Medium voltage superconducting cable systems for inner city power supply

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Content

- Basics of Superconductivity
- Superconducting Cable System Components
- Motivation for Inner City HTS Cables
- HTS Cable Design for MV
- Application Concept
- Case Study
- Ampacity Project
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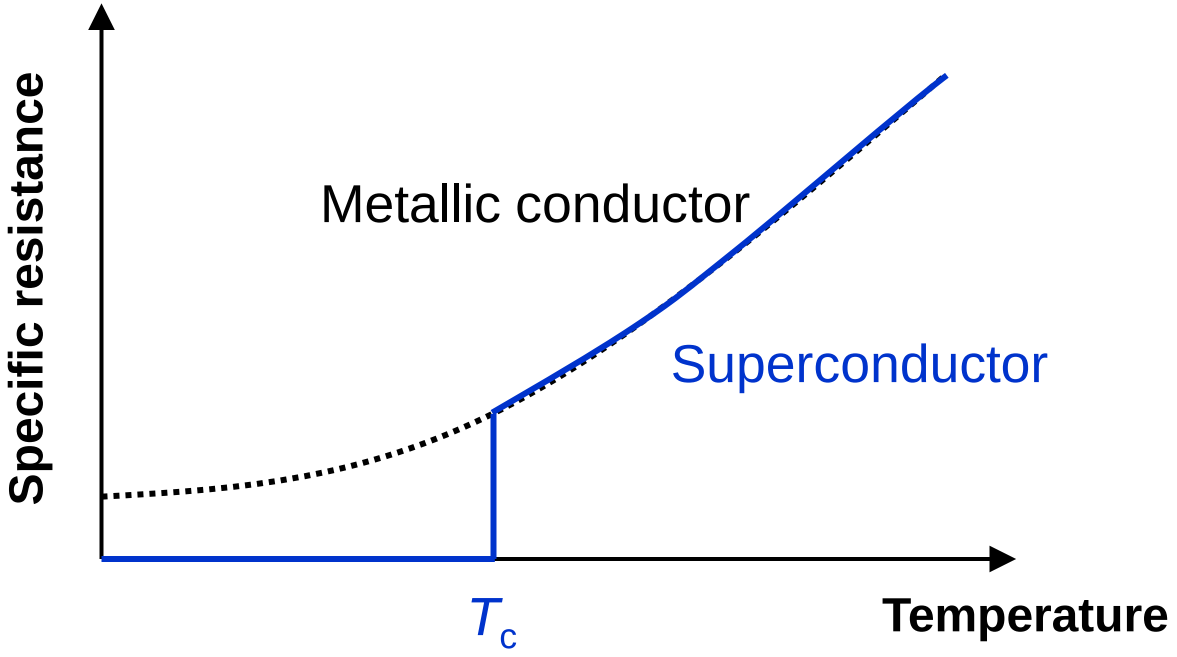
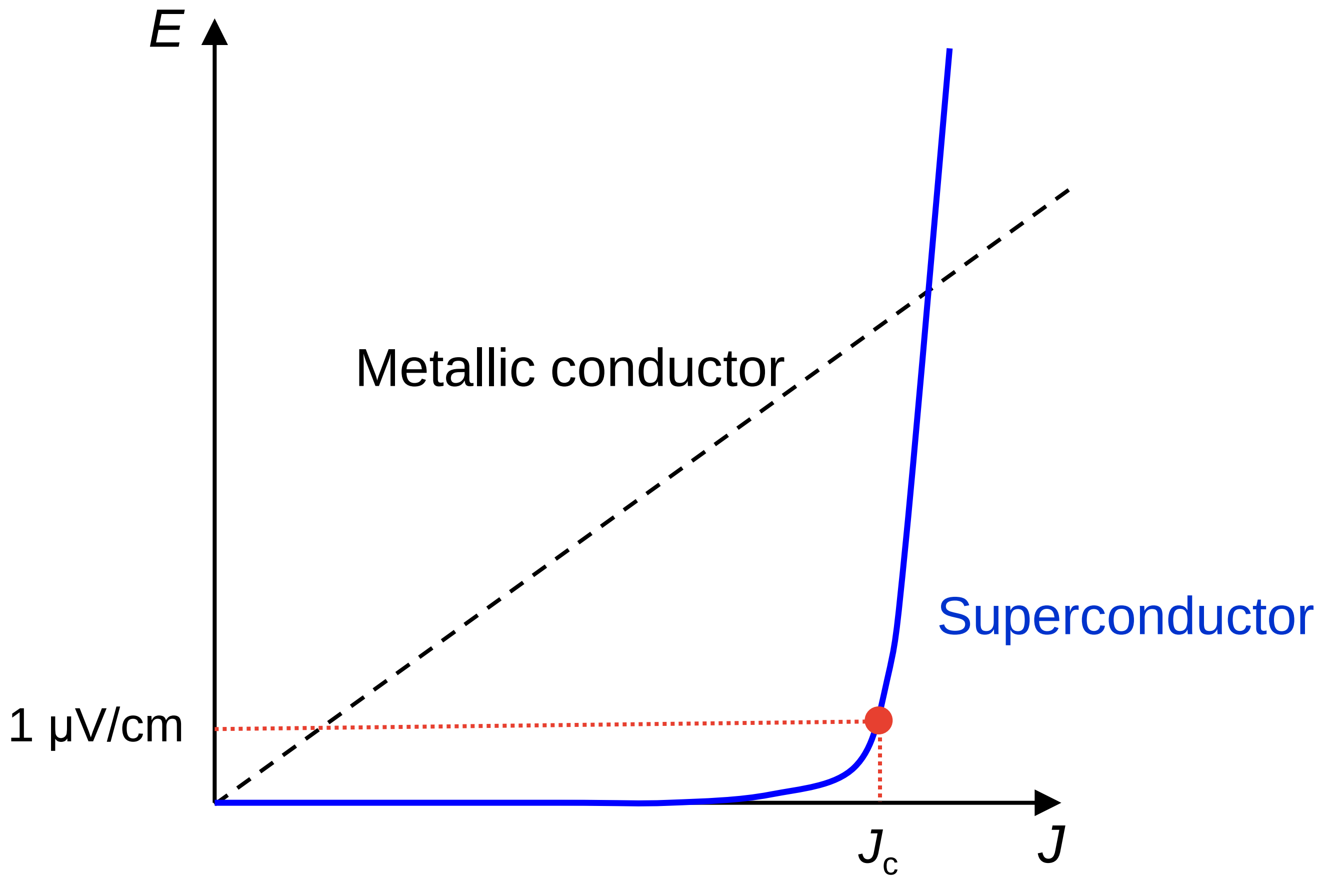


