Superconducting power cables: today and tomorrow

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ESAS'2023 School - Col de Porte, France

Superconducting power cables: today and tomorrow

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Content

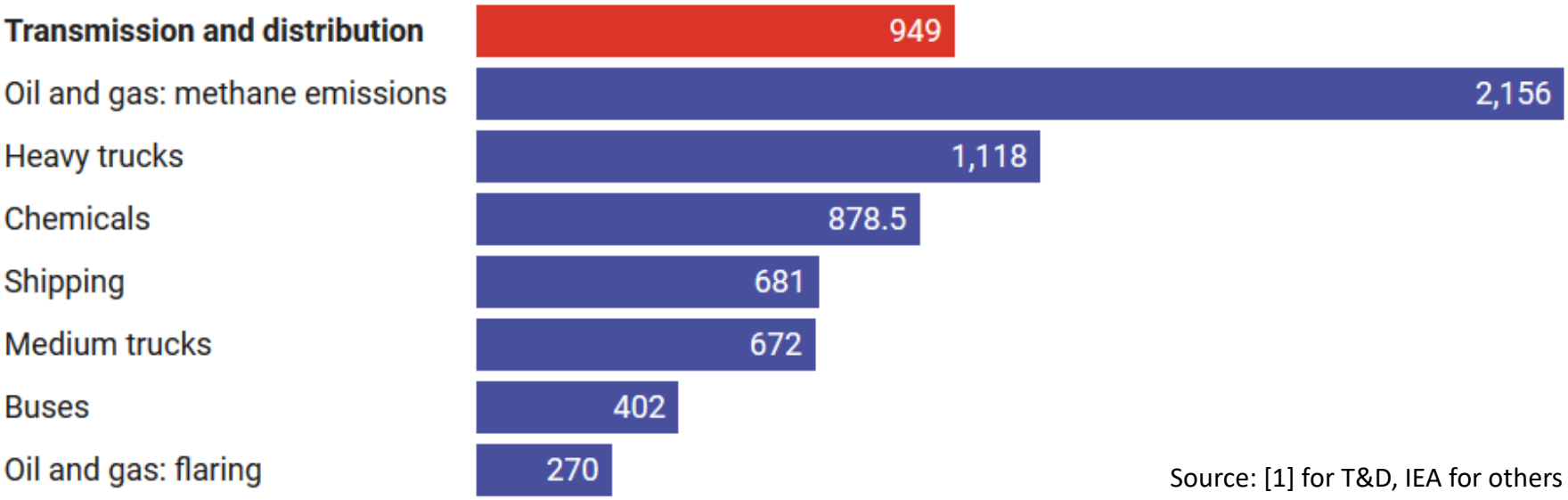
I. (Superconducting) power cables

II. Today

III. Tomorrow

World annual emissions from some industries

Measured in millions of tons of CO2 equivalents.

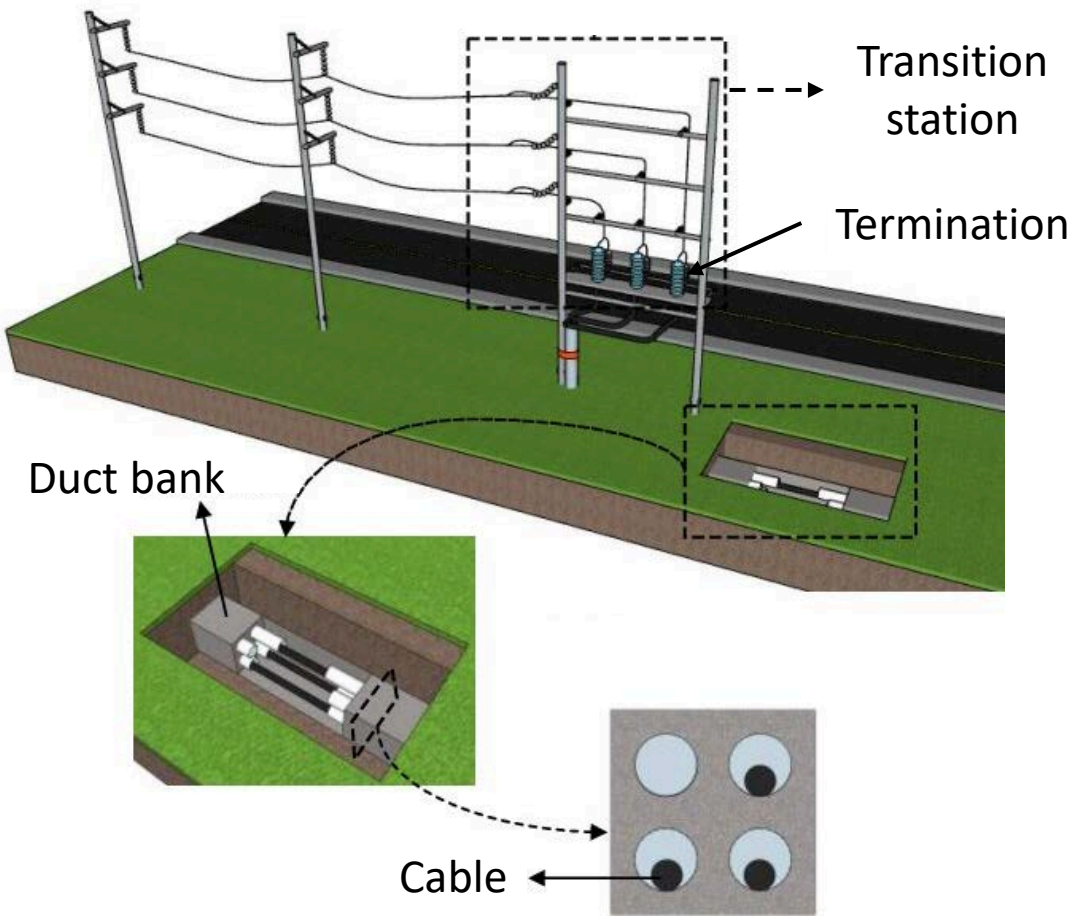


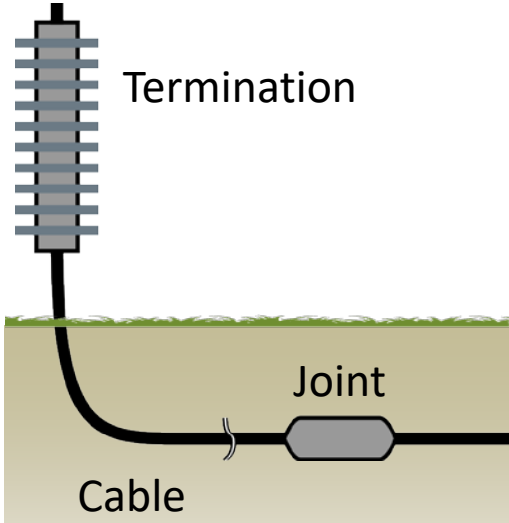
Source: [1] for T&D, IEA for others

[1] K. Surana, S.M. Jordaan, "The climate mitigation opportunity behind global power transmission and distribution," Nature Climate Change, vol. 9, pp. 660–665, 2019. Chart: The Conversation, CC-BY-ND.

I. (Superconducting) power cable

HVAC resisitive power cable system



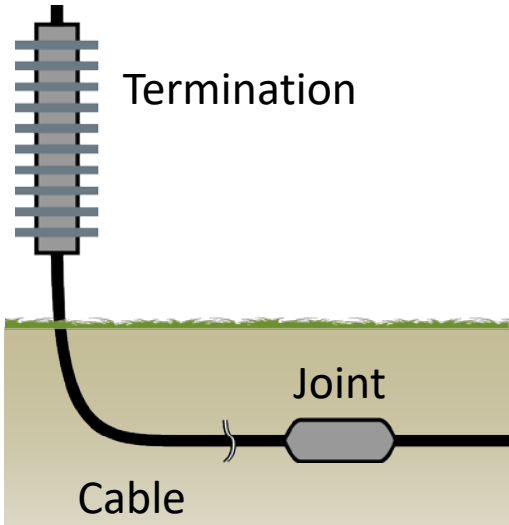


Adapted from [1] J. Klomjit, A. Ngaopitakkul, "Comparison of artificial intelligence methods for fault classification of the 115-kV hybrid transmission system" *Applied Sciences*, vol. 10, no. 11, pp. 3967, 2020.

HVAC resisitive power cable system

220 kV (L-N RMS) single core copper conductor, XLPE insulated, copper wire screen and HDPE

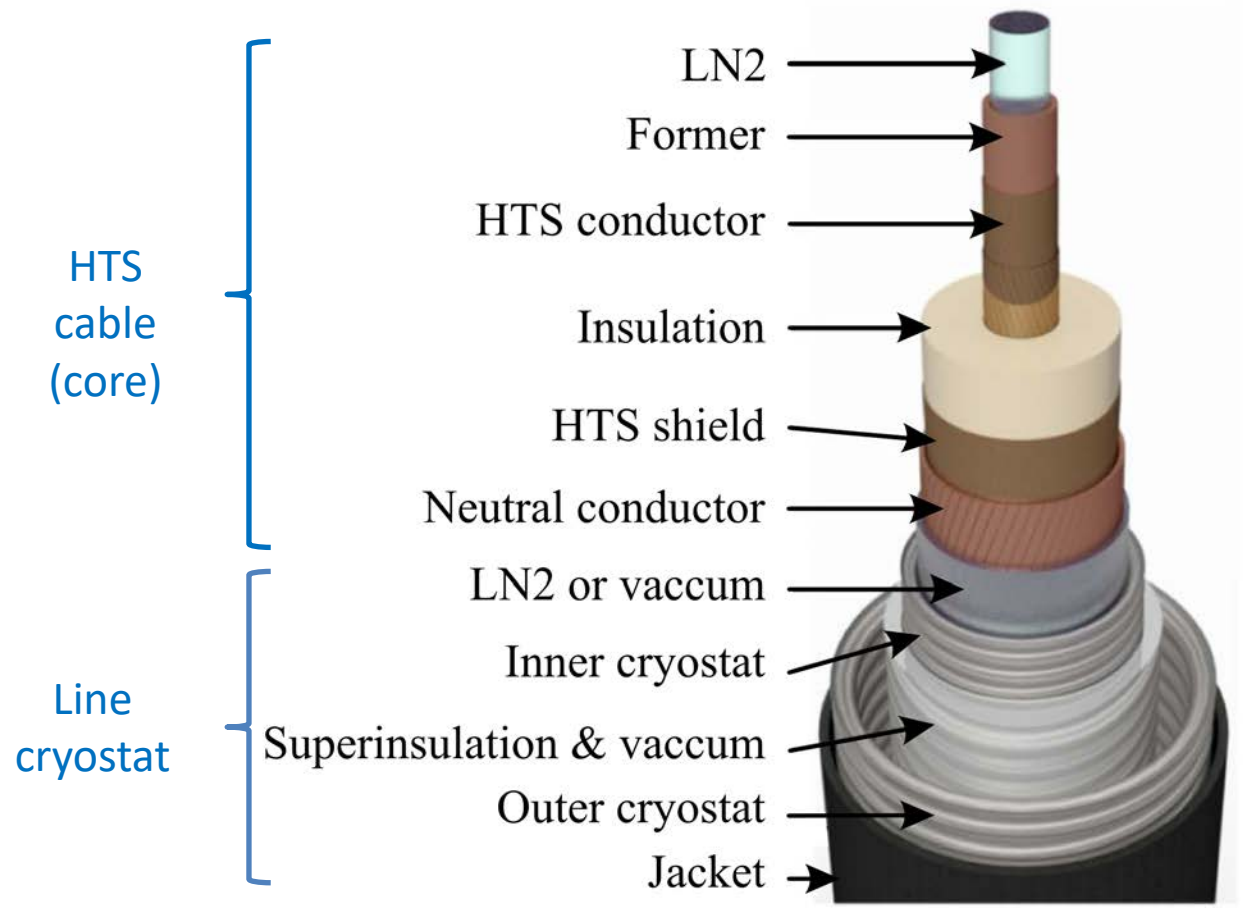
Conductor
Conductor binder
Conductor screen
Insulation
Insulation screen
Water blocking layer
Metallic screen
Longitudinal water blocking layer
Radial water blocking layer
Jacket

