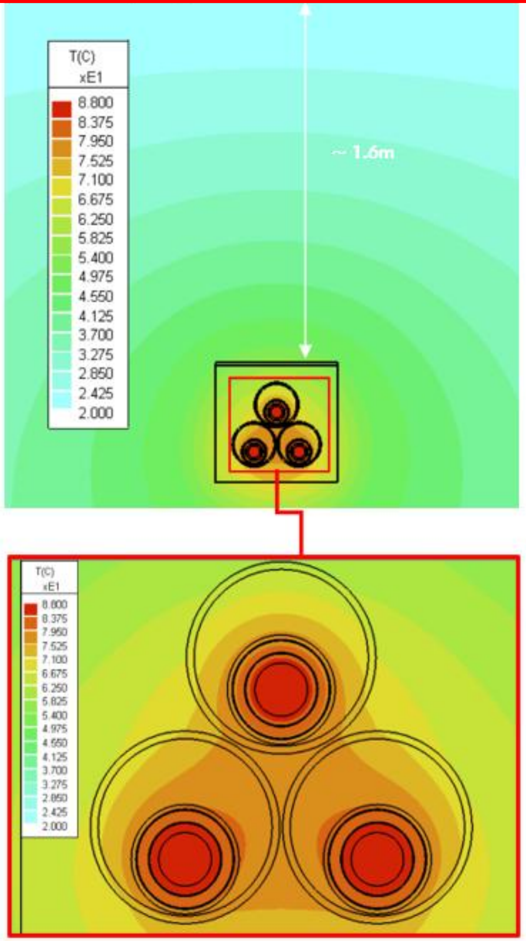


- ❑ **Conventional systems:** Increasing the complexity of the power grid
- ❑ **Superconducting systems:** Improving energy efficiency while simplifying the future power grid

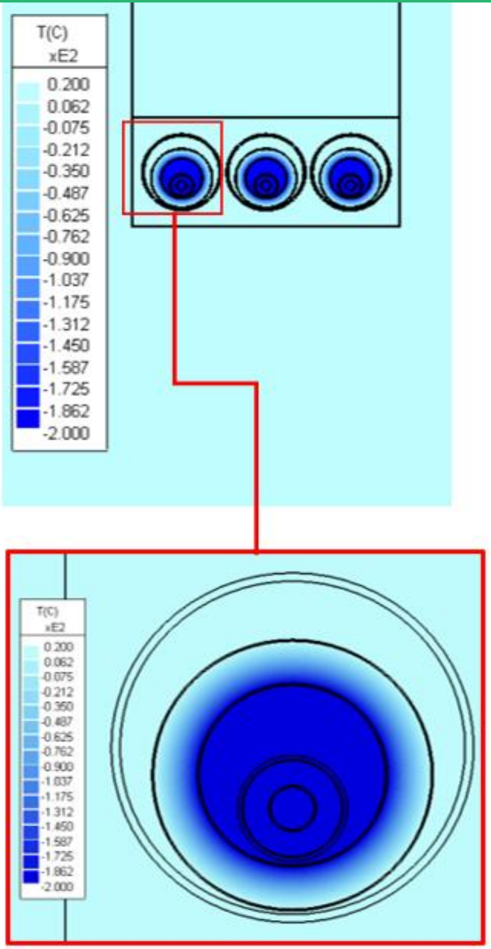
CURRENT
Enabling Network Technology throughout Europe

Conventional vs. Superconducting : Thermal impact

Conventional



Superconducting



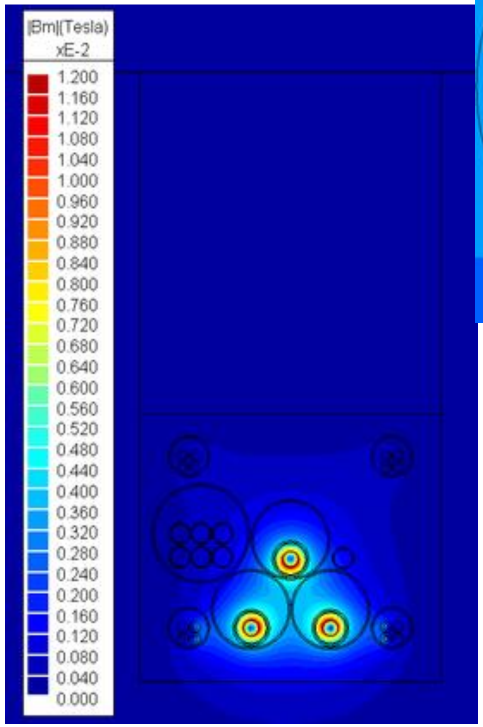
No Thermal Impact on the Surrounding Soil Thanks to the Cryogenic Envelope (Cryostat)