Superconducting state is reached below critical temperature Tc

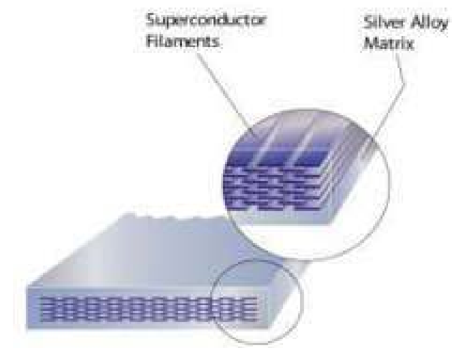
Current-Voltage-Characteristics

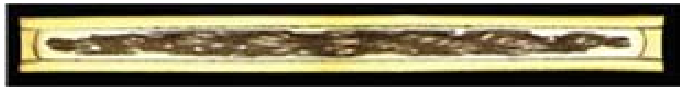


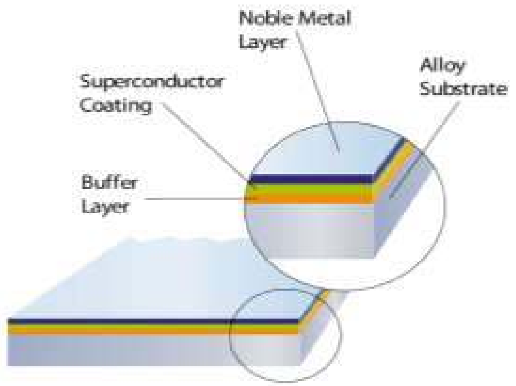
Practical definition of critical current density with 1 µV/cm criterion

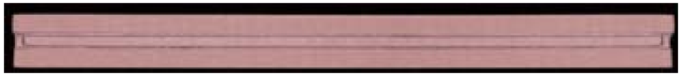
HTS Wire for Cable Applications

- Bi2Sr2Ca2Cu3O10 (Bi-2223)
  - 1st generation material (1G)
  - Available in long length (> 1 km)
  - Critical current up to 200 A
  - Wire geometry: 4.3 mm × 0.4 mm
- YBa2Cu3O7 (Y-123)
  - 2nd generation material (2G)
  - Different manufacturing process
  - Expected to be cheaper
  - Critical current up to 100 A
  - Wire geometry: 4.4 mm × 0.4 mm

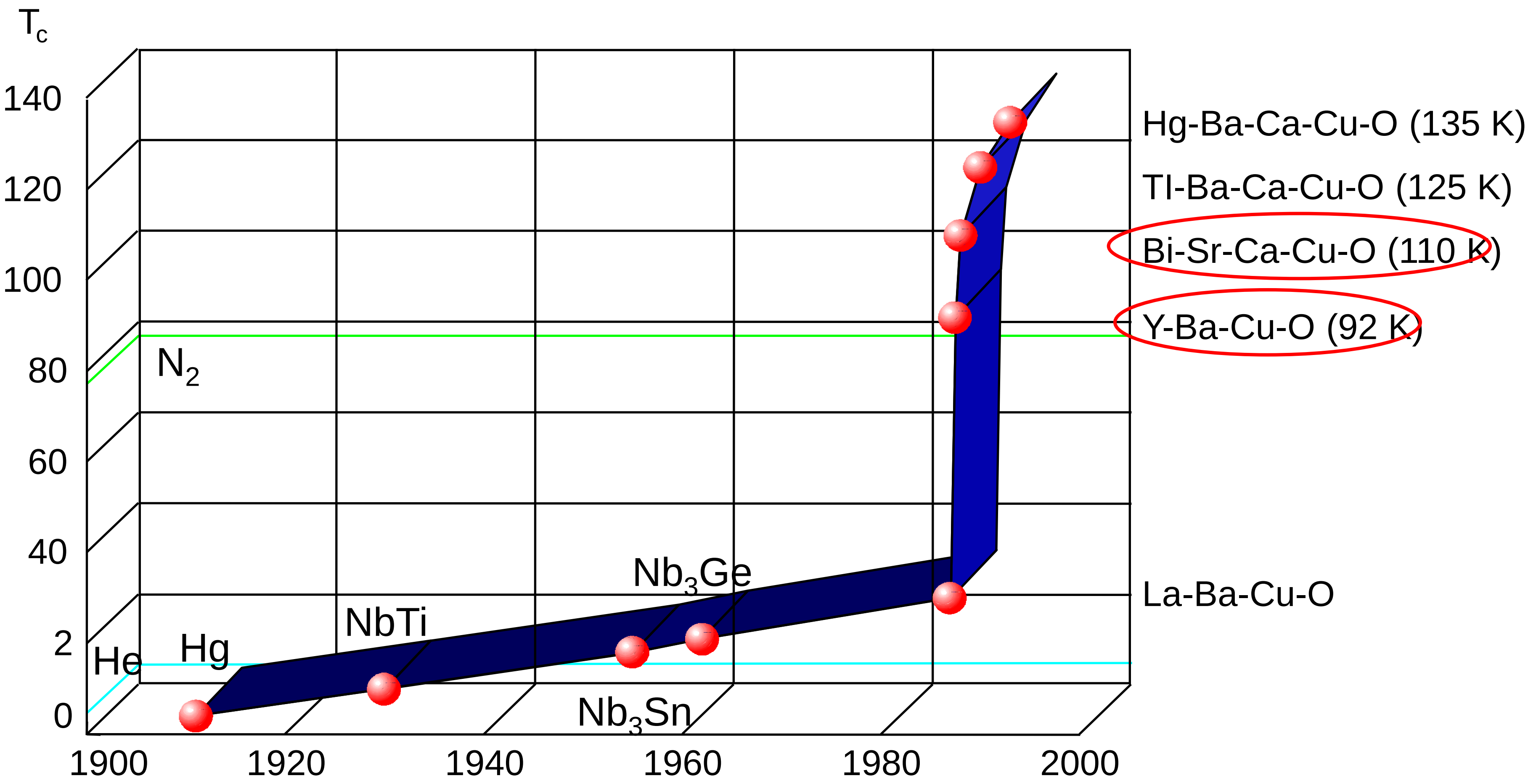








Materials showing Superconducting Behavior



High Temperature Superconductors (HTS) can be cooled with Liquid Nitrogen (LN2)

