HIGH-CAPACITY HIGH TEMPERATURE SUPERCONDUCTING POWER CABLES

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Rationale

High-capacity High Temperature Superconducting (HTS) cables provide electric utilities with a new tool to address key drivers

Growing power consumption in urban areas
Additional power can be transmitted through existing right-of-way

Safety
Transformers can be removed from city centers through high-capacity medium voltage HTS cables

Eco-friendliness
- **No thermal or magnetic impact on the environment**
- **Lower losses**
- **The cooling fluid, liquid nitrogen, is a low-cost, abundant and environment-friendly fluid**

Contents

- Introduction to HTS power cables
- High-capacity HTS cable projects
- Expectations
- Conclusion

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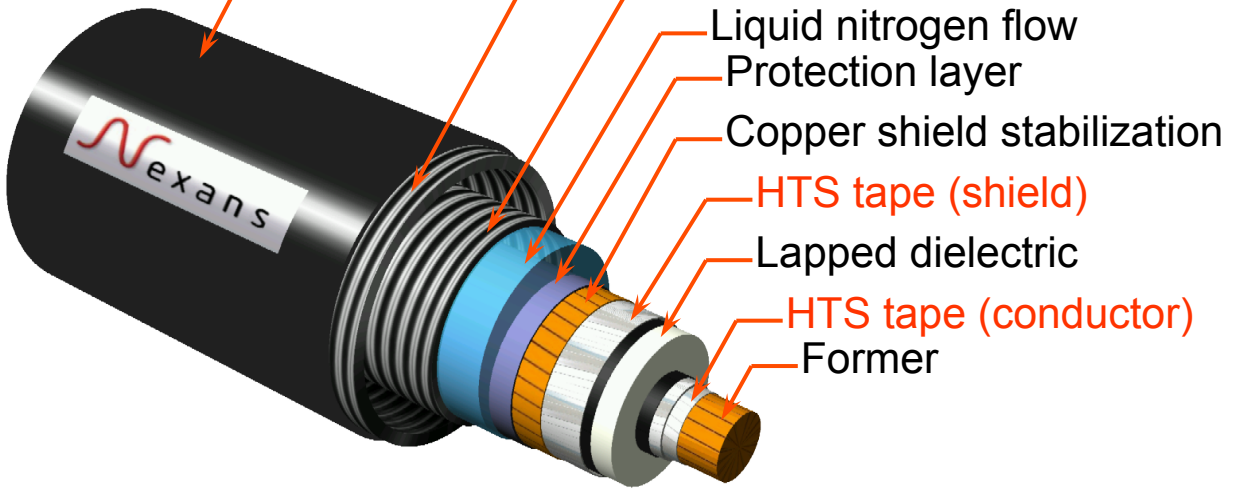
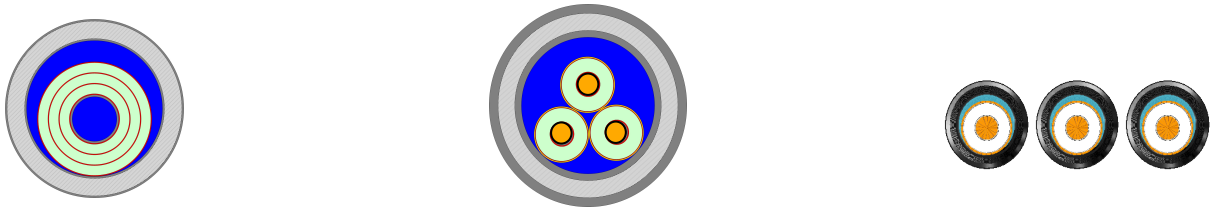
Introduction to HTS power cables





MV → Application voltage ↗ → HV

Introduction to HTS power cables
Cryogenic envelope

1. Corrugated inner tube
2. Low-loss spacer
3. Vacuum space (<10^{-5} mbar)
4. Multilayer superinsulation
5. Corrugated outer tube
6. PE jacket (optional)

Nexans is the world leader in flexible cryostats with more than 30 years of experience