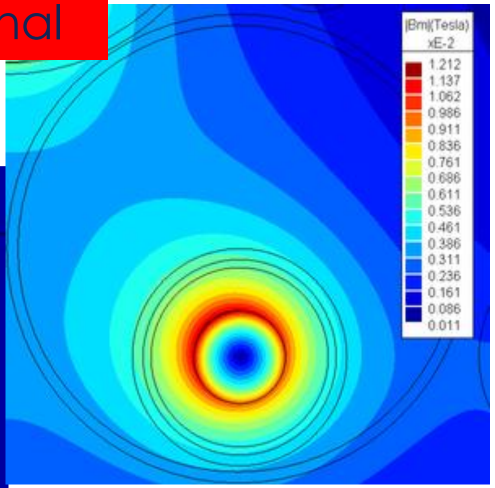
The cryostat is vacuum-insulated and incorporates Multi-Layer Insulation (MLI) to minimize thermal heat transfer.

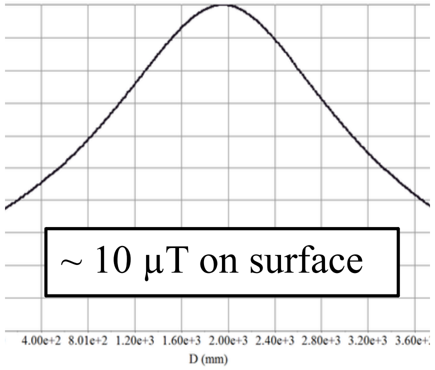
CurrENT
Enabling Network Technology throughout Europe