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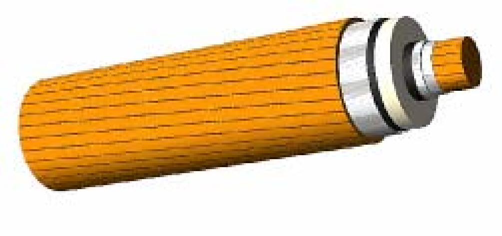
Components of an HTS-Cablesystem

- Core
  - Transport the current
  - Withstand the voltage

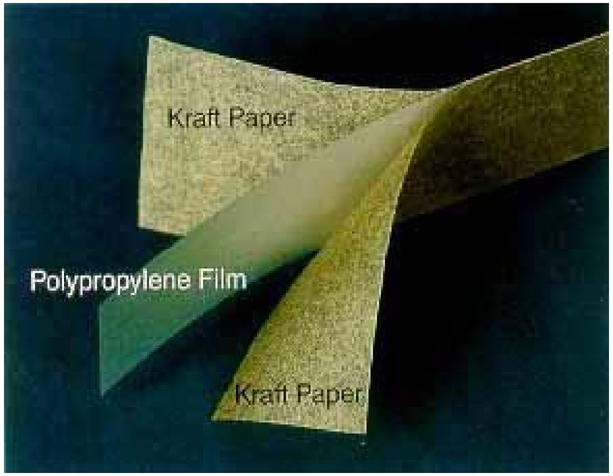


- Cryostat
  - Insulate thermally – keep the cable cold
  - Transport the liquid nitrogen
- Termination
  - Connect the system to the grid
  - Manage the transition between cold temperature and room temperature
  - Provide connection to the cooling system

- Joints
  - Connection of two cables
  - Intermediate access to cooling medium

High Voltage Dielectric for HTS Cables

- Lapped dielectric system using PPLP (Polypropylene laminated paper) is established as the insulation for high voltage superconducting power cables
  - Low dielectric losses
  - High dielectric strength
  - Can be used on conventional paper lapping machines
  - Very good mechanical properties (dry bending)
- Insulation is impregnated with LN_2 under pressure to avoid the formation of nitrogen bubbles
- Low dielectric loss factor tan δ is important for cables at higher voltage levels as all losses have to be removed by the cooling system

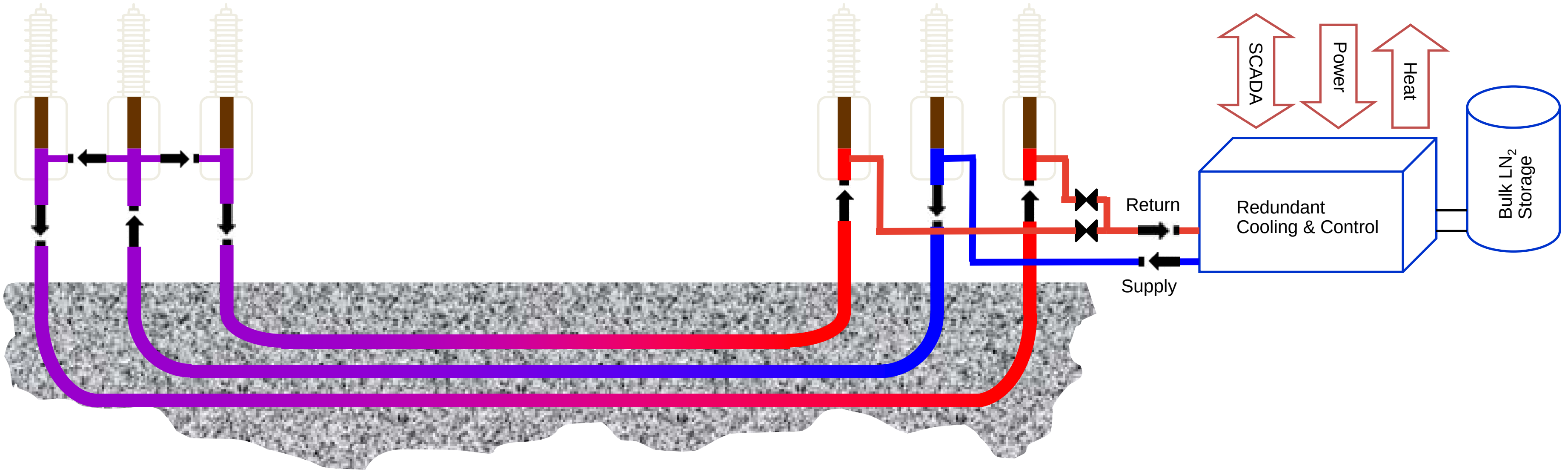


Thermal Insulation - Cryostat

- Design of cryogenic envelope
  - Two concentric longitudinal welded and corrugated stainless steel tubes
  - Multilayer Superinsulation in between the tubes
  - Low loss spacer to avoid contact between inner and outer tube
  - Vacuum to avoid convection heat losses (10^{-5} mbar)
  - PE-outer sheath (optional)
- Manufactured in a continuous process on UNIWEMA machines (Nexans own built machine)
- Quality control
  - Helium leak test of all welds and pieces to ensure long term vacuum tightness

Nexans has delivered more than 100 km of flexible transferlines

Cooling Flow



No separate return line required in case of individual cryostats

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Motivation for Inner City HTS Cables

- Power supply within European cities predominantly with cables
  - Many quite old cables and substations
  - Refurbishment / replacement in upcoming years
  - Adaption of substations to new load requirements

- Study was done investigating employment of high temperature superconductor systems (HTS cables in combination with HTS fault current limiters)
  - Option for replacing conventional cables
  - Enabling of new grid concepts