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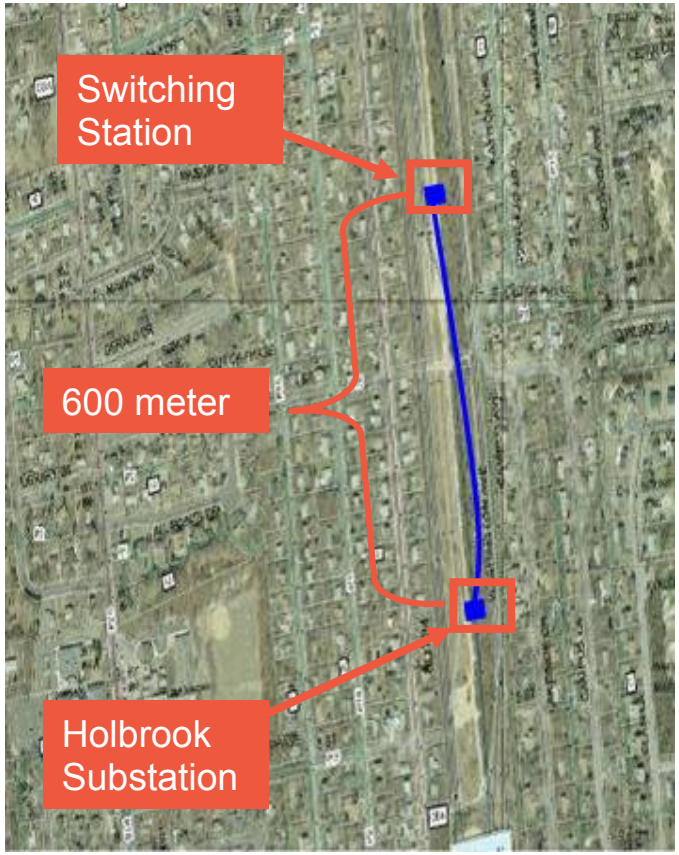
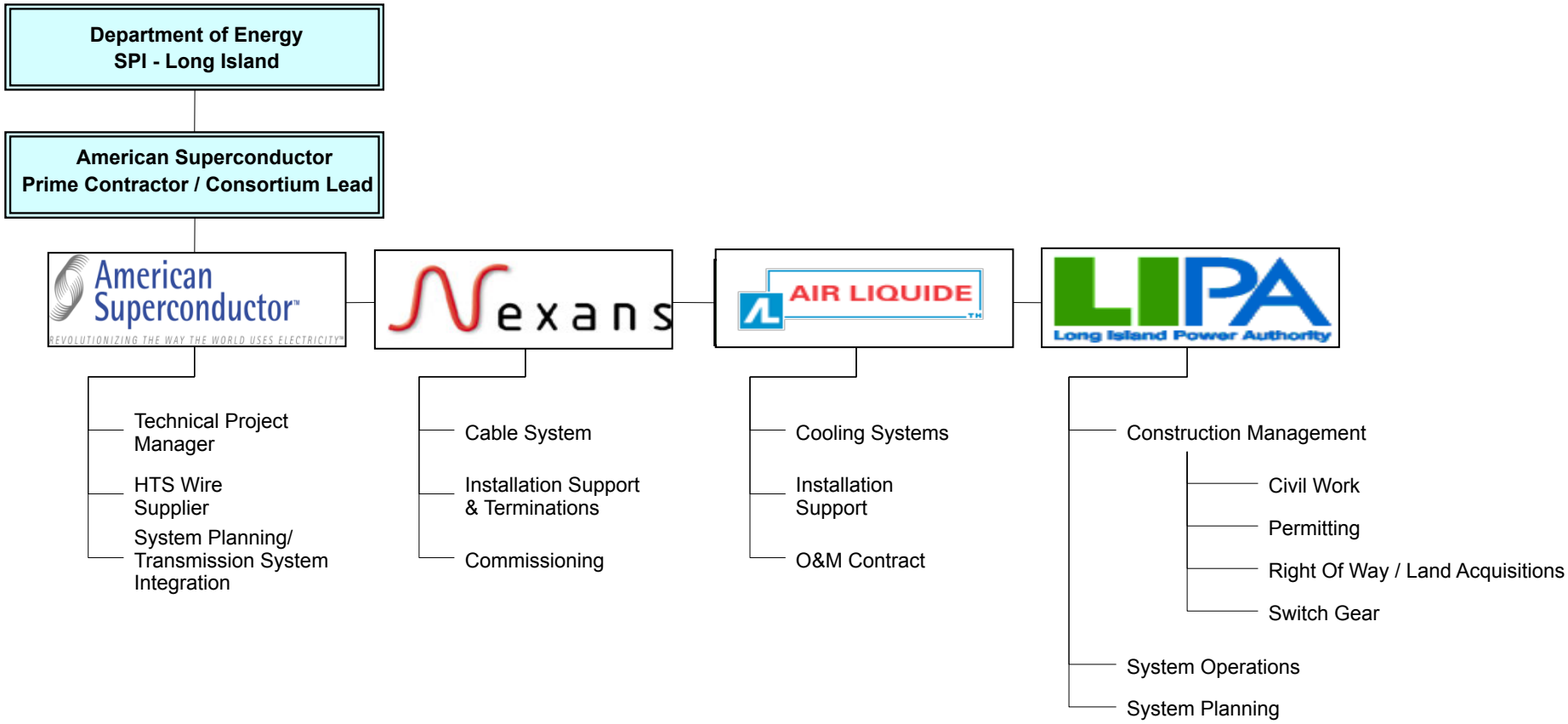
Demonstrating feasibility of HV HTS cable technology

- Long Island Power Authority – Holbrook Substation
- 600 m long cold dielectric cable system 138kV/2400A ~ 574MVA
- Design fault current: 51 kA @ 12 line cycles (200ms)
- 600 meter cable pulled in underground HDPE conduit