Conventional vs. Superconducting : Electro Magnetic impact

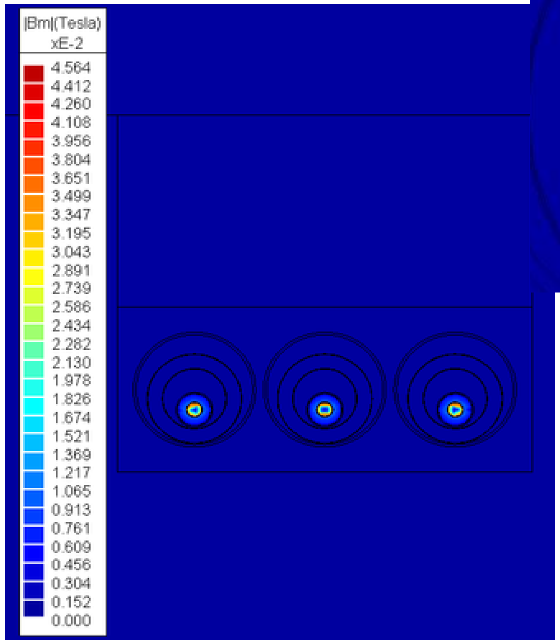
Conventional

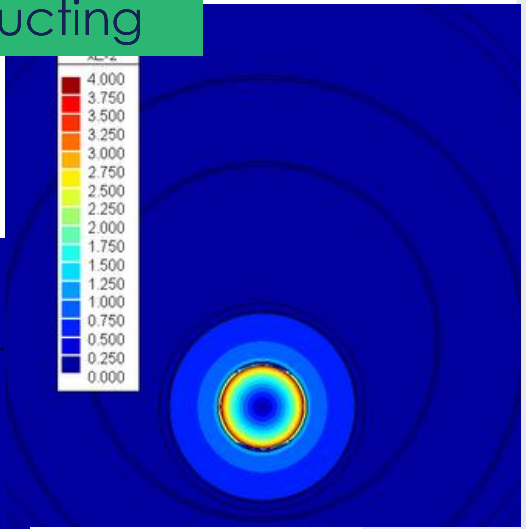


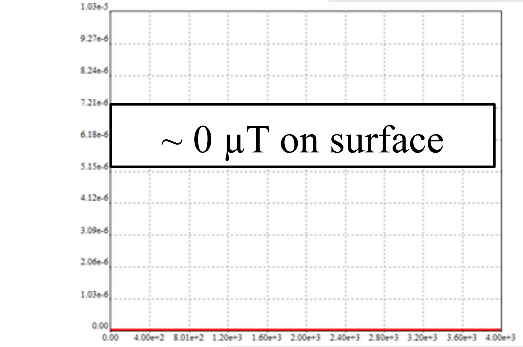




Superconducting





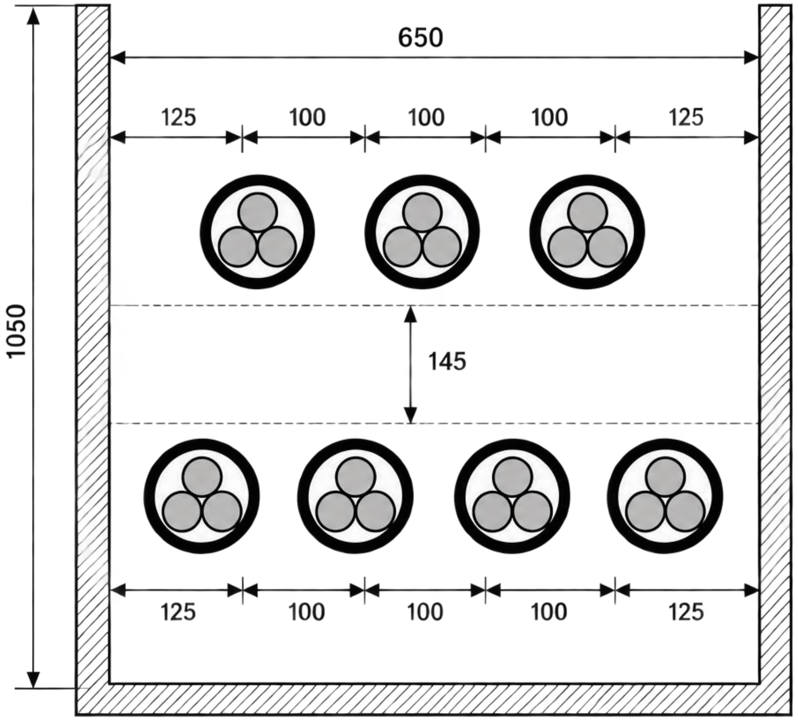


CURRENT
Enabling Network Technology throughout Europe

No Magnetic field impact on soil thanks to superconducting screen (for AC 3 phases system)

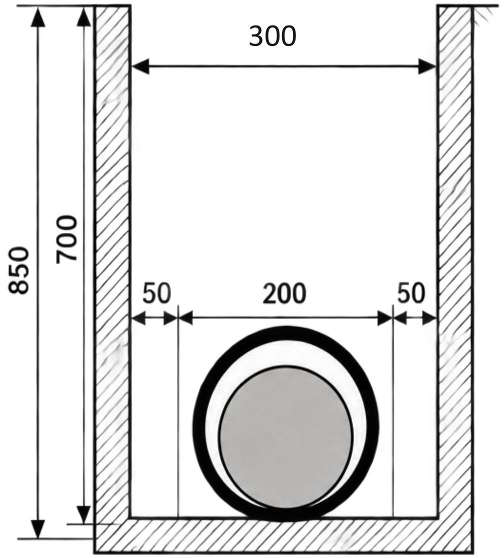
Conventional vs. Superconducting: Civil Works and Delivery

Conventional Conductor



Voltage : 34.5 kV

Superconducting conductor



	Conventional	Superconducting
Excavation Volume per 1 km	682.5 m³	255 m³
Estimated Excavation Time	~22.8 h	~8.5 h
Number of 10 m³ Trucks	~69	~26
Reduction in Earthworks	—	**~63%**
Potential Reduction in Construction Traffic	—	**~63%**