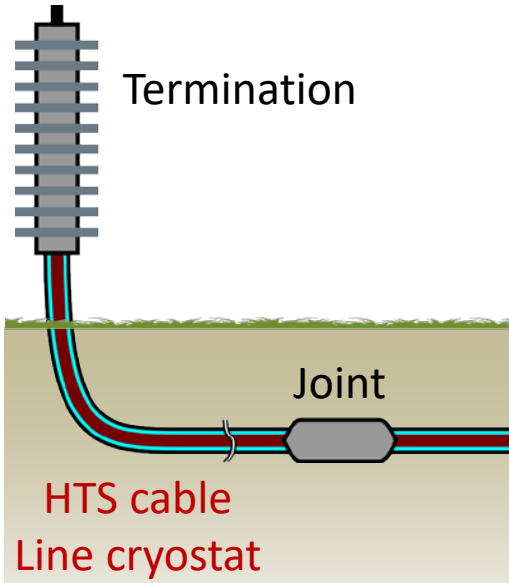


[1] HVAC single core copper conductor, XLPE insulated, copper wire screen and HDPE sheath cable, (Elsewedy Electric, Egypt, Cat. # CX8-TX01-K85)

HVAC HTS power cable system

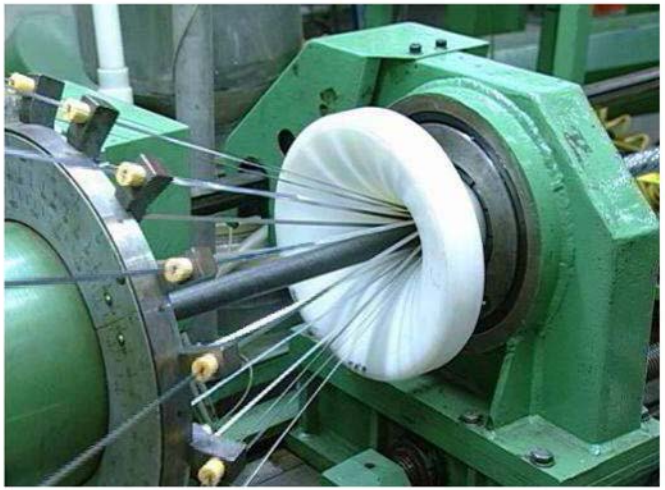
HVAC HTS cable: single core corrugated tube former cold dielectric LN2 cooled

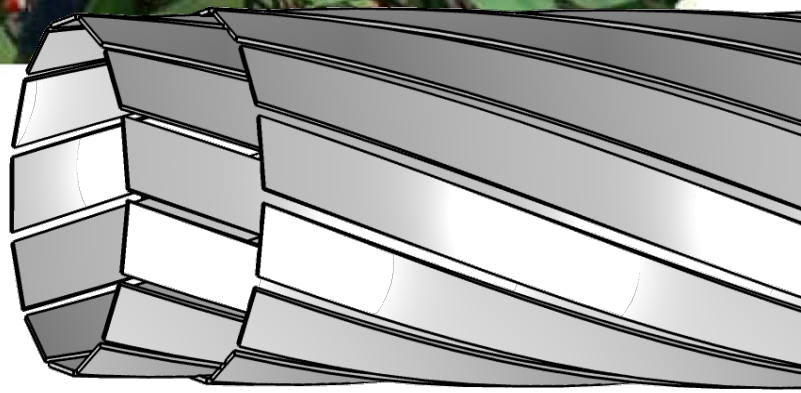




Adapted from [1] M. Noe, "EUCAS short course on power applications: superconducting cables", 13th European Conference on Applied Superconductivity (EUCAS2017), Geneva, Switzerland, Sep. 2017.

HVAC HTS power cable system

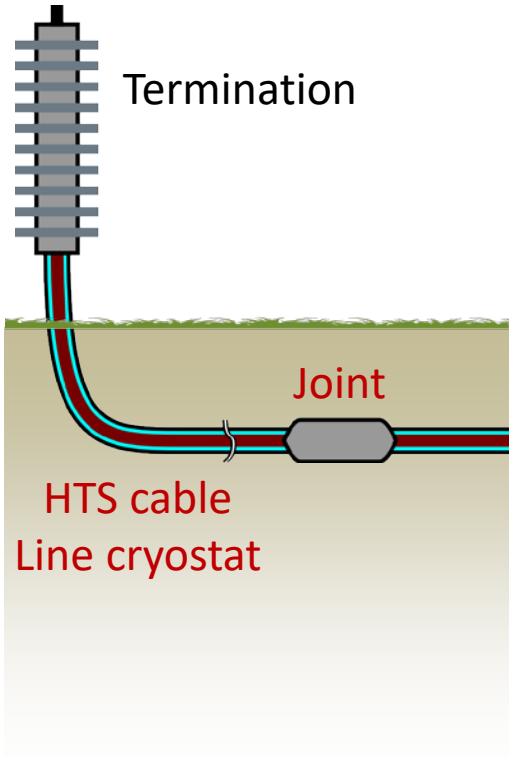


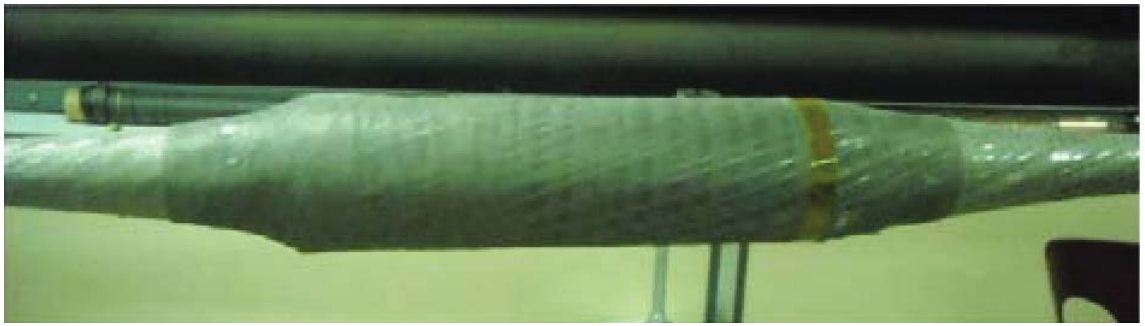


[1] F. Merschel, "AmpaCity, Energieverteilung von Morgen mit Hochtemperatur-Supraleiterkabeln und Strombegrenzern für Zentren mit hoher Lastdichte," VDE / IHK Forum Technische Innovationen, Köln, Germany, Sept. 2015.

HVAC HTS power cable system

Joint

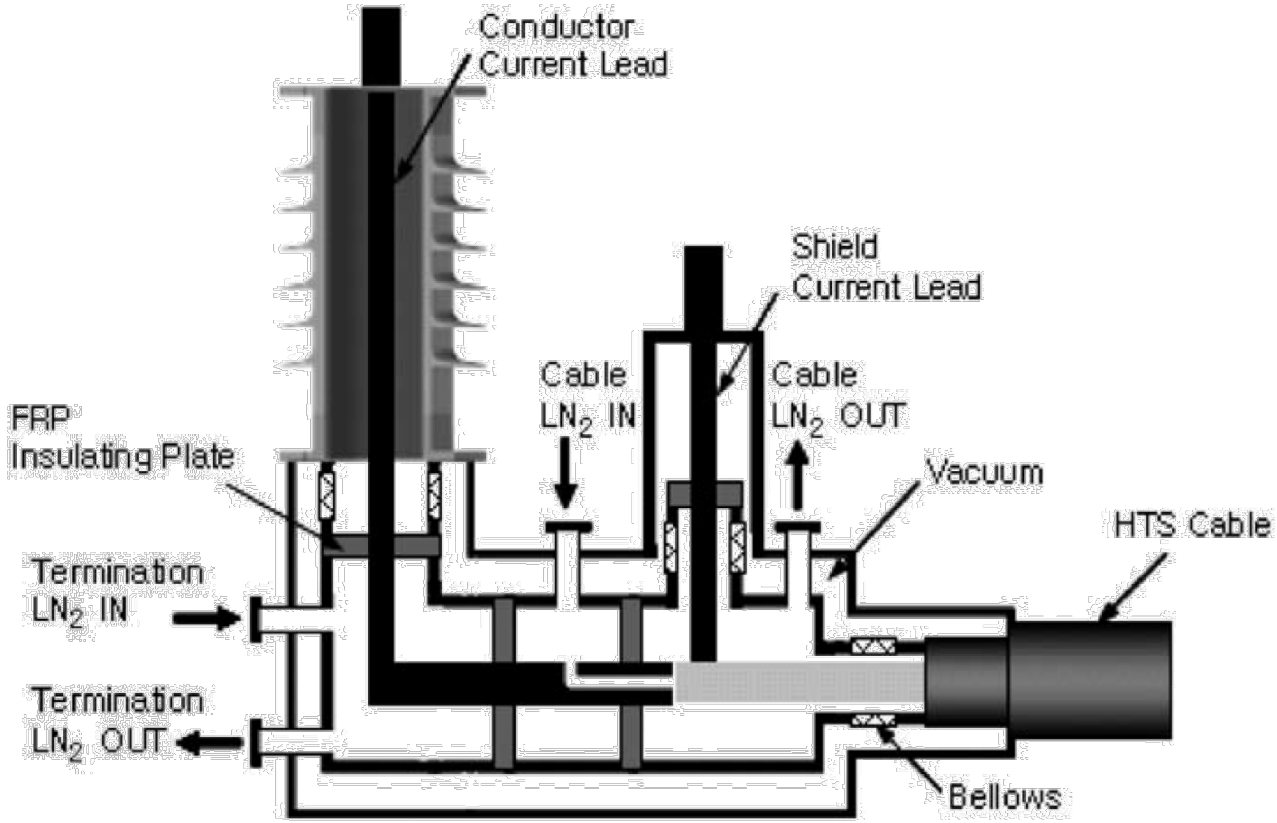


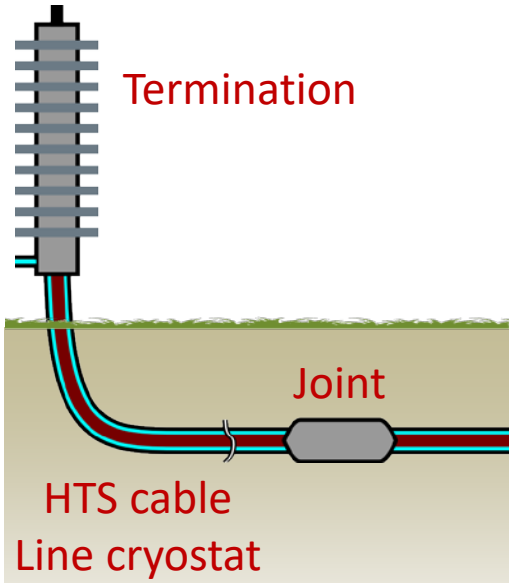


[]1 F. Schmidt, J. Maguire, T. Welsh, S. Bratt, "Operation experience and further development of a high-temperature superconducting power cable in the Long Island Power Authority grid," Physics Procedia, vol. 36, pp. 1137-1144, 2012.