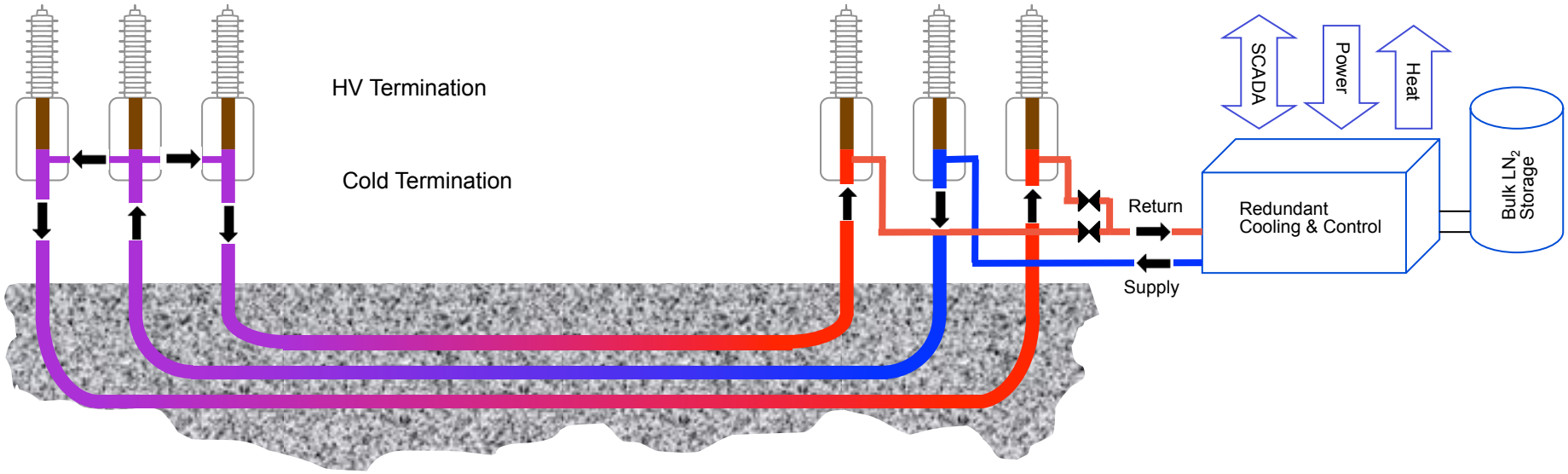


World's longest HTS cable and first installation at transmission voltage level

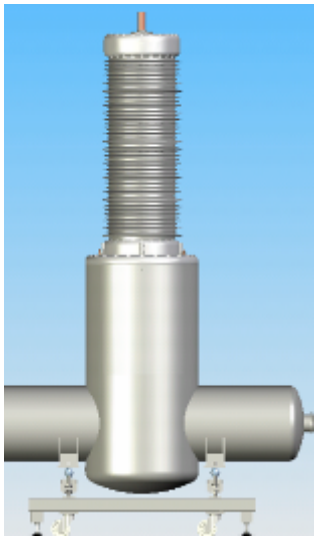
LIPA1 project Team



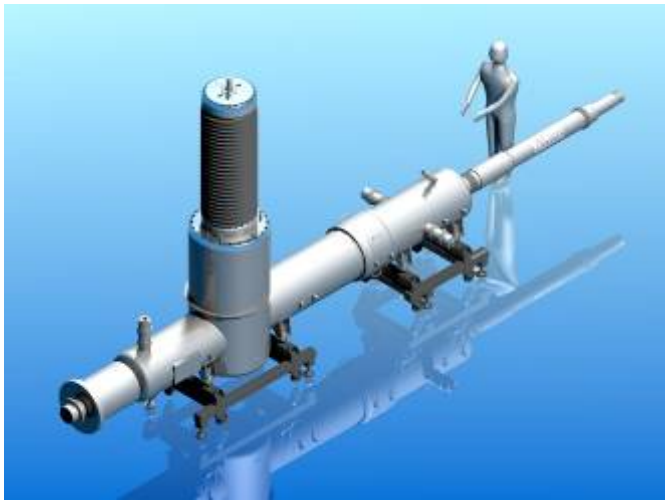
LIPA1 project
Cable cooling flow



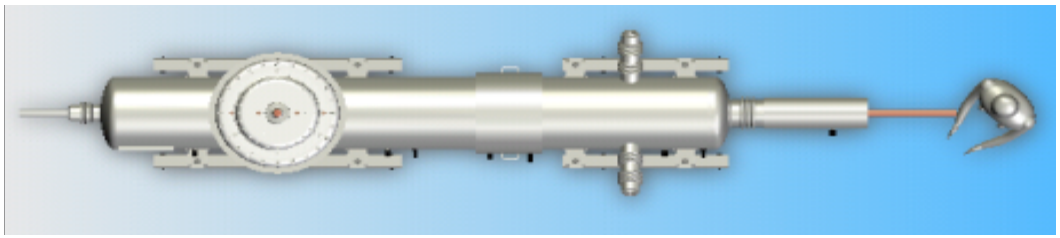
LIPA1 project
Termination concept



- Vertical part:
  - Thermal gradient management (from 77 to 300 K)
  - Connection to grid