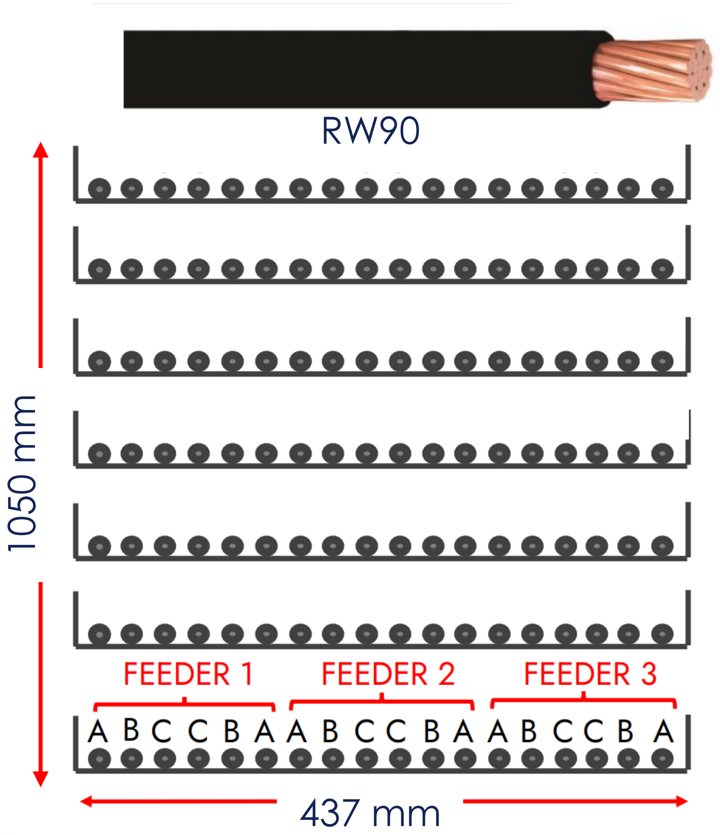
CURRENT
Enabling Network Technology throughout Europe

Conventional vs. Superconducting: Case Study (LV)

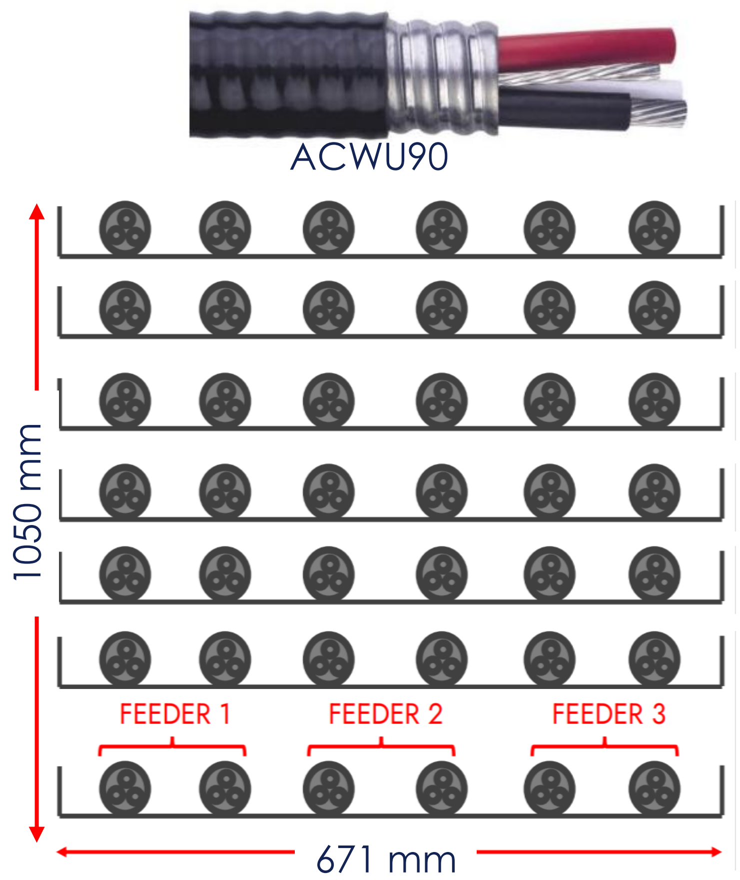
CurrENT
Enabling Network Technology throughout Europe