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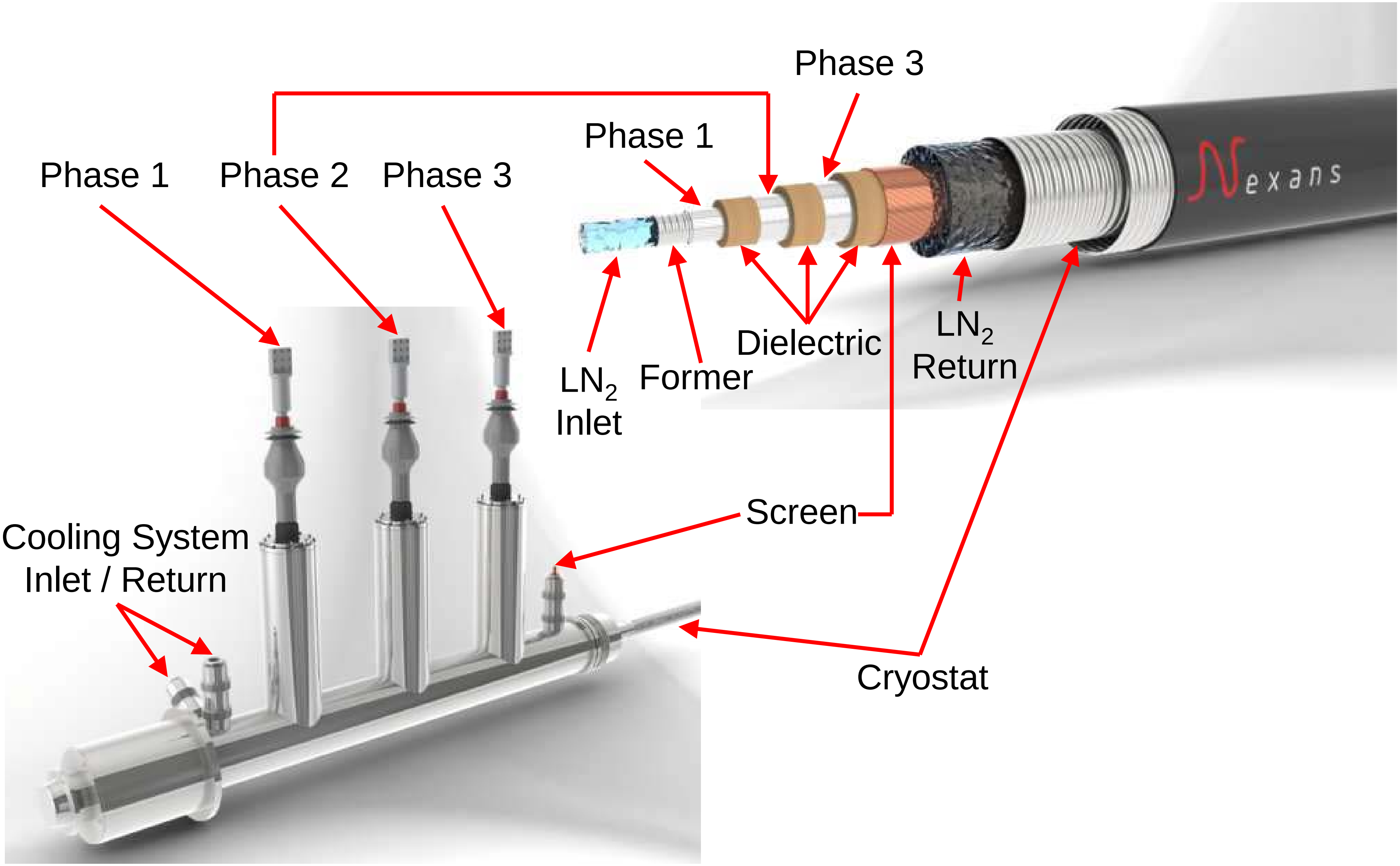
Cable and Termination Design