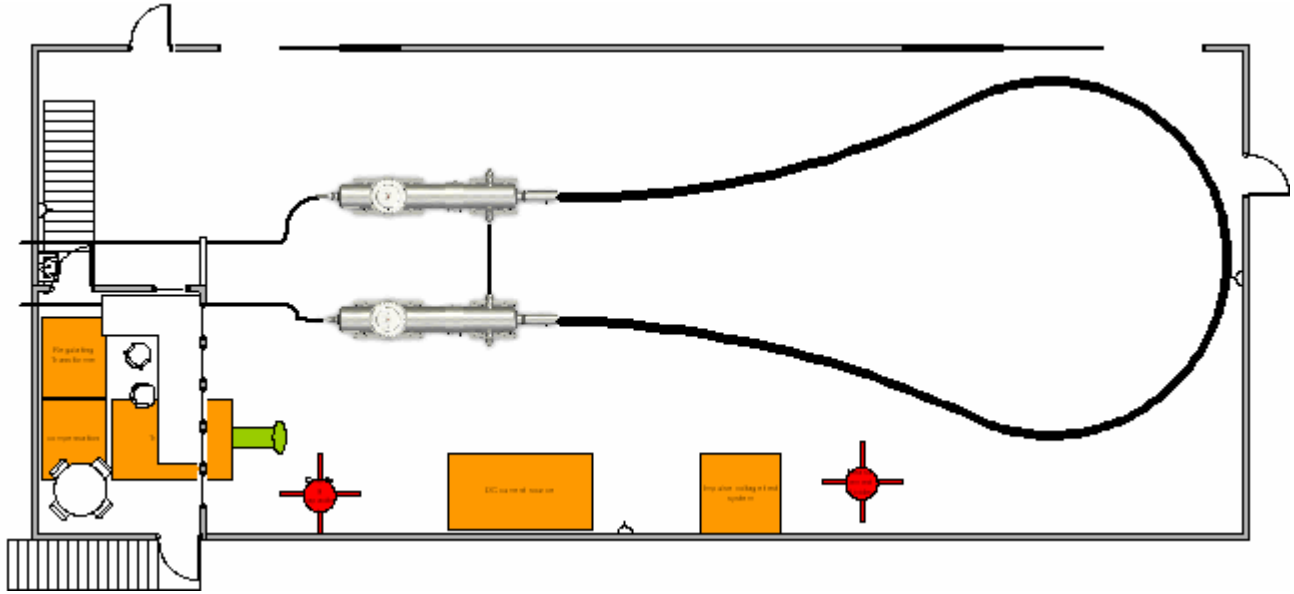


- Horizontal part:
  - Connection to HTS cable
  - Management of cable thermal shrinkage



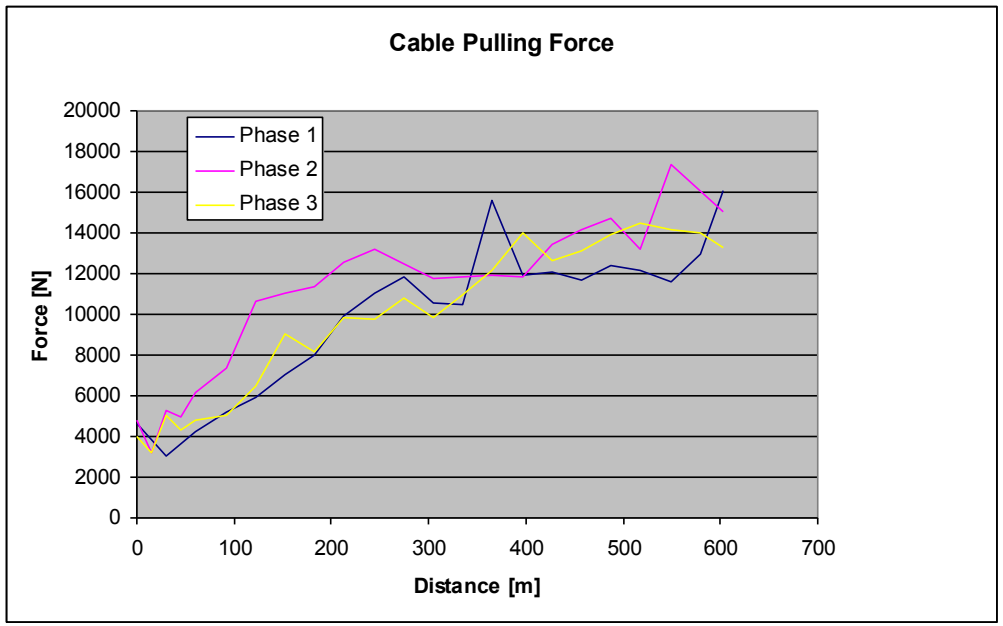
LIPA1 project
Qualification of prototypes

- Cable and termination prototypes were tested in a dedicated high voltage test field in Hanover
- The 30 m x 12 m x 9 m screened room is connected to a liquid nitrogen cooling system liquid nitrogen (temperature around –200°C)



LIPA1 project
Cable pulling

- Pulling was carried out for all phases without any issue
- Cryogenic envelope vacuum integrity verified after pulling