Comparison of Low-Voltage Solutions for Data Centers

Conventional Solution 1



Conventional Solution 2



Superconducting Solution

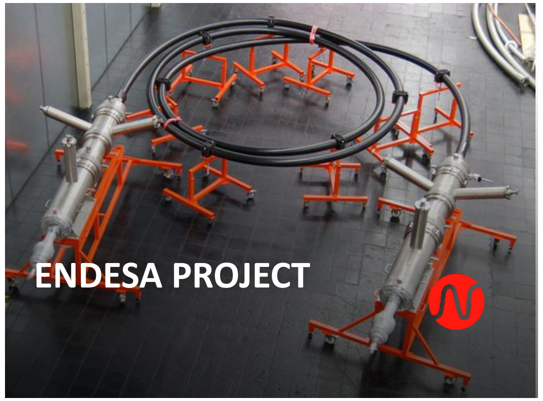
CurrENT
Enabling Network Technology throughout Europe

Low Voltage 3.5 kA AC Cable for Data Centers at 480V & 600V (3MW/3.5MW)

Real-World Superconducting Cable Projects

CURRENT
Enabling Network Technology throughout Europe

Completed Superconducting Projects

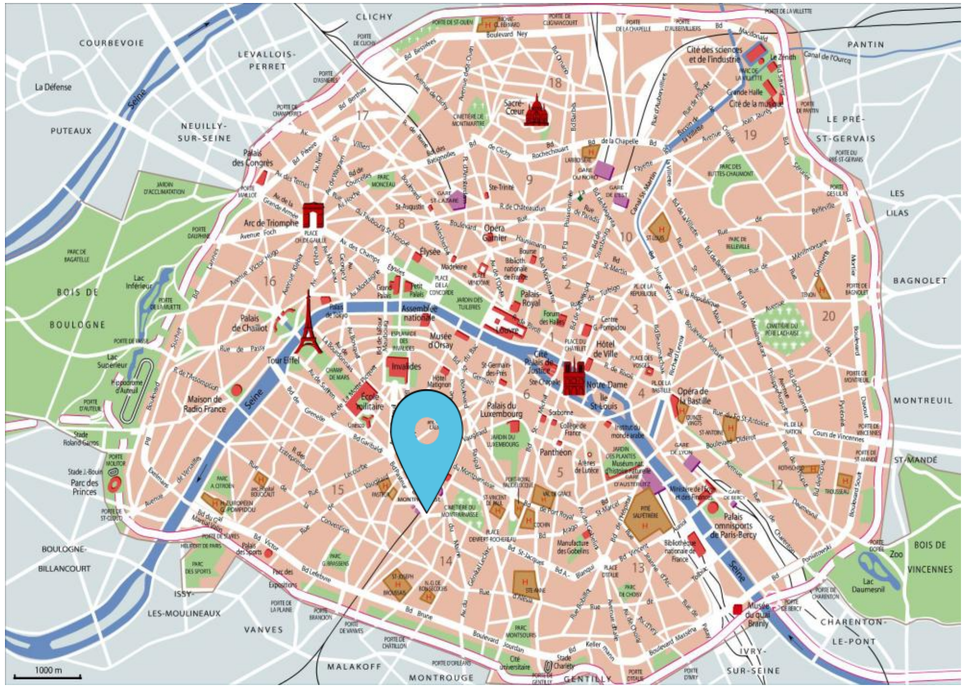


Since 2000, more than **35 AC and DC superconducting cable systems** have been developed worldwide.

CURRENT
Enabling Network Technology throughout Europe

SuperRail Project / Paris, France

SUPERRAIL SNCF PROJECT
Paris,France



Motivation: Increase the transmitted power to 5.3 MW

Reinforcement of Paris Montparnasse train station

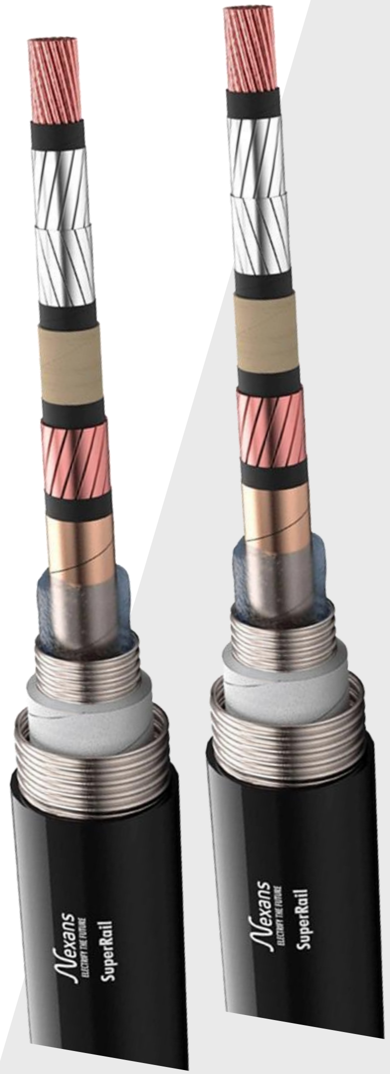
28 tracks, 200 000 passengers/day on 750 trains