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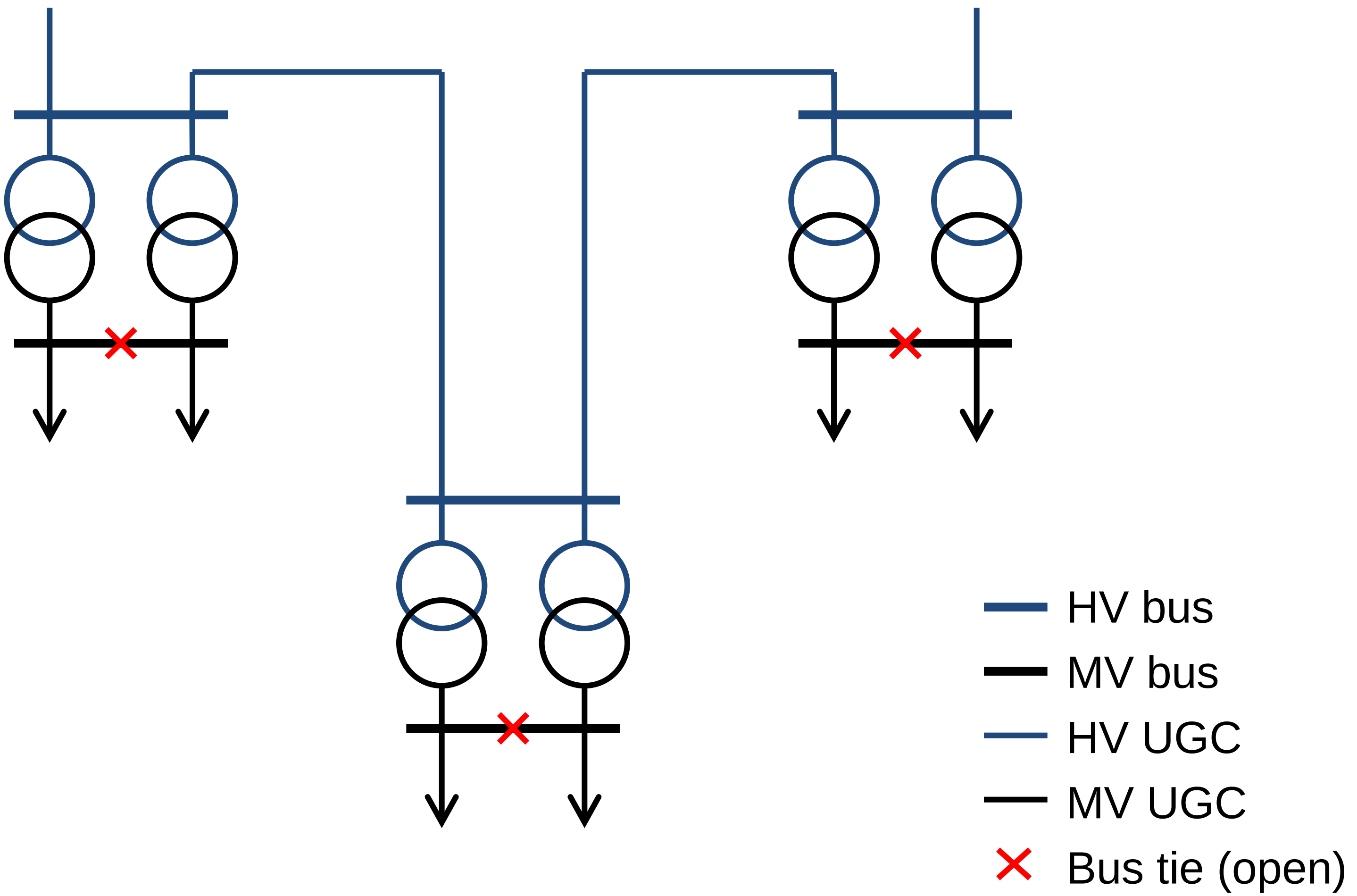
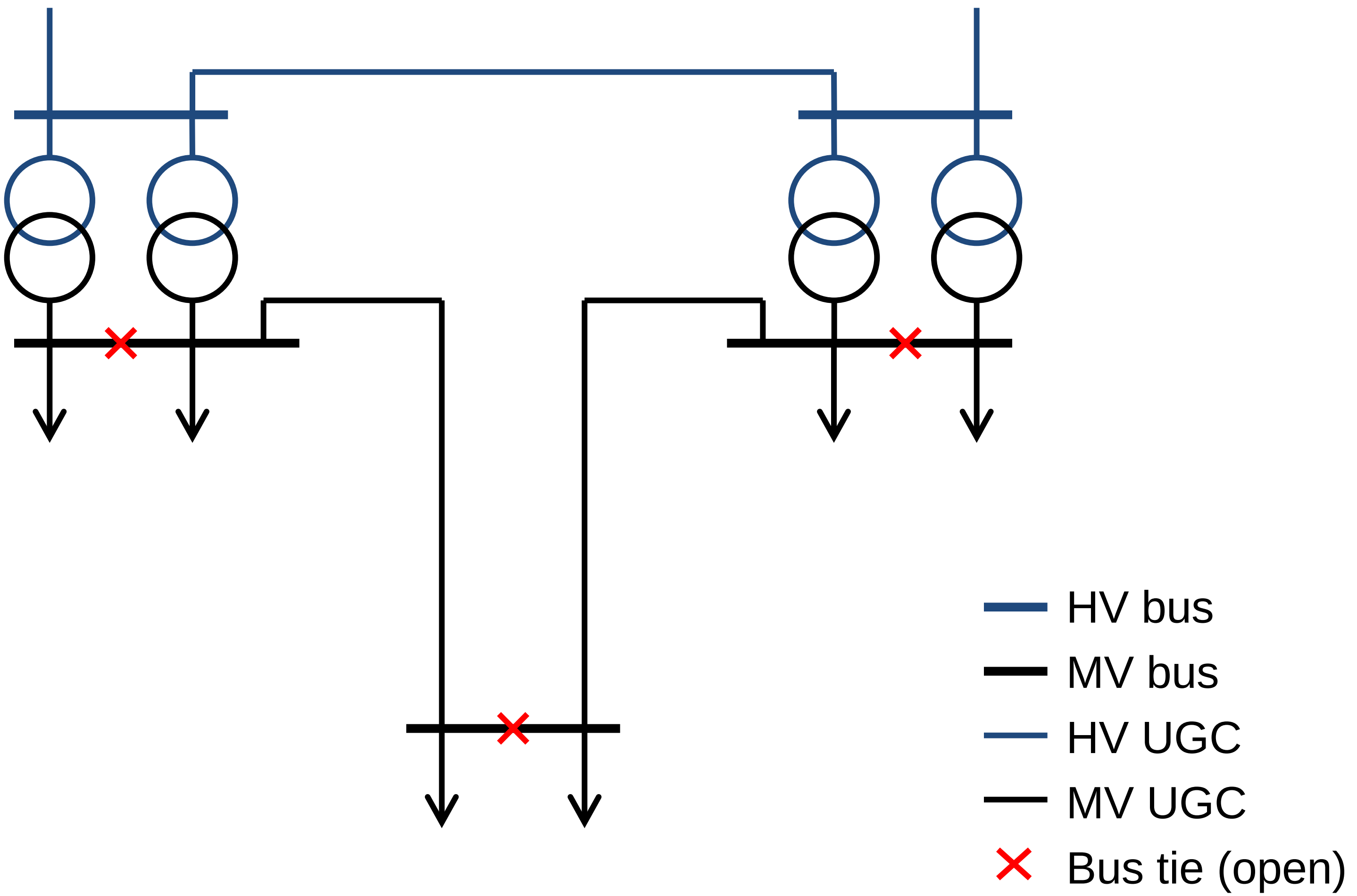
Grid Concept with HV Cables