LIPA1 project
Assembling of terminations

Terminations were assembled on site after cable pulling

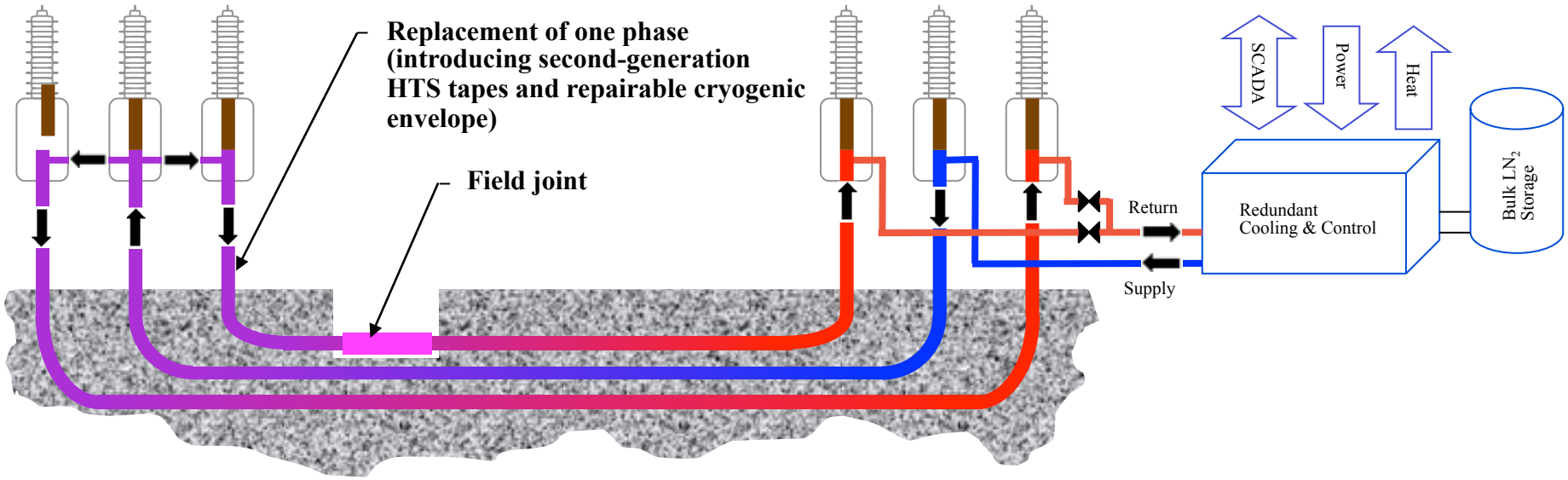
LIPA1 project
Assembling of terminations

LIPA1 project
Connection to grid

World's longest HTS cable successfully energized on April 22, 2008

Preparing for multi-kilometer HV HTS cables

- Project funded by the U. S. Department of Energy
- Same partners (American Superconductor, Air Liquide and LIPA) and same site as for the LIPA1 project