50 Millions of passengers in 2020, 90 Millions in 2030

SuperRail Project / Paris, France

Before Using Superconducting Cables

2 Superconducting Cables Replace **12** Conventional Cables



VOLTAGE CAPACITY

1.5 kV DC

CURRENT

3,500 A

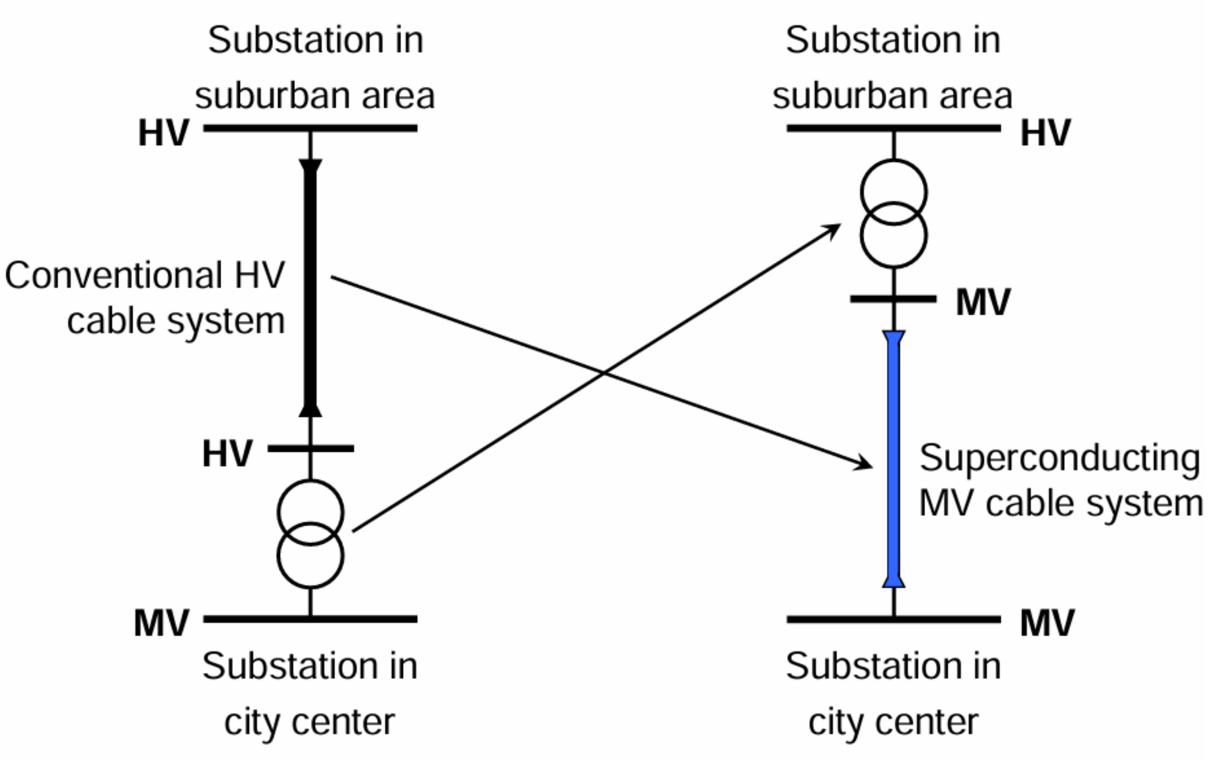
POWER

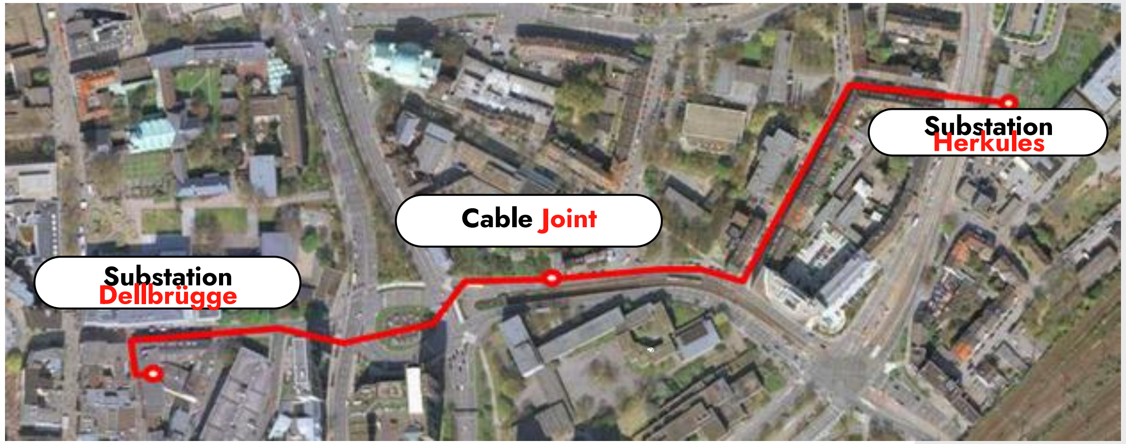
5.3 MW

CURRENT
Enabling Network Technology throughout Europe

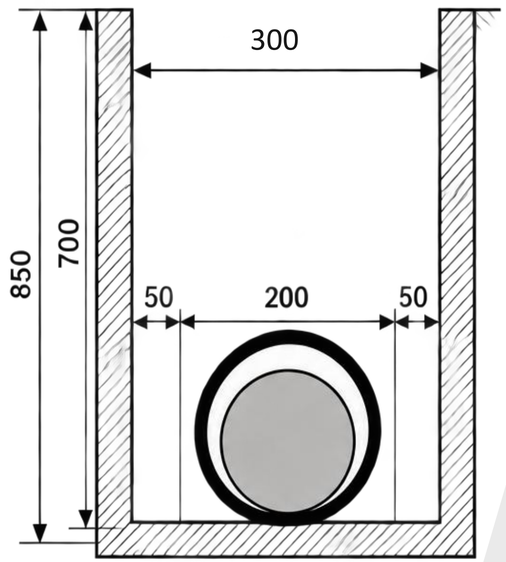
Ampacity Project / Essen, Germany

Motivation:





1 × Single 10 kV superconducting cable



CURRENT
Enabling Network Technology throughout Europe

Ampacity Project / Essen, Germany

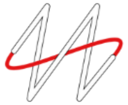
- World's first longest superconducting link (1000 m) installed in 2013 (commissioning March 2014)
- Triphasic cable technology (3 concentric phases in one cable)
- Demonstration of long-distance, including joints