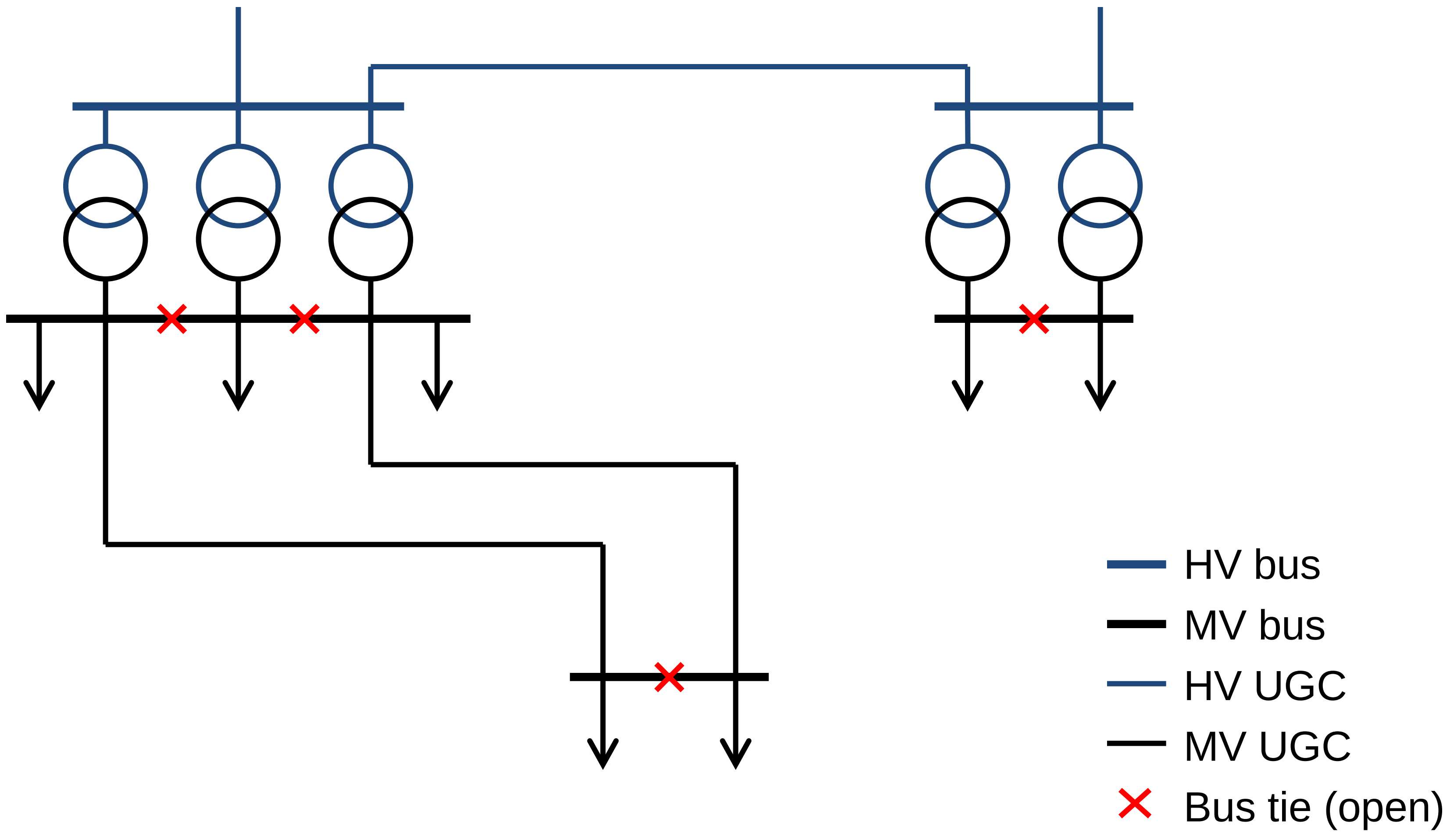
Capacity of one transformer equals total load in each substation

Grid Concept with MV HTS Cables (1)



Capacity of one transformer equals total load in each substation

Grid Concept with MV HTS Cables (2)



Capacity of one transformer equals total load in each substation

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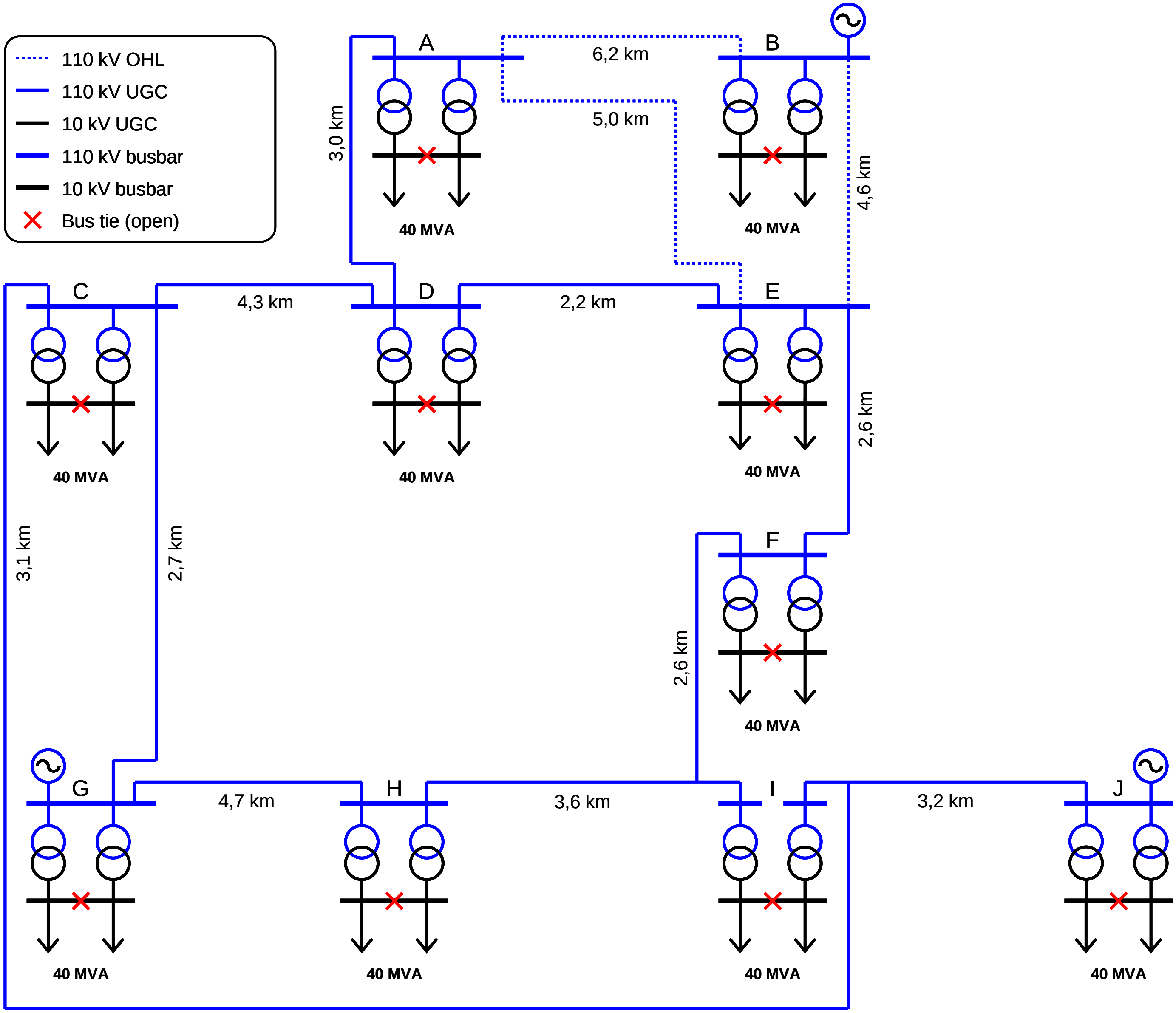
Superconducting MV Cables for Power Supply in Urban Areas