Installation and commissioning around the end of 2011

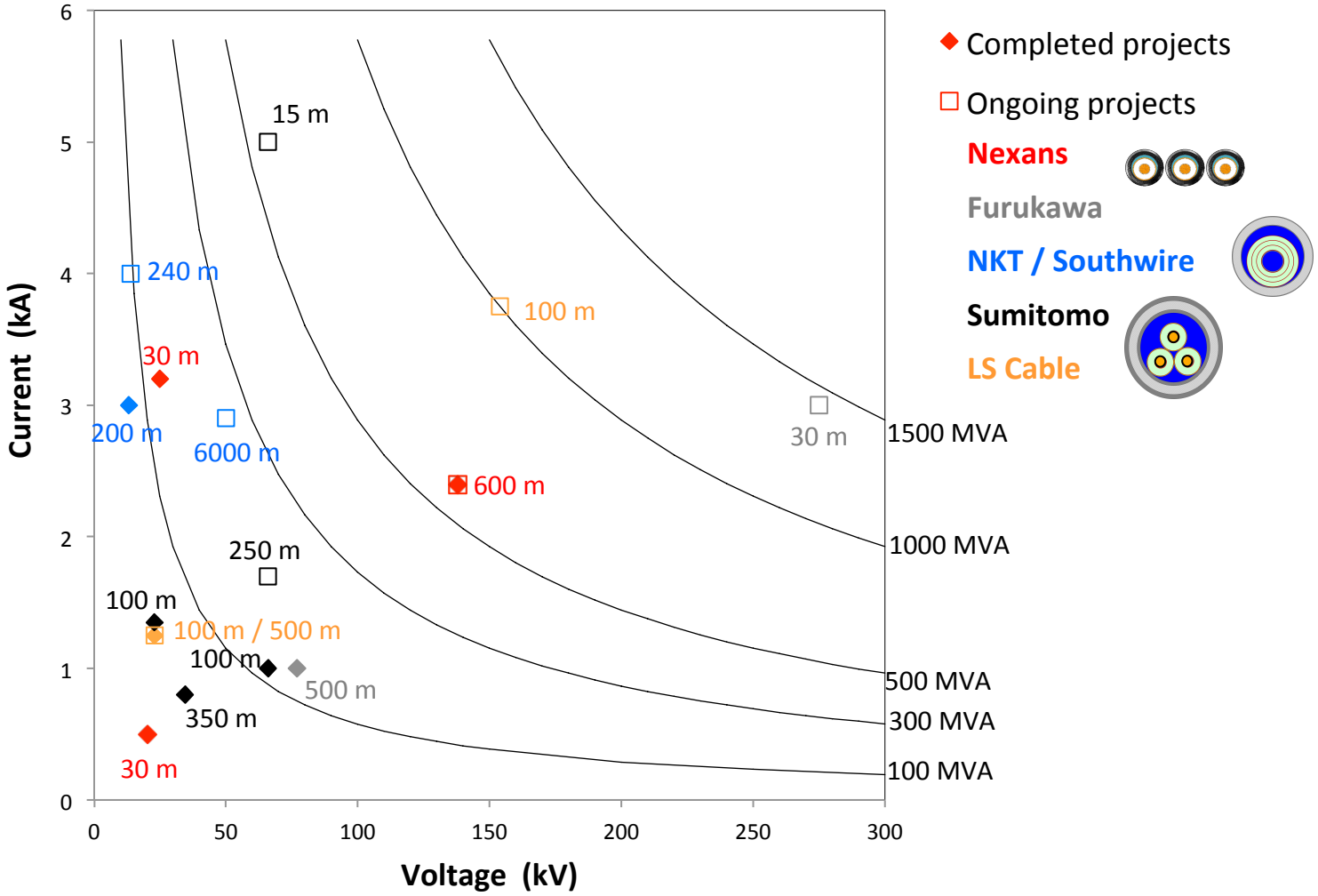
World's ampacity record: 3200 A

- Project funded by Endesa in Spain
- Other partners: ICMAB, Labein
- Key features:
  - One 30-meter phase
  - 24 kV, 3200 A
- Cable manufactured by Nexans and tested in the Hanover laboratory

Supercable termination

Project successfully completed in December 2009

Main HTS AC cable projects



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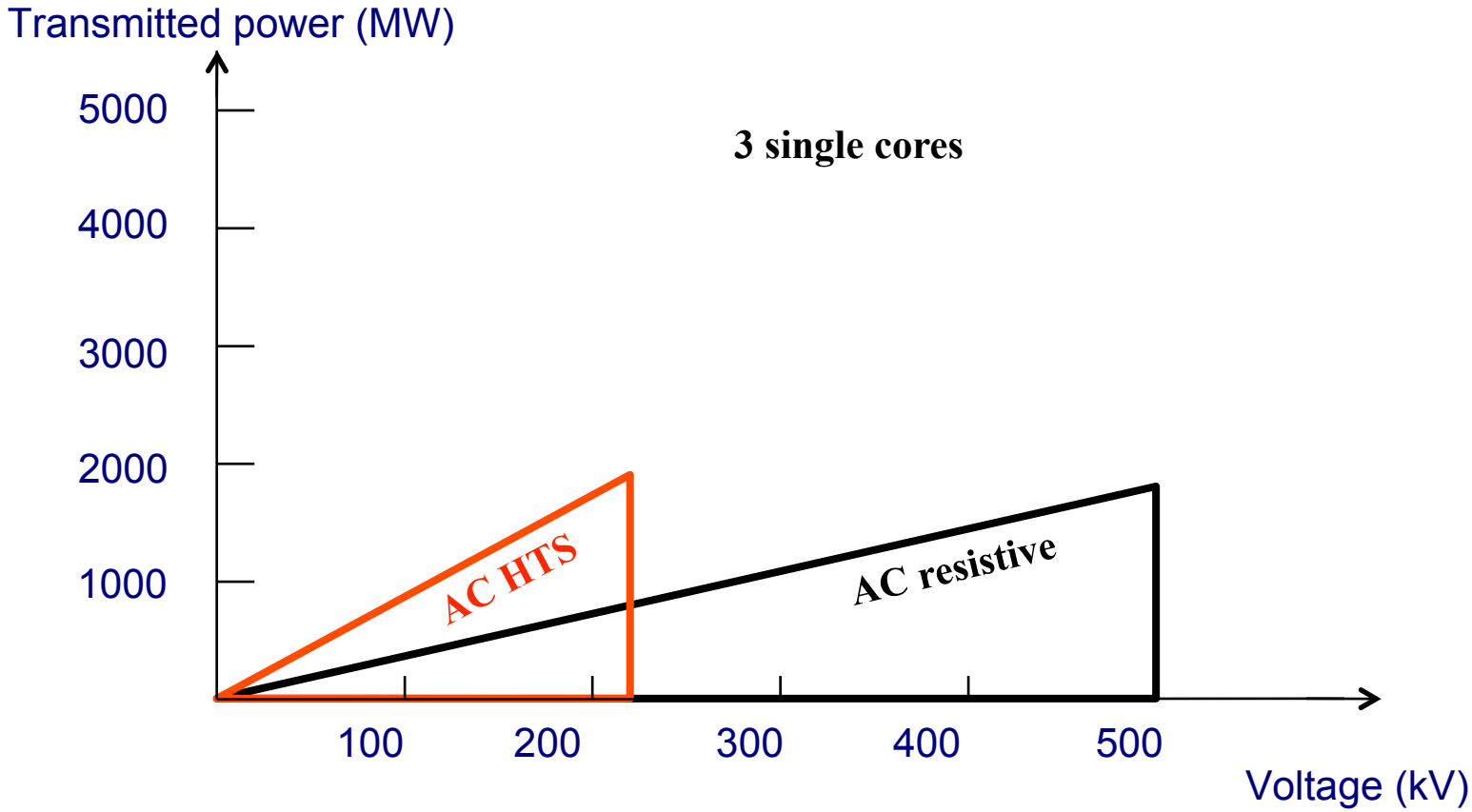
Expectations
High-capacity HTS **AC** cables