HVAC HTS power cable system

Termination

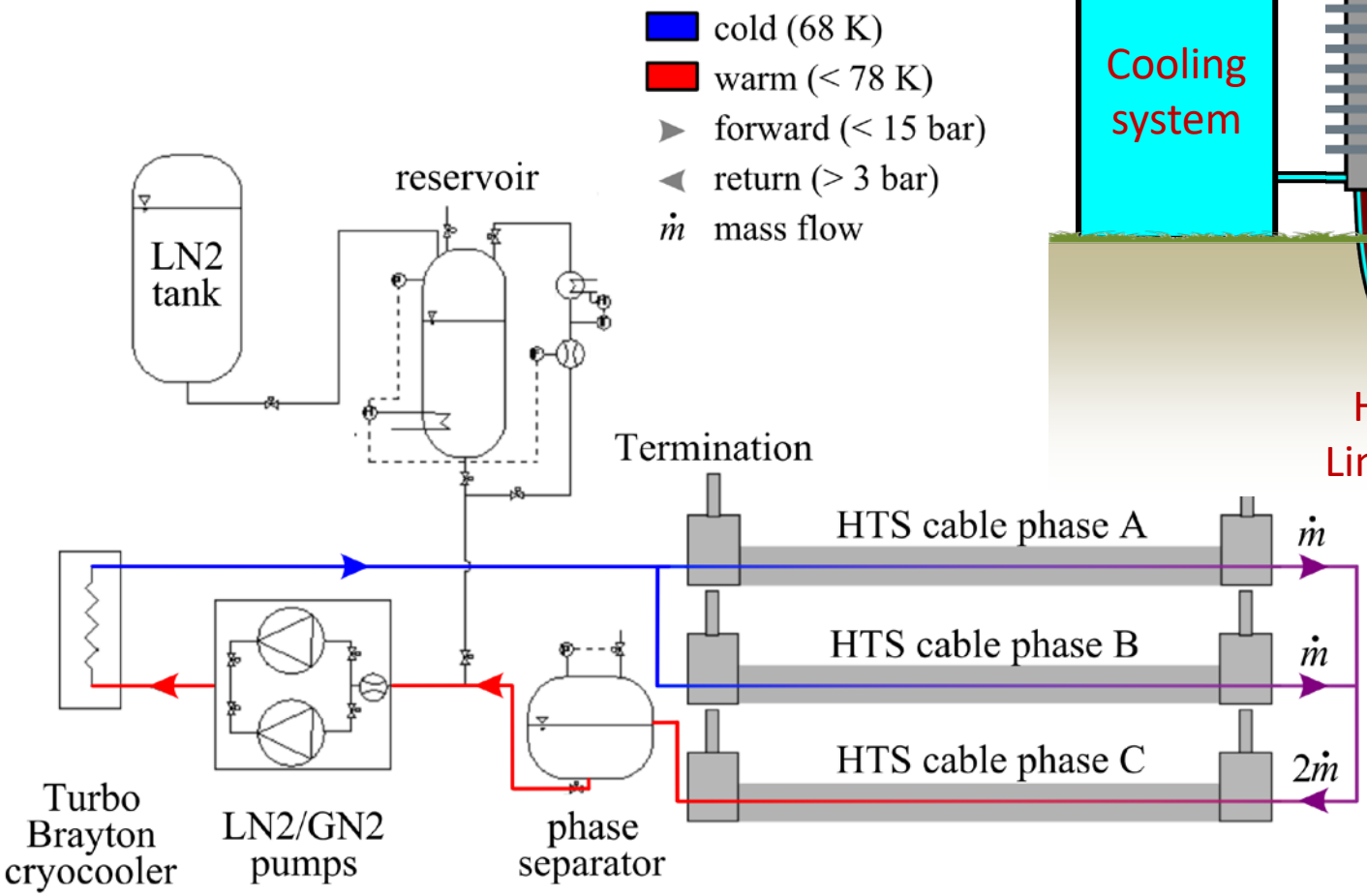


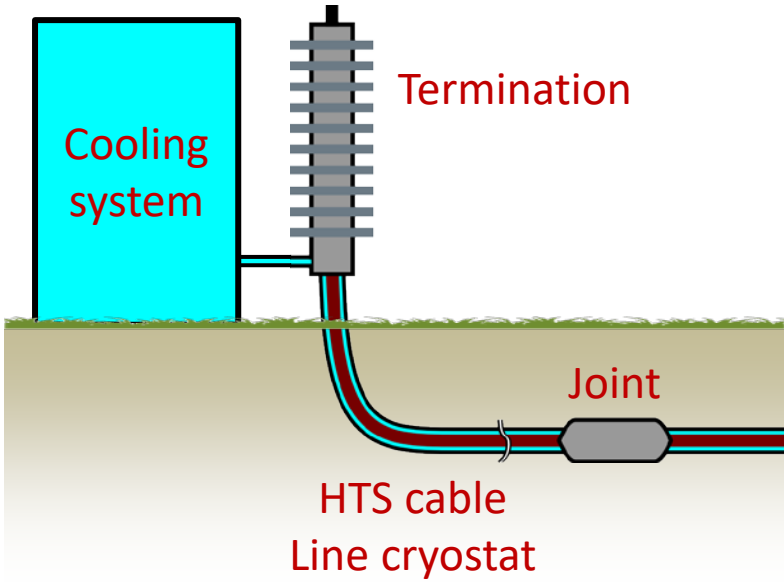


[1] J. Cho, J.-H. Bae, H.-J. Kim, K.-D. Sim, S. Kim, H.-M. Jang, C.-Y. Lee, D.-W. Kim, ”Development of a single-phase 30m HTS power cable,” Cryogenics, vol. 46, no. 5, pp. 333-337, 2006.

HVAC HTS power cable system

One-sided closed cooling system

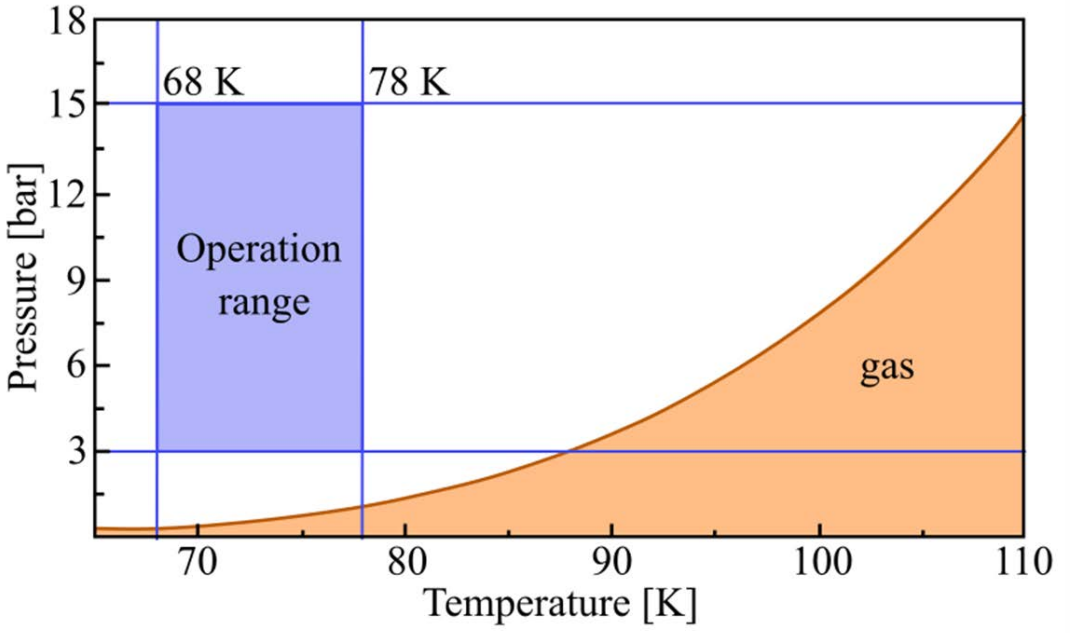


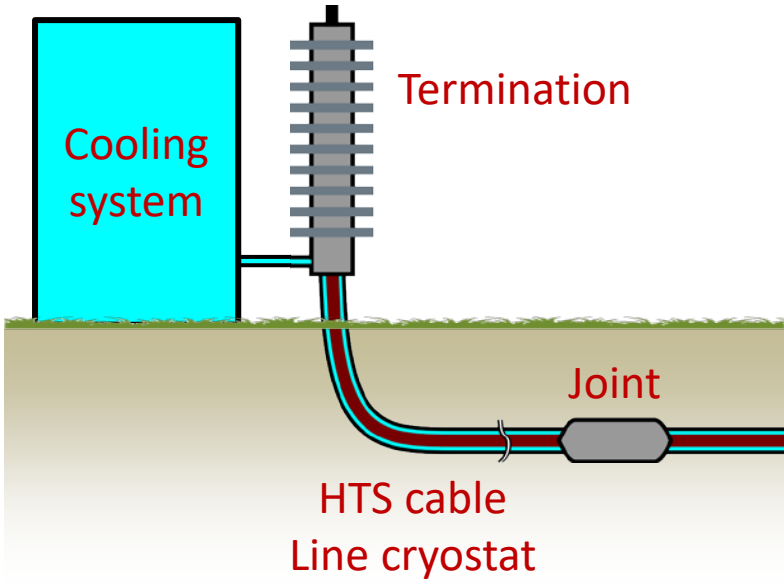


Adapted from [1] D. Kottonau et al., Bewertung des einsatzes supraleitender 380-kV-Kabel, vol. 26. KIT Scientific Publishing, 2019.

HVAC HTS power cable system

Operation range of a LN2-cooled HTS cable

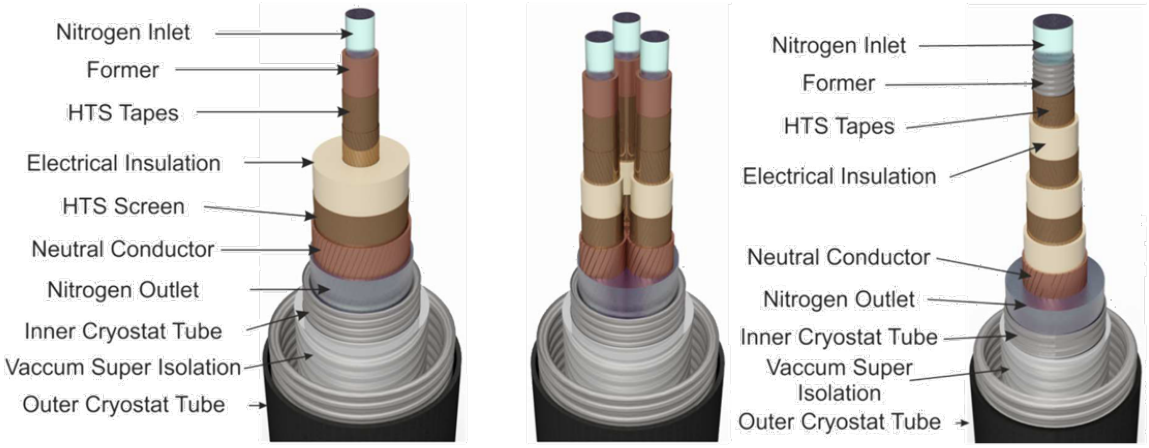




[1] C. Martin-Sanz Garrido, "Efforts towards the standardization of superconducting cables," Trabajo fin de grado, Comillas Pontifical University, ICAI, Spain, 2021.