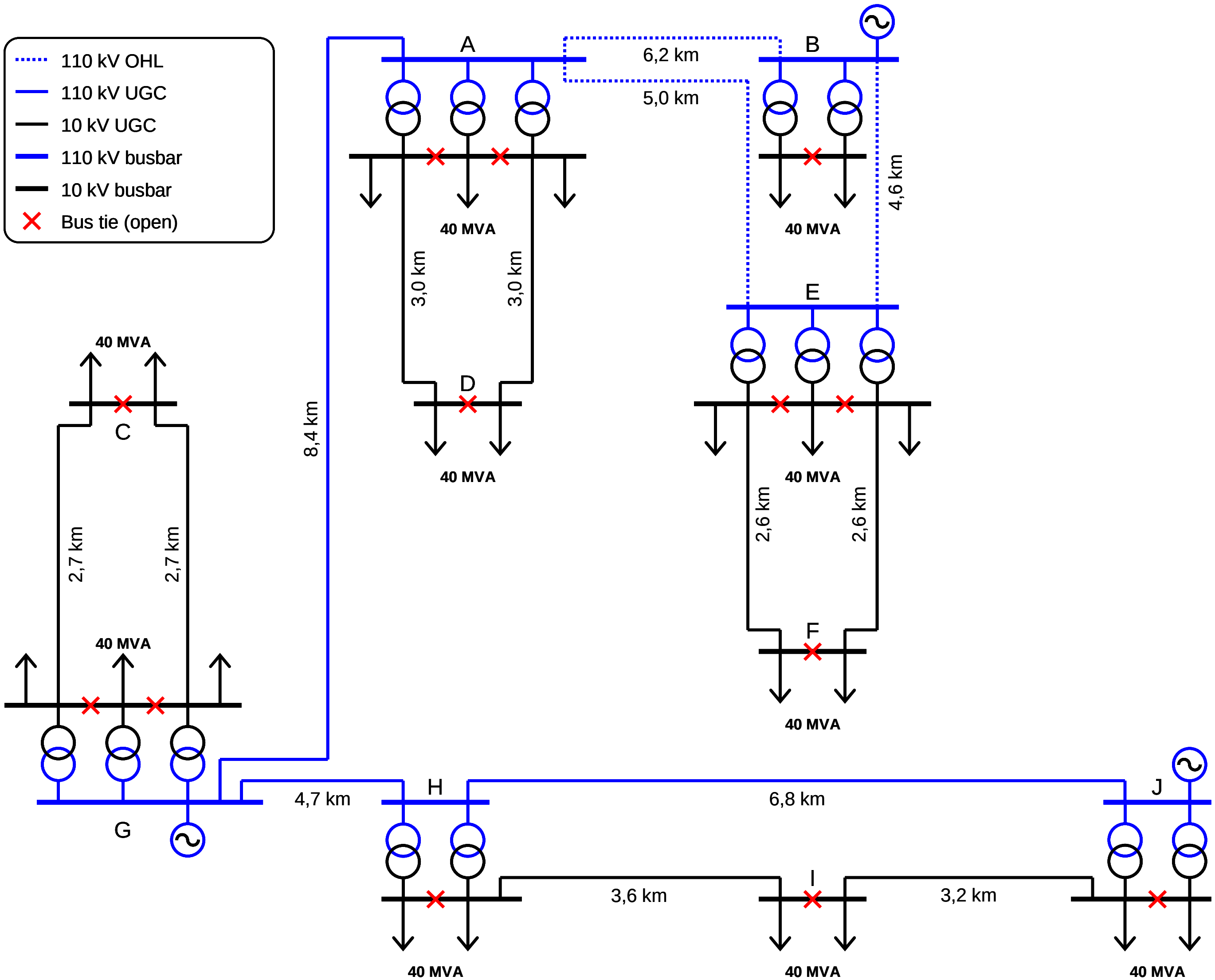
Contents

- Applications and specification
- Cable design
- Operation parameters
- HTS cables in the grid
- Economic feasibility
- State-of-the-art of HTS cable R&D
- Tests