With HTS AC cables, the same power can be transmitted at a lower voltage



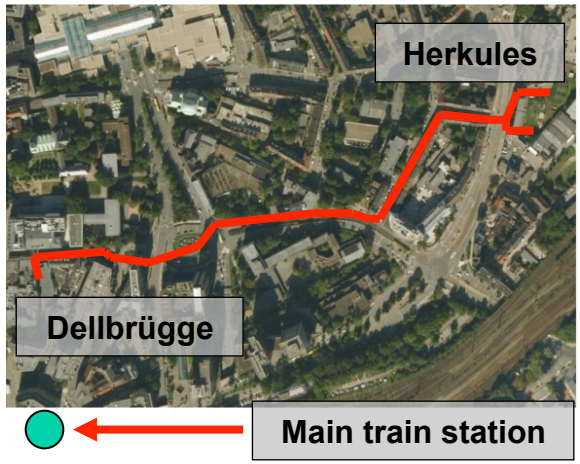
High-capacity HTS AC cables
Technical hurdles to be overcome

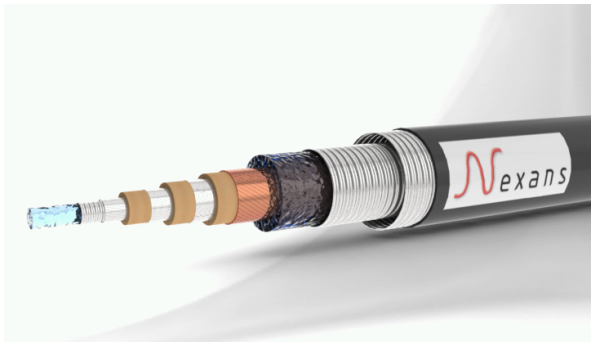
- High-current HTS tapes (to minimize the number of HTS layers):
  - Avoid current distribution issues
  - Reduces mechanical issues
- Low-loss system:
  - HTS tapes with low AC-losses
  - Low-loss cryogenic envelope
  - High-efficiency cooling system
- High-voltage accessories (complexity increasing quickly with voltage):
  - In-field demonstration of 138 kV terminations completed
  - Ongoing developments: 138 kV joint, 154 kV system, 275 kV system

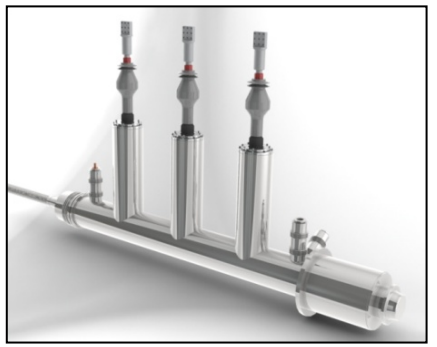
Losses similar to the ones of conventional systems

HTS cable project under discussion
Supply of city center with MV HTS cable

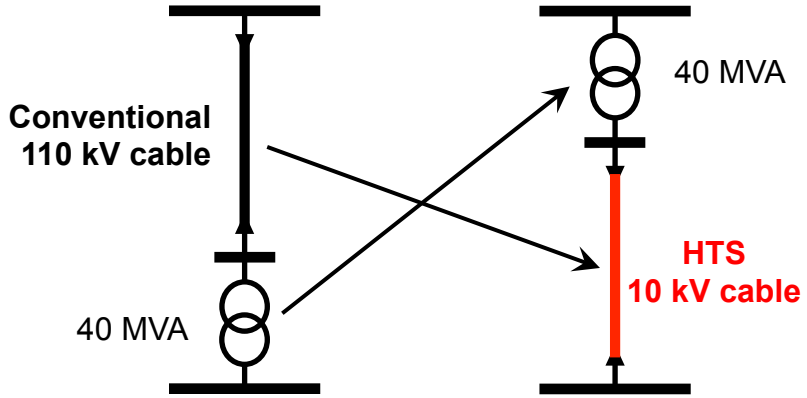
High-power 10 kV link for feeding the center of Essen







110 kV substation (Herkules in suburban area)