Other options…

Cable Types

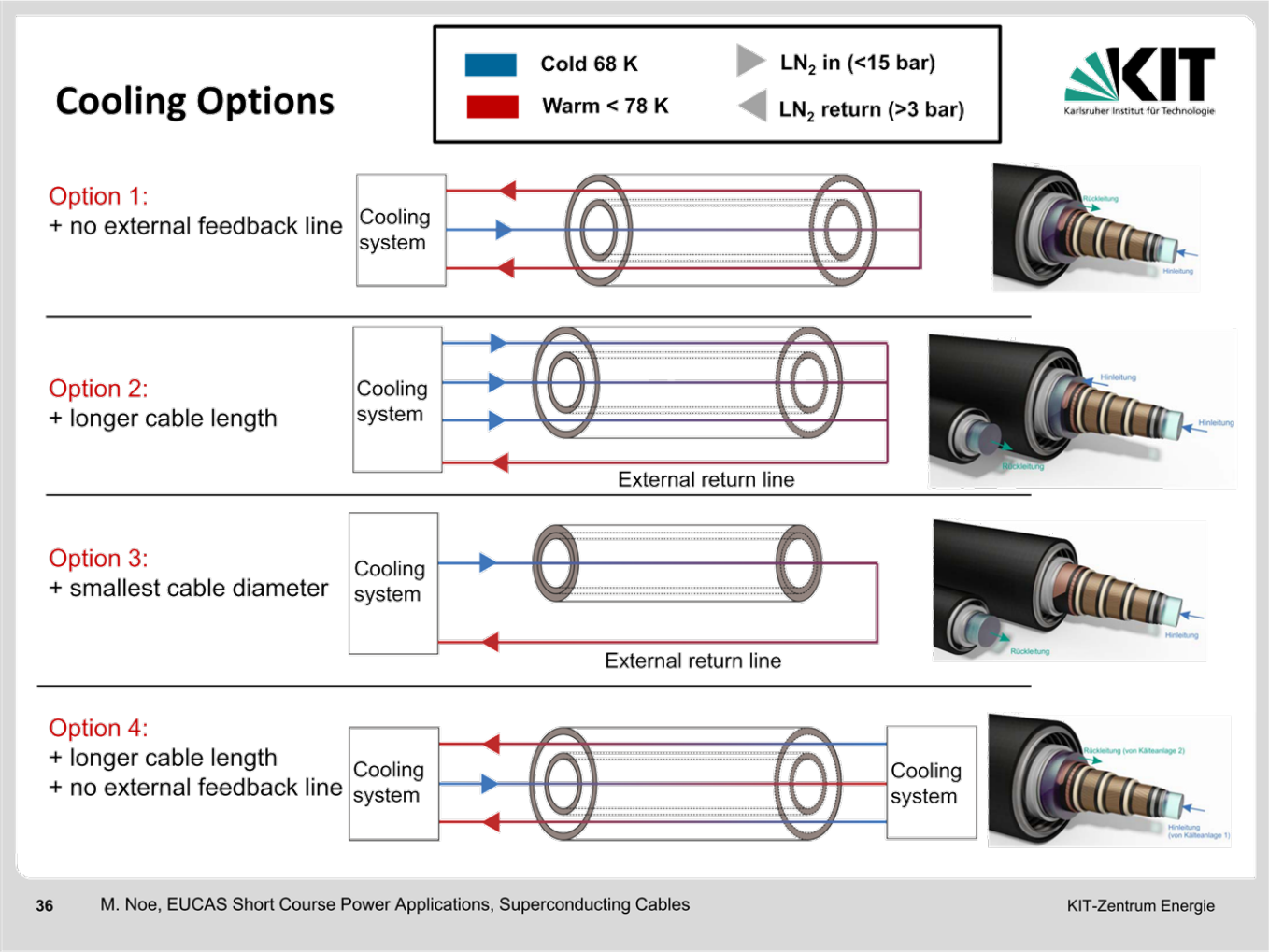


	Three single phases	Three phase in one cryostat	Three phase concentric
Voltage level	High voltage > 110 kV	30-110 kV	10-50 kV
Amount of superconductor	higher	higher	smaller
Cryostat loss	higher	smaller	smaller

32 M. Noe, EUCAS Short Course Power Applications, Superconducting Cables KIT-Zentrum Energie

[1] M. Noe, "Superconducting Cables," EUCAS Short Course Power Applications, Geneva, Switzerland, Sept. 2017.

Other options…

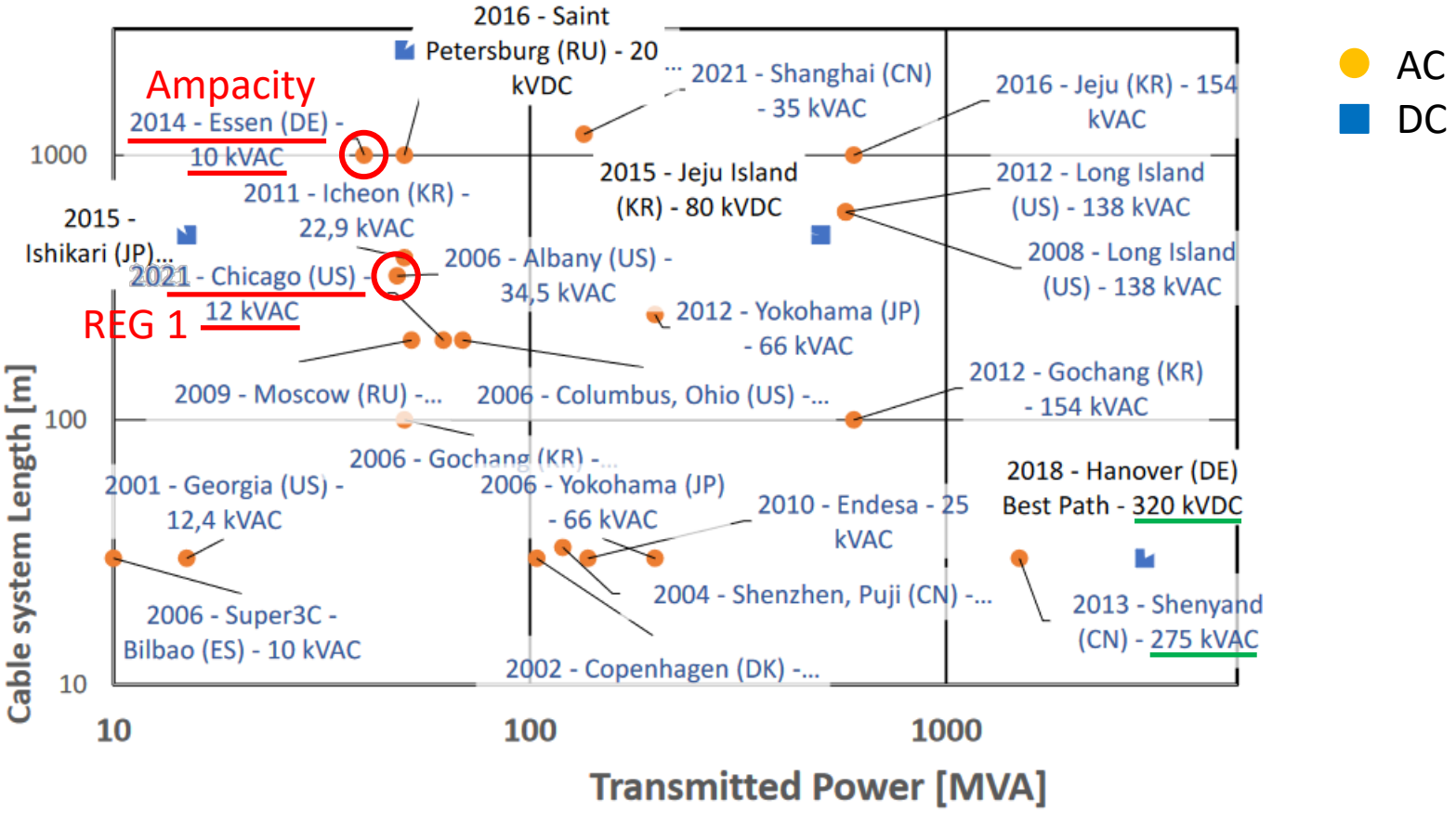


[1] M. Noe, "Superconducting Cables," EUCAS Short Course Power Applications, Geneva, Switzerland, Sept. 2017.

II. Today

State of the art

2001 - 2021



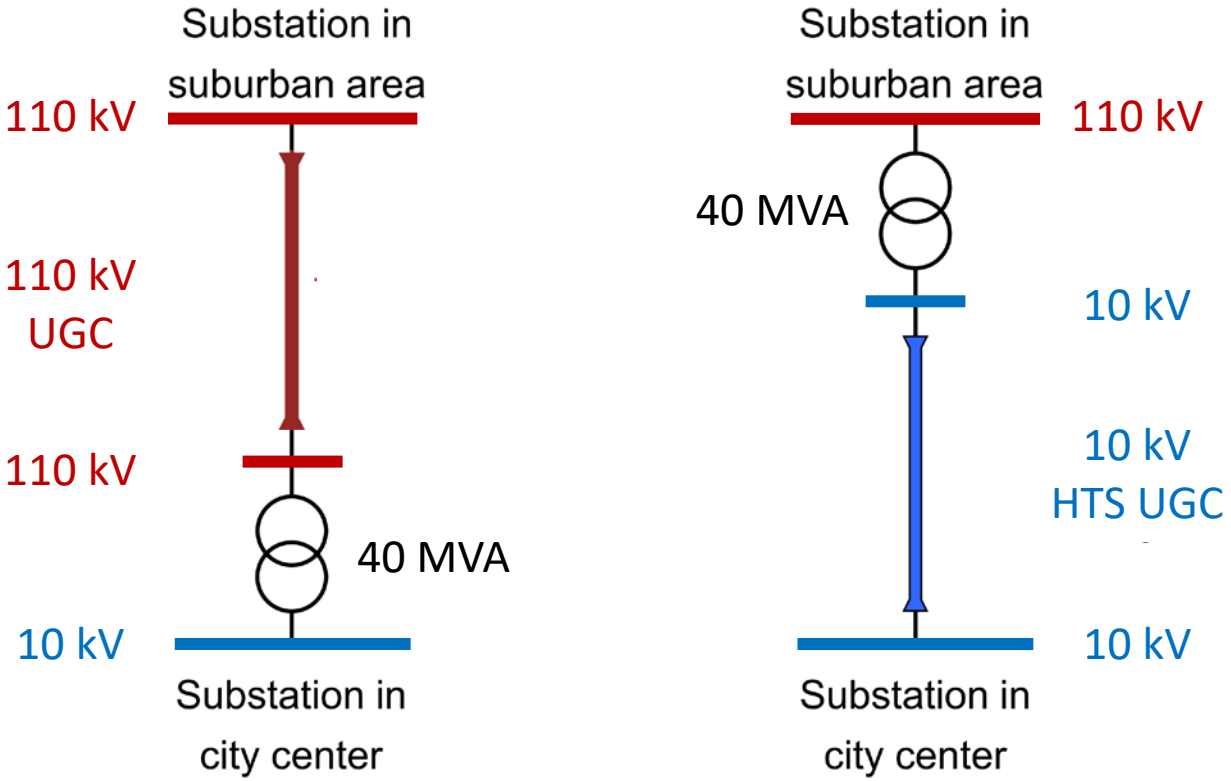
[1] A. Allais, "Nexans is paving the way for a superconducting electric world," 8th International Workshop on Numerical Modelling of High Temperature Superconductors, Nancy, France, Jun. 2022.