VOLTAGE

10 kV

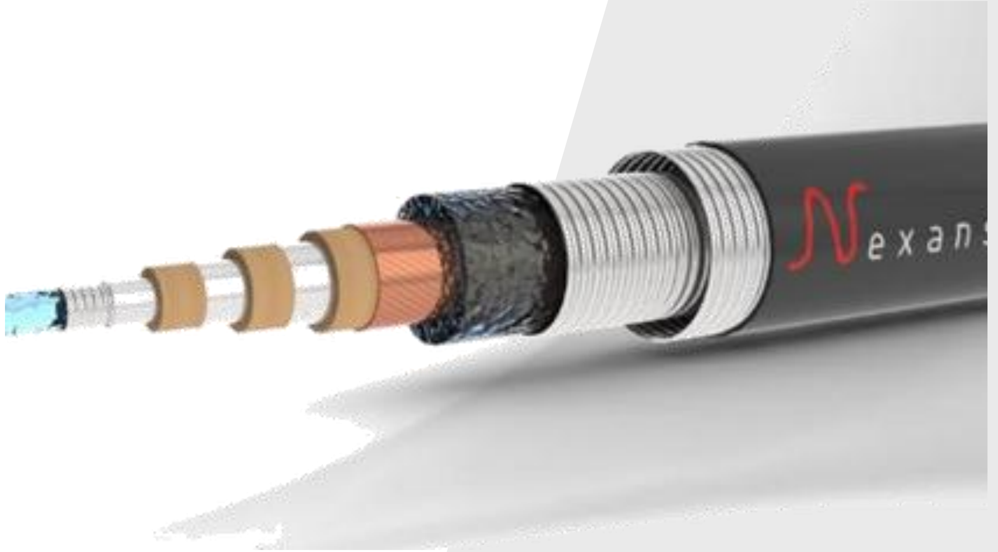
CURRENT

2300A



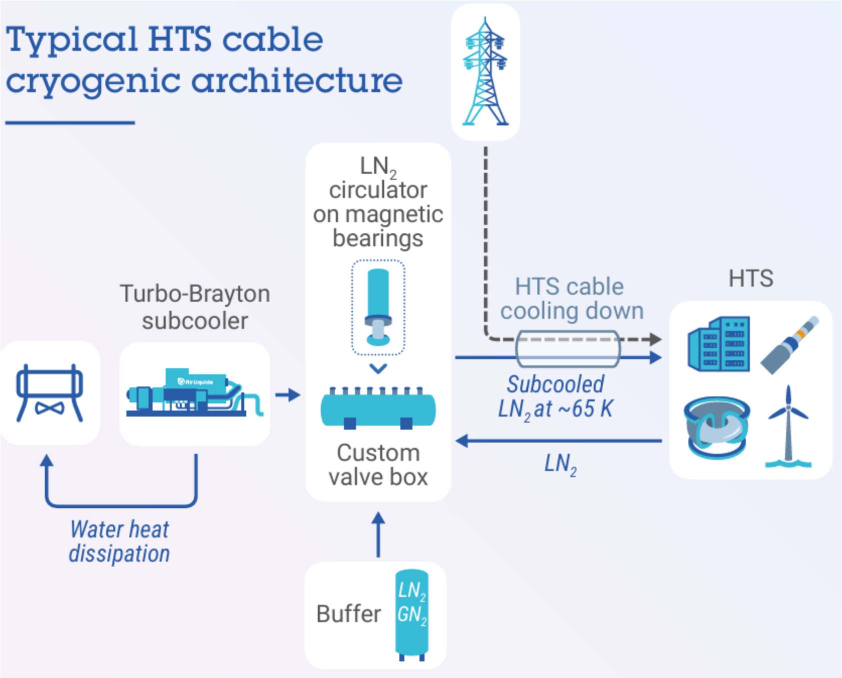
POWER CAPACITY

40 MVA



CURRENT
Enabling Network Technology throughout Europe

Example of a Standard Cooling System for Superconducting Applications



- **5-year maintenance-free interval.**
- **Plug & play solution: compact, skid-mounted design for fast, low-cost installation.**

[Ingénierie & Technologies | Air Liquide]

Key Benefits &Conclusion

What are the key benefits of superconductivity?

Conventional vs. Superconducting – Key Benefits

	Conventional	Superconducting
⚡ Energy Efficiency	⭐⭐	⭐⭐⭐⭐
🌱 CO_2 Footprint	⭐⭐	⭐⭐⭐⭐
📦 Compactness	⭐⭐	⭐⭐⭐⭐⭐
🚀 Power Density	⭐⭐	⭐⭐⭐⭐⭐
🔌 Grid Simplification	⭐⭐	⭐⭐⭐⭐⭐
🏗️ Civil Works	⭐⭐	⭐⭐⭐⭐⭐
🌡️ Soil Heating	⭐⭐	⭐⭐⭐⭐⭐
🧲 External EMF	⭐⭐	⭐⭐⭐⭐⭐
🚚 Installation	⭐⭐⭐	⭐⭐⭐⭐
⏱️ Delivery Time	⭐⭐⭐	⭐⭐⭐⭐
📈 Power Upgrade	⭐⭐	⭐⭐⭐⭐⭐
🏭 Technology Maturity	⭐⭐⭐⭐⭐	⭐⭐⭐

Conclusion

Copper has the **experience**; superconductors have the **potential** — one knows the road, the other is **ready** to shift gears.

CURRENT
Enabling Network Technology throughout Europe

Q&A

Thank you for your attention.