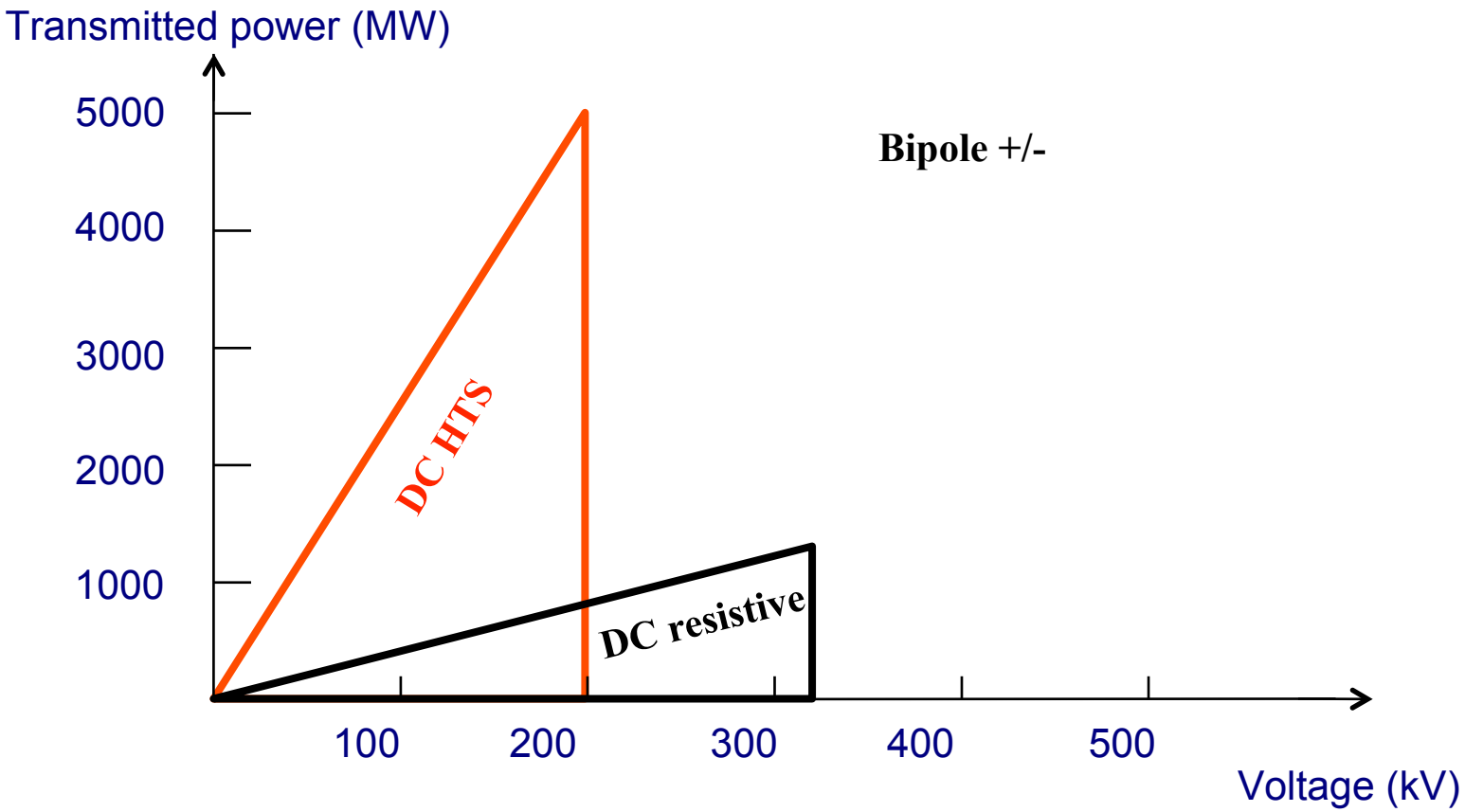


10 kV substation (Dellbrügge in city center)

- Key features:
  - Cable system with concentric phases
  - **World's first combination with HTS fault current limiter**
- End user: RWE
- Funding: RWE and BMWi

Expectations
High-capacity HTS **DC** cables

With HTS DC cables, a much larger power can be transmitted



High-capacity HTS **DC** cables
Technical hurdles to be overcome

- High-current HTS tapes (to minimize the number of HTS layers):
  - Reduces mechanical issues
- Low-loss system:
  - Low-loss cryogenic envelope
  - High-efficiency cooling system
- High-voltage accessories (complexity increasing quickly with voltage):
  - Laboratory demonstration at Nexans of 200 kV termination

Lower losses than with conventional systems

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Conclusion

- The feasibility of HTS AC power cables has been demonstrated up to 138 kV and this technology is now mature enough for in-field implementation
- Demonstration projects are now moving to longer lengths (up to 6 km !), higher voltages eyond 200 kV for both AC and DC !) and greater currents (up to 5 kA AC whereas more than 10 kA DC are envisioned !)
- High-capacity HTS cable systems constitute a new energy-efficient solution to improve congestion management in both distribution and transmission AC power grids but there are only economically viable in some niche applications
- HV HTS DC systems are expected to lead to much lower losses than conventional systems
- **The industry needs to focus on reducing the HTS technology cost**
- Incentives from local governments could help significantly

Nexans

Thank you for your attention !