II. Today

Ampacity

Ampacity

Essen, Germany

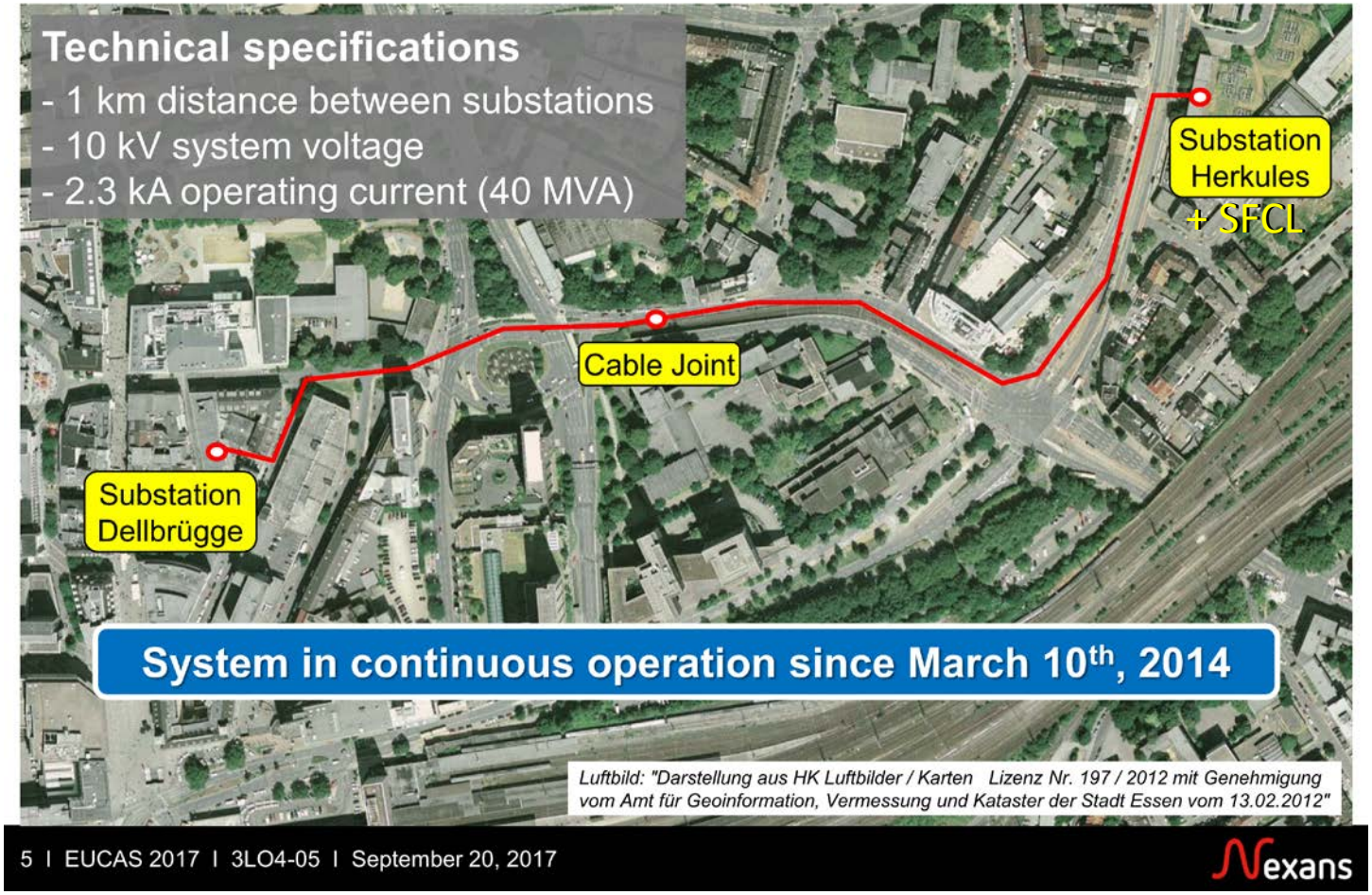


Adapted from [1] M. Stemmle, K. Allweins, F. Merschel, T. Kugel, F. Herzog, T. Kutz, J.-M. Saugrain, "Three years operation experience of the AmpaCity system installation in Essen, Germany," European Conference on Applied Superconductivity (EUCAS 2017), Geneva, Sept. 2017.

Ampacity

Essen, Germany

- 1 km long
- 10 kV
- 2.3 kA
- 40 MVA
- In service 2014



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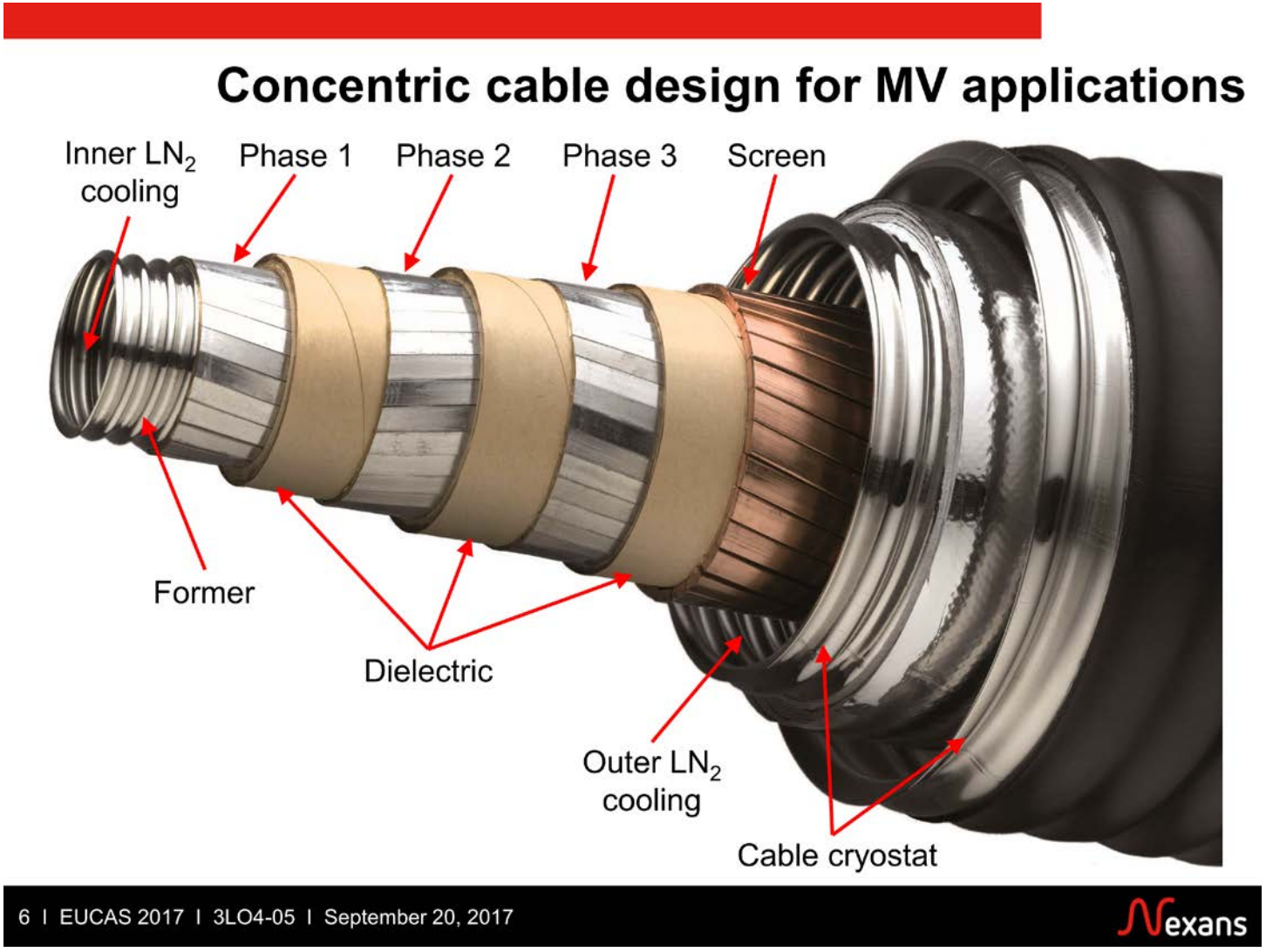

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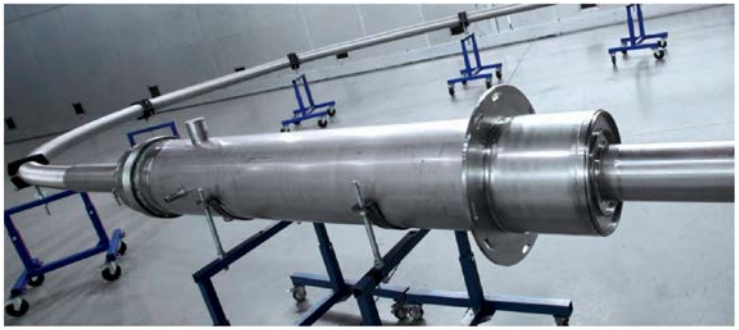

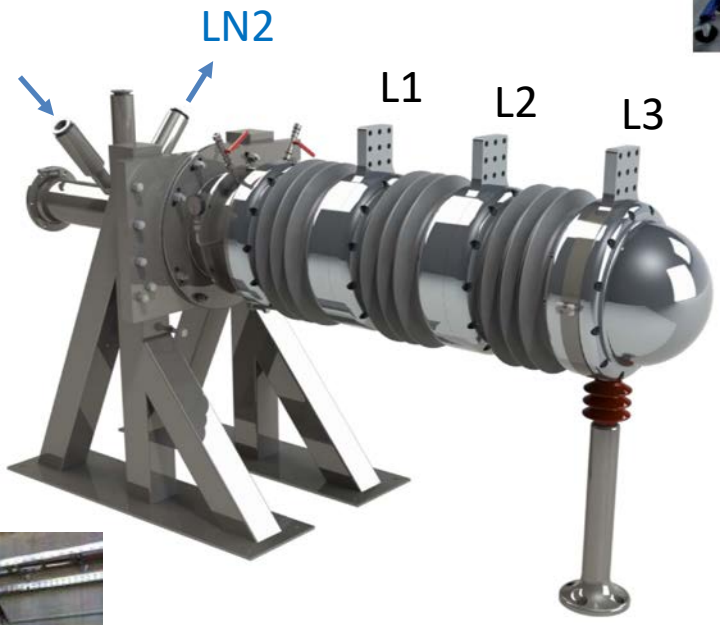

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[2] F. Merschel, "AmpaCity, Energieverteilung von Morgen mit Hochtemperatur-Supraleiterkabeln und Strombegrenzern für Zentren mit hoher Lastdichte," VDE / IHK Forum Technische Innovationen, Köln, Germany, Sept. 2015.

II. Today

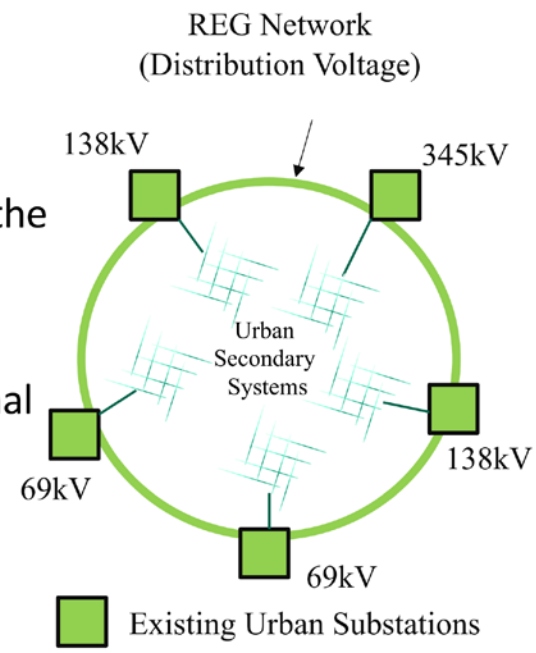
REG 1

REG 1

Chicago, USA

REG Networks Utilize High Temperature Superconductor (HTS) Cables

- ✓REG Networks provide **resiliency** by creating grid **redundancy**
- ✓REG Networks c**onnect** urban substations on the d**istribution side**, effectively **reinforcing** the transmission system
- ✓REG Networks provide **high capacity, distribution voltage connections** with minimal footprint, civil work and permitting
- ✓Approach is independent of **transmission voltage levels,** but compliments the existing transmission system



amsc

-8-

ComEd
An Exelon Company

56th Annual Minnesota Power Systems Conference 8

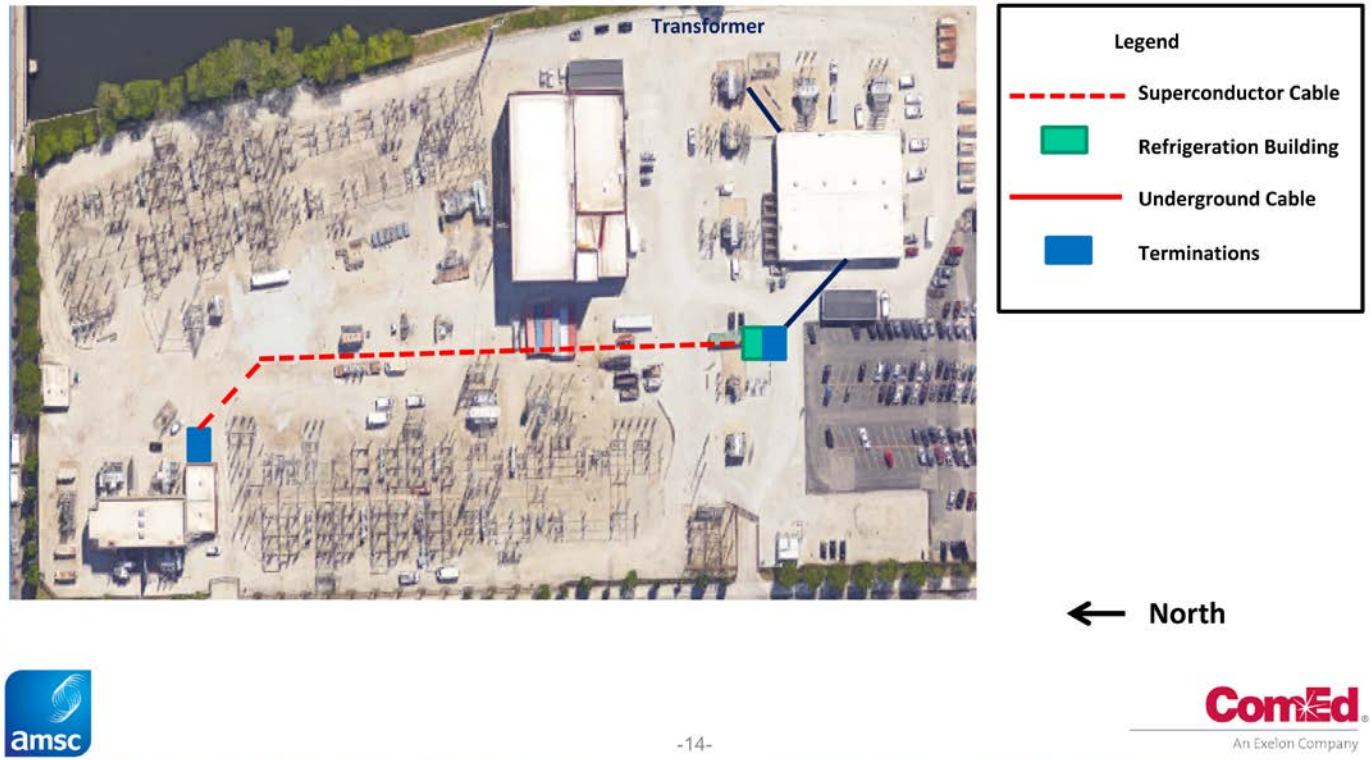
[1] D. Brotzman, M. Ross, "Chicago superconductor cable project and vision for the technology," 56th Annual Minnesota Power Systems Conference, [online], Nov. 2020.

REG 1

Chicago, USA

- 200 m long
- 12 kV
- 3 kA
- 62 MVA
- In service 2021

Superconductor Cable – Initial Project



[1] D. Brotzman, M. Ross, "Chicago superconductor cable project and vision for the technology," 56th Annual Minnesota Power Systems Conference, [online], Nov. 2020.

REG 1

Chicago, USA

- 200 m long
- 12 kV
- 3 kA
- 62 MVA
- In service 2021

[1] M. Ross, "Resilient electric grid networks: achieving enhanced resiliency in today's grid," Superconductors for power transmission webinar, [online], Jul. 2022.

II. Today

@ research laboratories

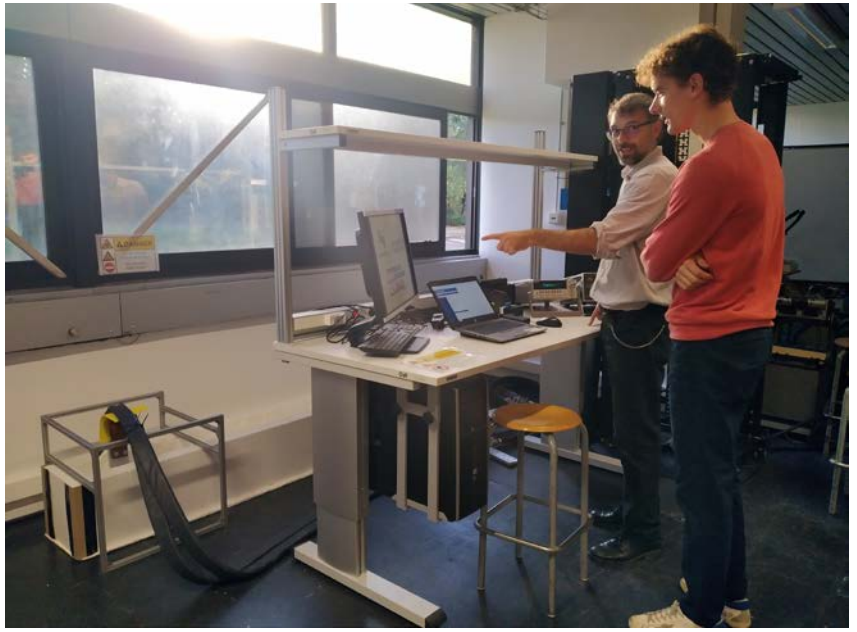
Gargantua

GeePs' HTS cable DC test station:

- DC power supply (4x SGX1200)
- Open LN2 bath (2m long)
- Nanovoltmeter & thermometer

<u>Test capabilities</u>

- 2m-long cables
- 4800 A at 10 V DC
- at ~77 K under atmospheric pressure
- Measure nV voltage drop

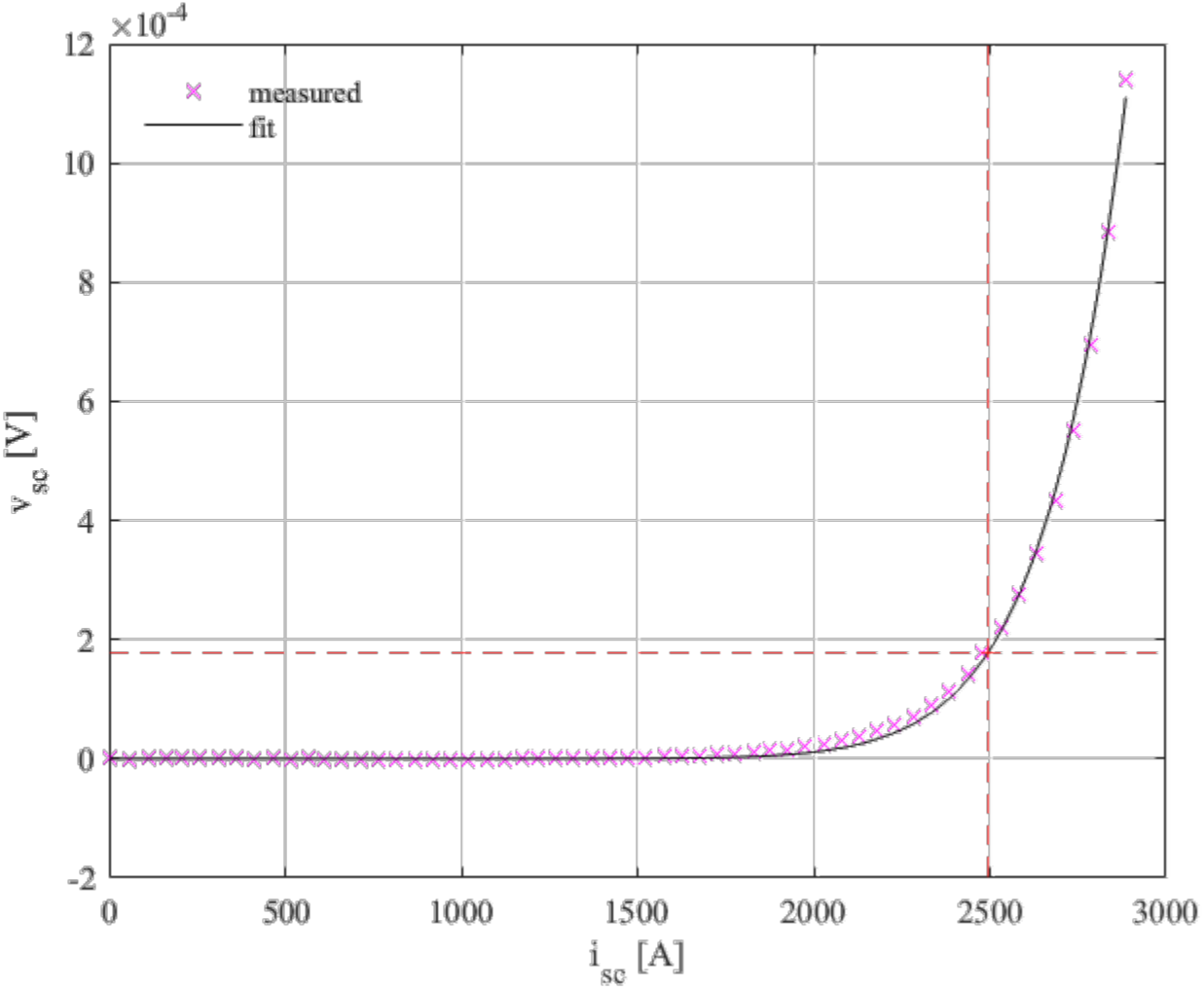


Some results

Measured V-I characteristic @77 K

$I_c = 2487$ A

$n = 12$



III. Tomorrow

SuperLink

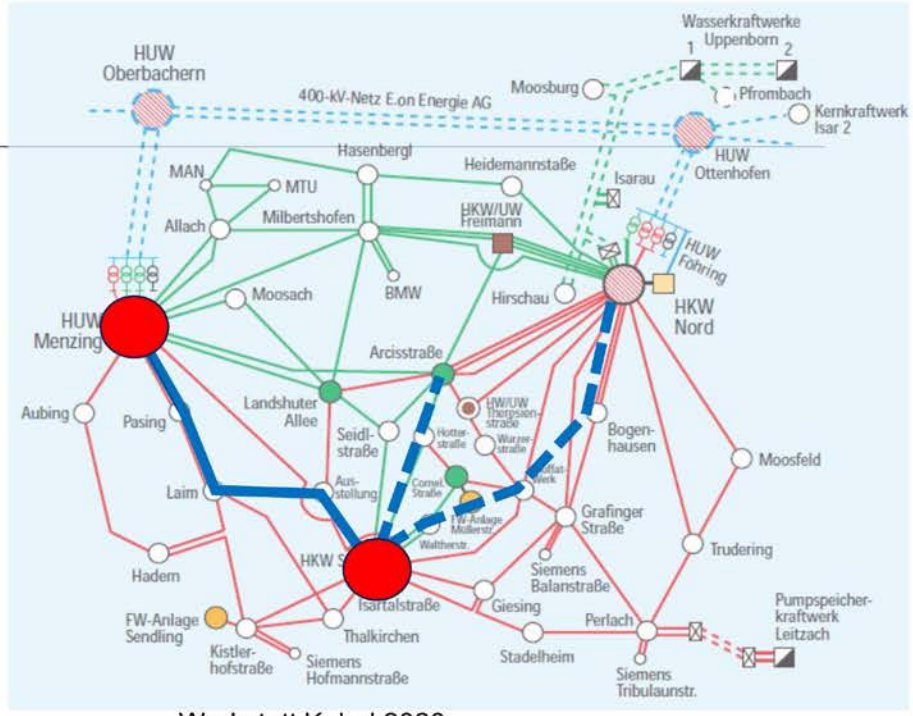
SuperLink

Chicago, USA

Task Description

High-density load area Munich

- Connect Kraftwerk Süd to the OH lines north of Munich
- Power rating 500 MVA
- Operation voltage 110 kV
- Length ~12 km
- Routed through the center og Munich



Werkstatt Kabel 2020

[1] D. Willén, “NKT HTS cable technology," *Superconductors for power transmission webinar*, [online], Jul. 2022.

SuperLink

Chicago, USA

NKT

Most Important requirements - Overview

The SuperLink must provide these advantages:

Criteria	Background
Save space	Very limited room for construction, Influence of other services, Routes and Right-of-way
Acceptance	Electromagnetic fields, Ground heating, Building sites
Economic	Cost of building and operating
Technically mature	Electric networks are critical infrastructure
Power Rating	Deliver 500 MVA or more in smallest space
Energy efficient	Reducing CO_2 Emissions

Werkstatt Kabel 2020

NKT HTS 21.06.202 50

[1] D. Willén, "NKT HTS cable technology," *Superconductors for power transmission webinar*, [online], Jul. 2022.

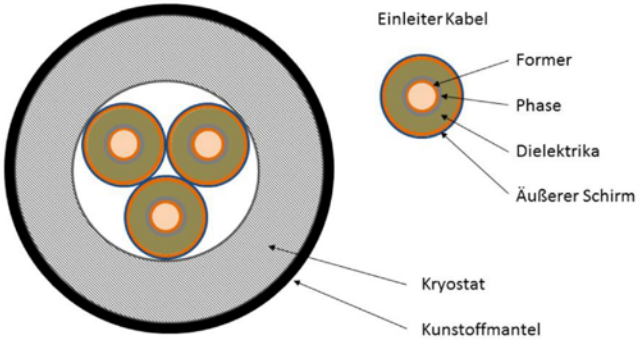
SuperLink

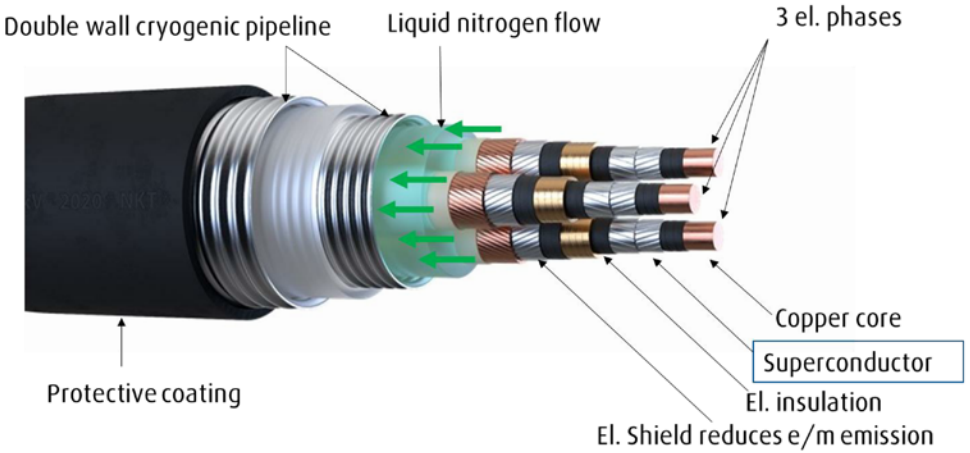
Chicago, USA

NKT

Development of the Cable System

- Three single-phase cables
- Terminations and joints
- Common Cryostat
- Ultra compact
  (Option to Retrofit)





110 kV SuperLink Kabel

- Three-phase cable with High-Temperature Superconductor (HTS)
- One cable in one trench replaces 5 conventional 110 kV cables in separate trenches

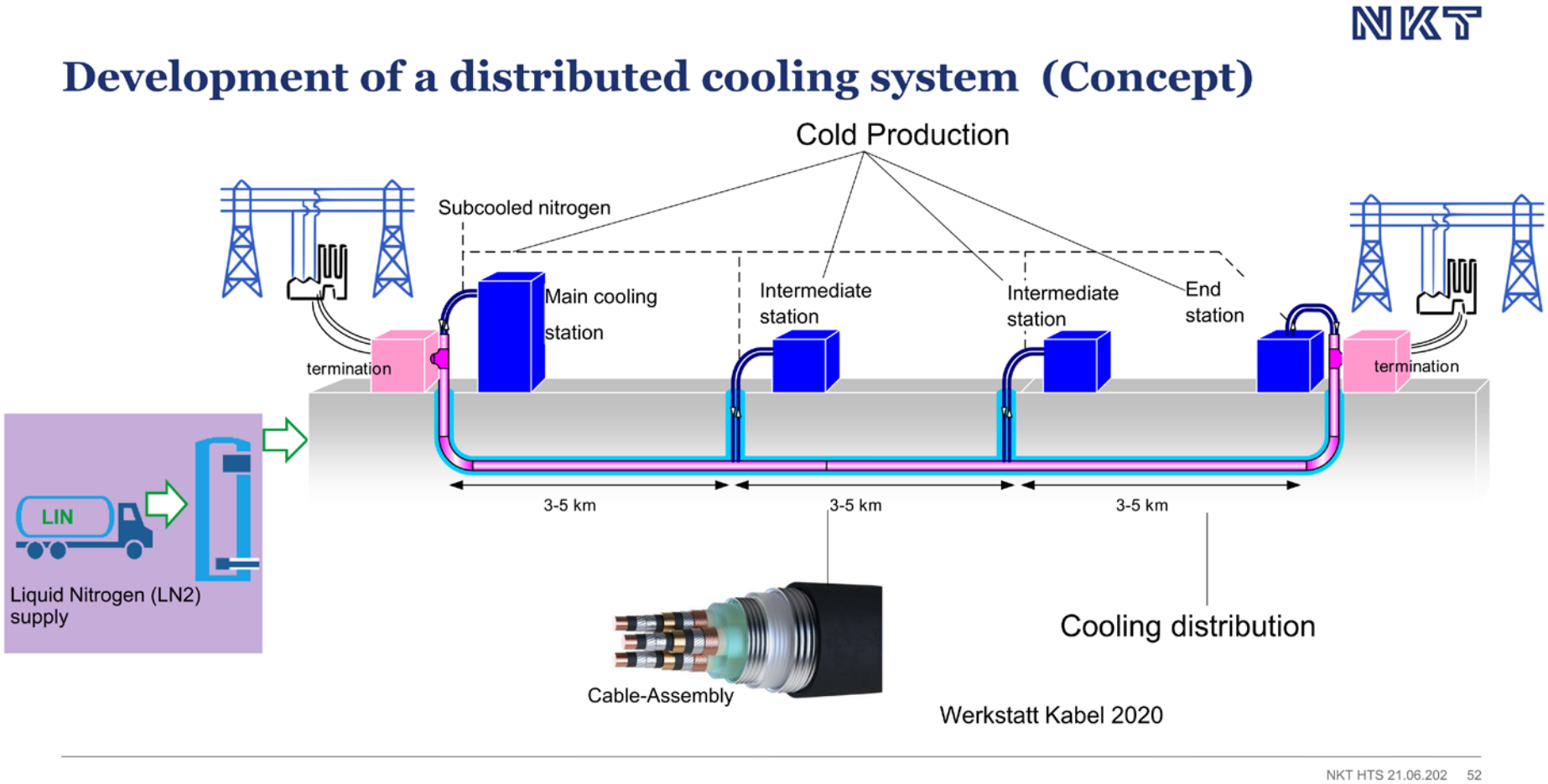
Werkstatt Kabel 2020

NKT HTS 21.06.202

[1] D. Willén, “NKT HTS cable technology," *Superconductors for power transmission webinar*, [online], Jul. 2022.

SuperLink

Chicago, USA



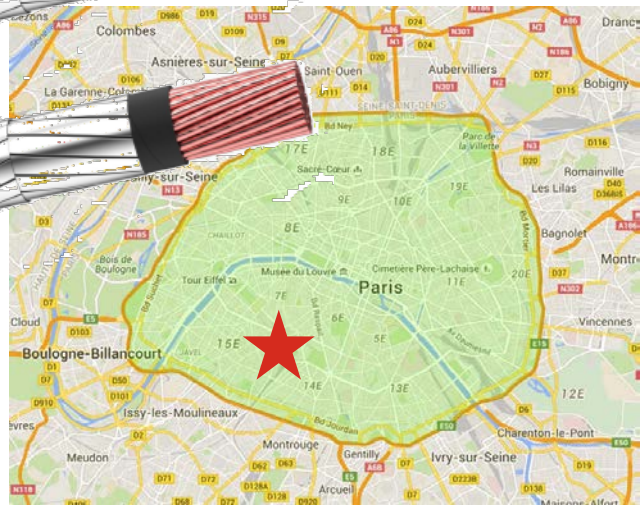
[1] D. Willén, “NKT HTS cable technology," *Superconductors for power transmission webinar*, [online], Jul. 2022.

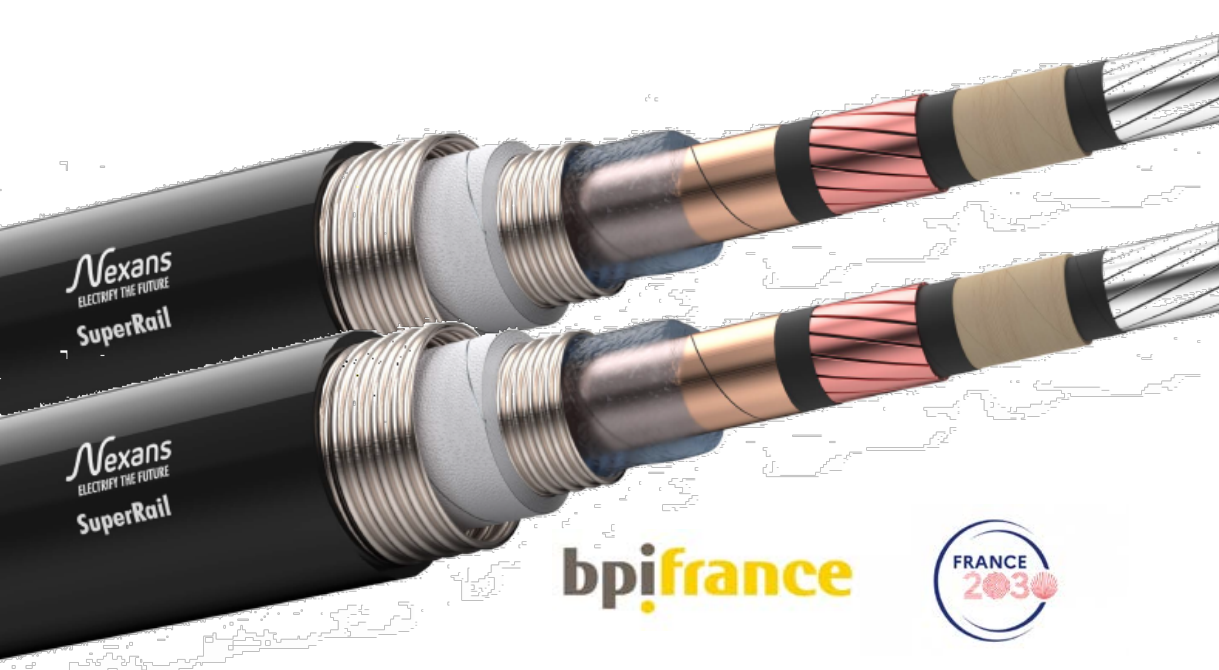
III. Tomorrow

SuperRail

SuperRail

Paris, France



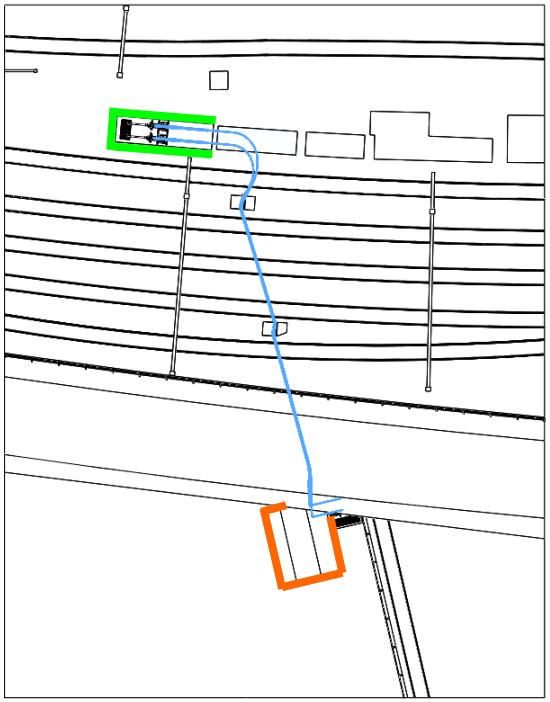


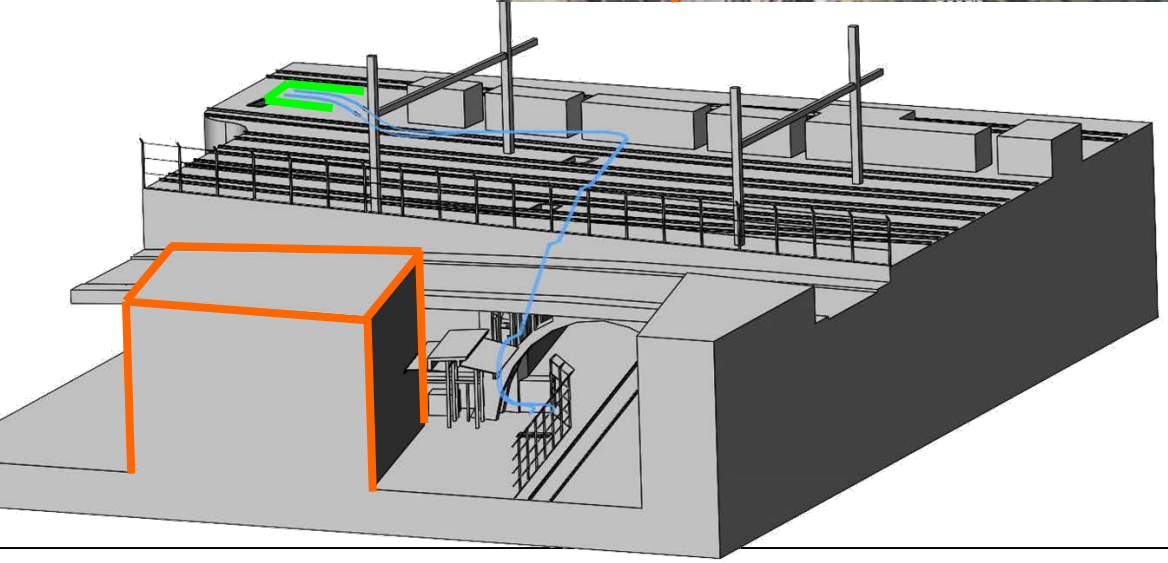
SuperRail

Railway AC/DC substation

HTS cables

Platform

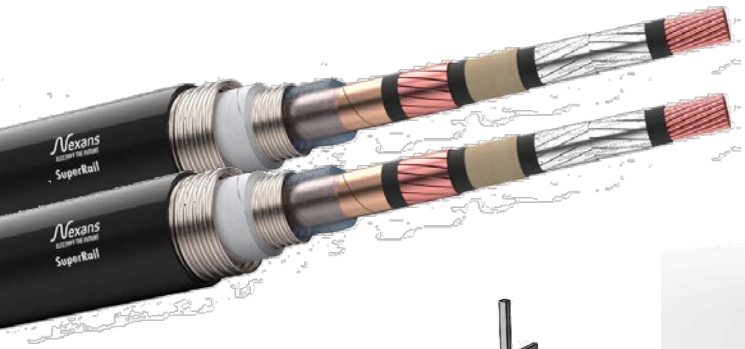


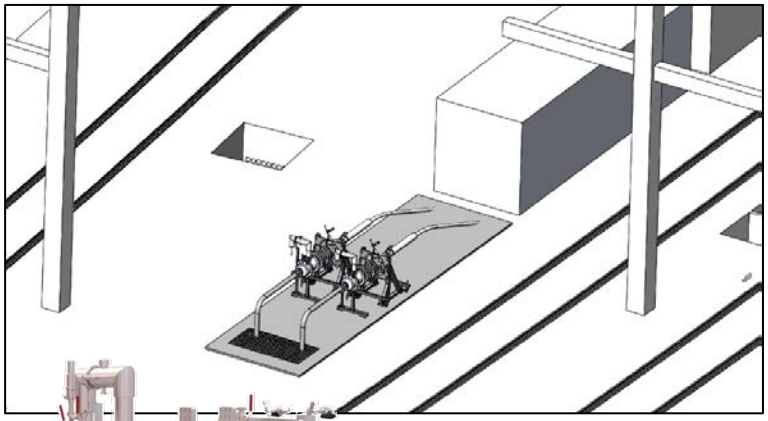


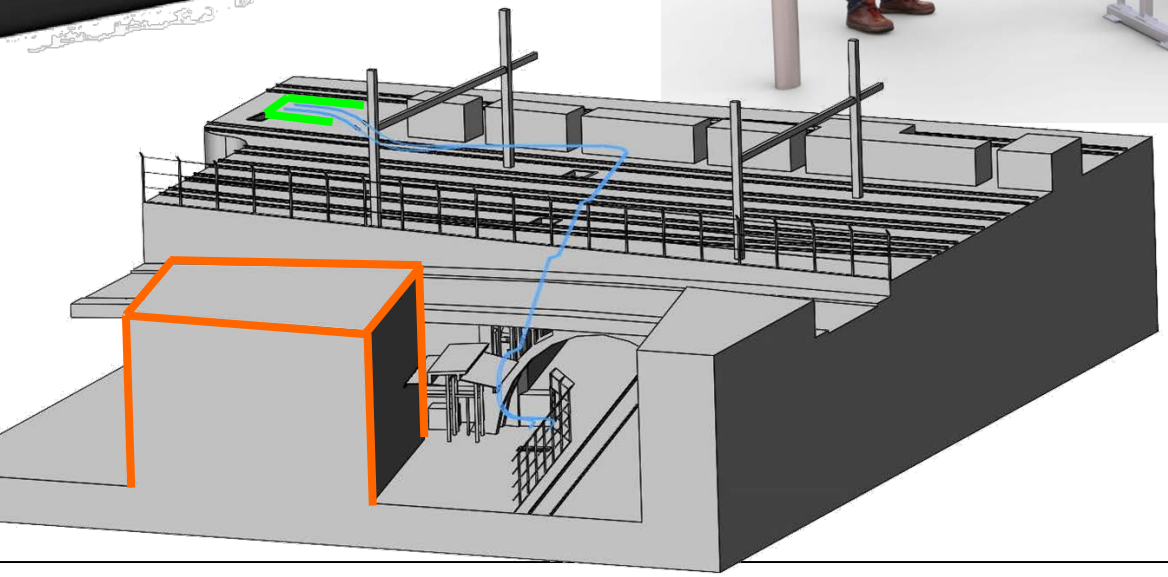
Length	2 x 80 m
Voltage	1500 V DC
Current	3500 A
Power	2 x 5 MW

SuperRail

- Railway application
- Continuous operation

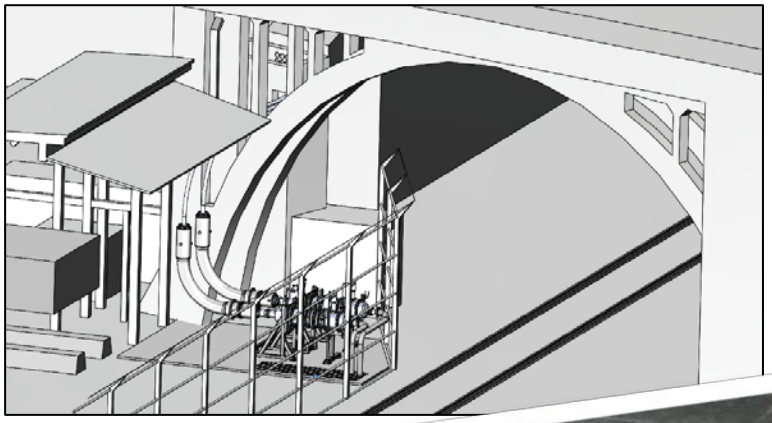


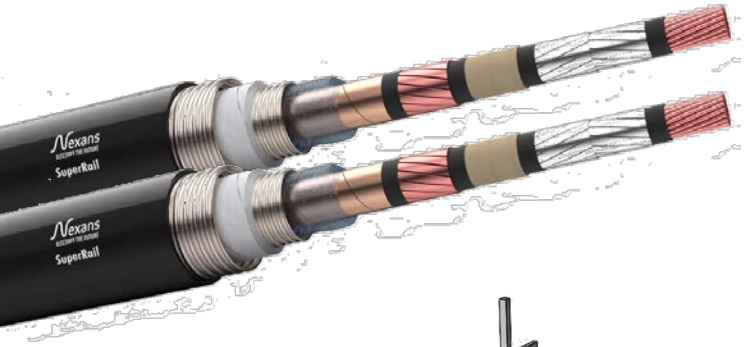


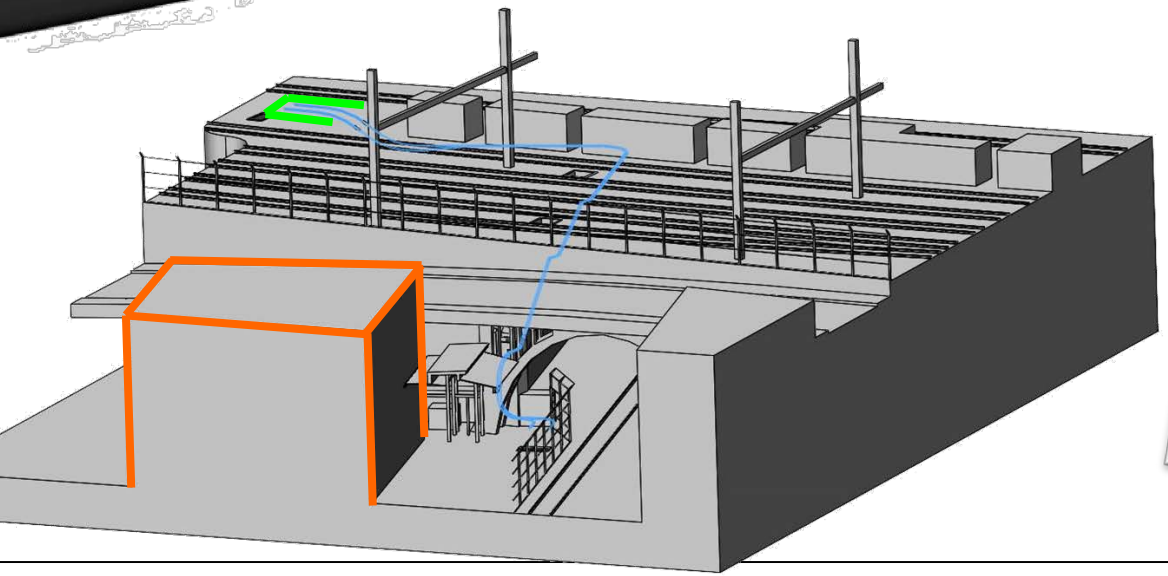


SuperRail

- Installation in existing pipes
- Sharp gradient and turns







SUPERRAIL

V. Conclusion

Conclusion

- The HTS power cable is an innovative device with potential to improve grids.
- HTS power cables are out of the laboratory development phase.
- Currently midway between pilot projects and industrial deployment. AC cable systems TRL 7-8. DC cable system TRL 5-6.
- First commercial products now available for LV, MV, and HV grids.
- More communication needed regarding successful field test experiences. Grid designers should be aware of this new device.
- Cryogenics does not pose a particular issue. Need to overcome psychological fears related to cryogenics.
- More long-term testing required to alleviate utility fears.
- Room for improvement in terms of conductor and cryostat costs and in terms of cryogenic processes.

GeePS
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Merci !

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Technology Readiness Levels

TRL 0: **Idea**. Unproven concept, no testing has been performed.

TRL 1: **Basic research.** Principles postulated and observed but no experimental proof available.

TRL 2: **Technology formulation**. Concept and application have been formulated.

TRL 3: **Applied research**. First laboratory tests completed; proof of concept.

TRL 4: **Small scale prototype** built in a laboratory environment ("ugly" prototype).

TRL 5: **Large scale prototype** tested in intended environment.

TRL 6: **Prototype system** tested in intended environment close to expected performance.

TRL 7: **Demonstration system** operating in operational environment at pre-commercial scale.

TRL 8: **First of a kind commercial system**. Manufacturing issues solved.

TRL 9: **Full commercial application**, technology available for consumers.