Urban Grid with HV Cables

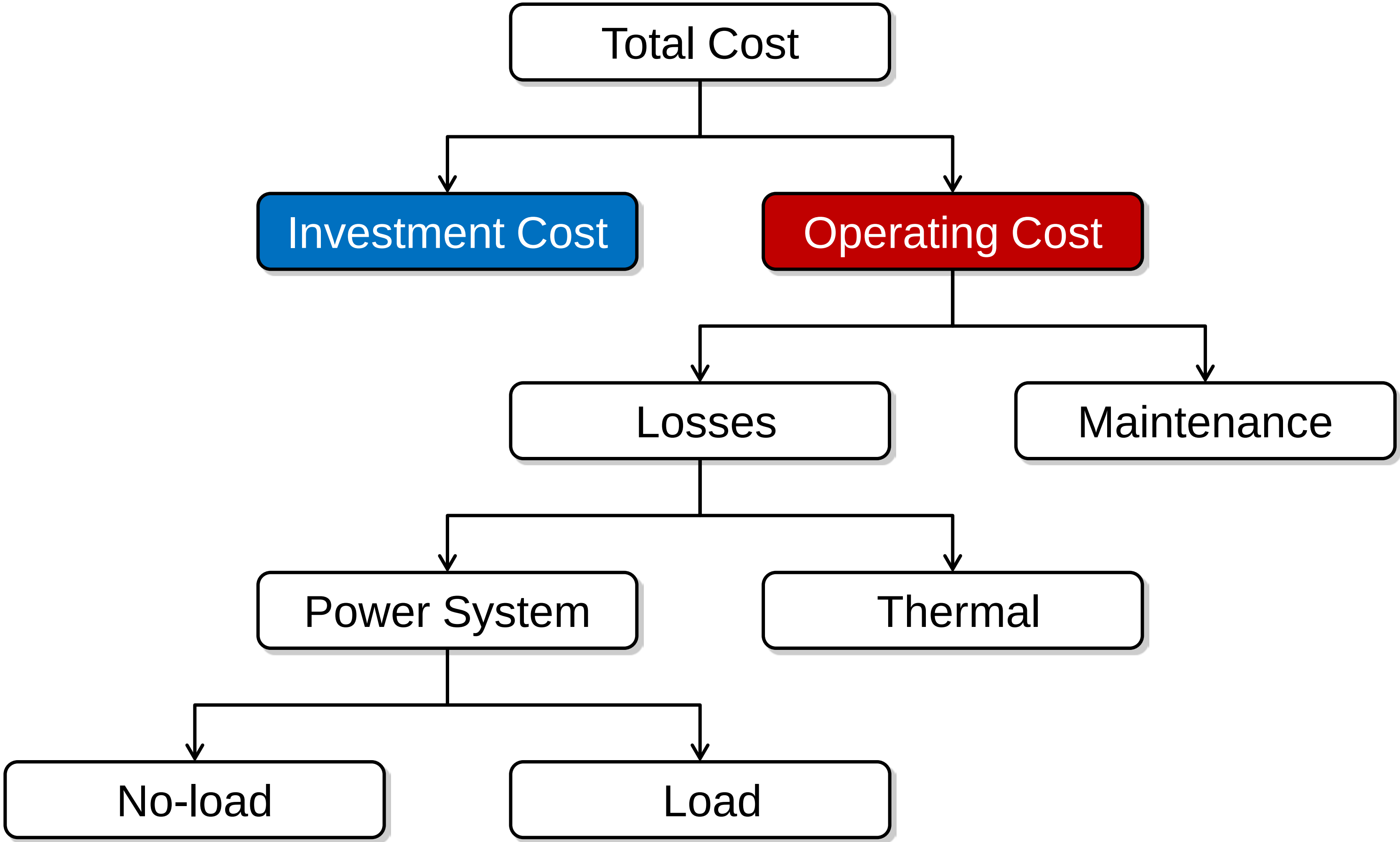


Urban Grid with MV HTS Cables

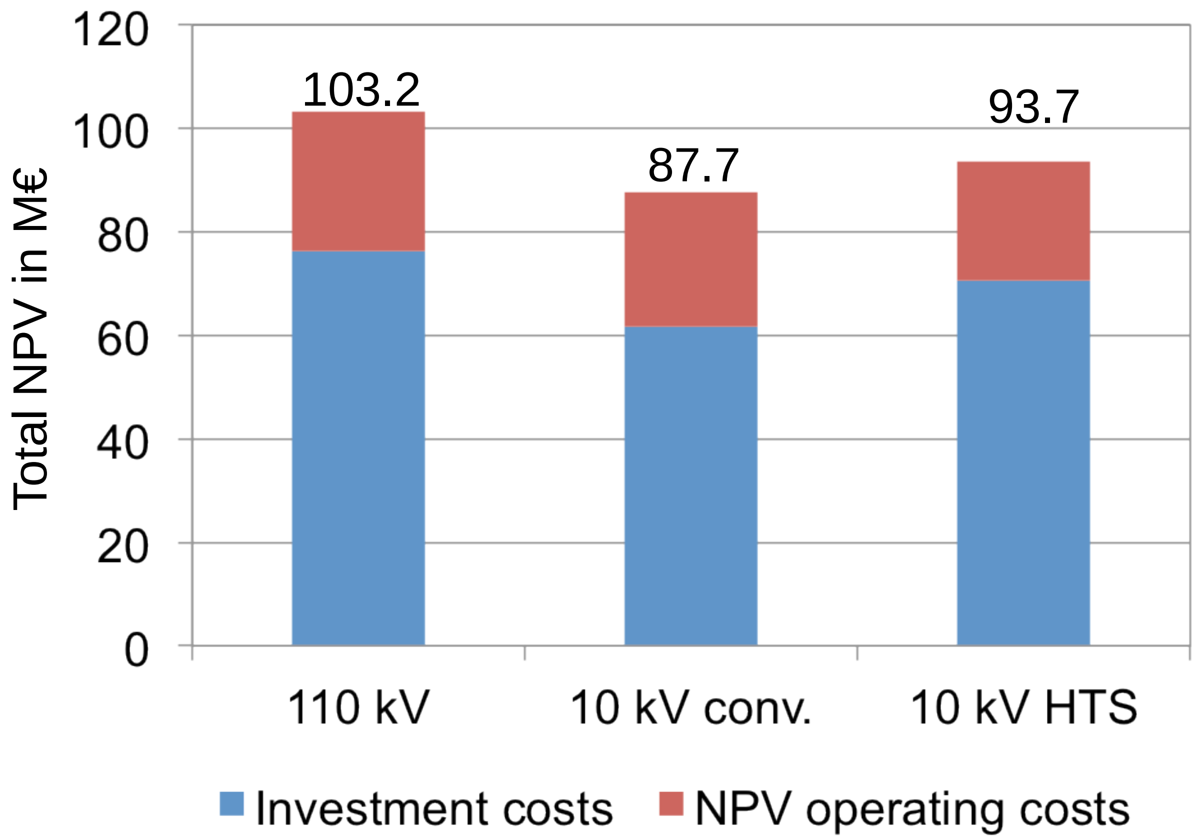


Overall Changes in the Grid

- Dispensable devices for new grid concept
  - 12.1 km of 110 kV cable systems
  - 12 x 110 kV cable switchgear
  - 5 x 40 MVA, 110/10 kV transformers
  - 5 x 110 kV transformer switchgear
  - 5 x 10 kV transformer switchgear
- Additionally required devices for new grid concept
  - 23.4 km of 10 kV HTS cable system
  - 16 x 10 kV cable switchgear
  - 3 x 10 kV bus ties


Total Cost
Investment Cost
Operating Cost
Losses
Maintenance
Power System
Thermal
No-load
Load

- Comparison of 3 different options based on NPV method
- Investment costs and operating costs (maintenance and losses)
- 40 years
- 2 % yearly increase
- 6.5 % interest rate
- 65 €/MWh



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Project objectives

- Development and field test of a 1 km long 10 kV, 40 MVA (2.3 kA) HTS cable in combination with a resistive type SFCL
- Project start: 09/2011

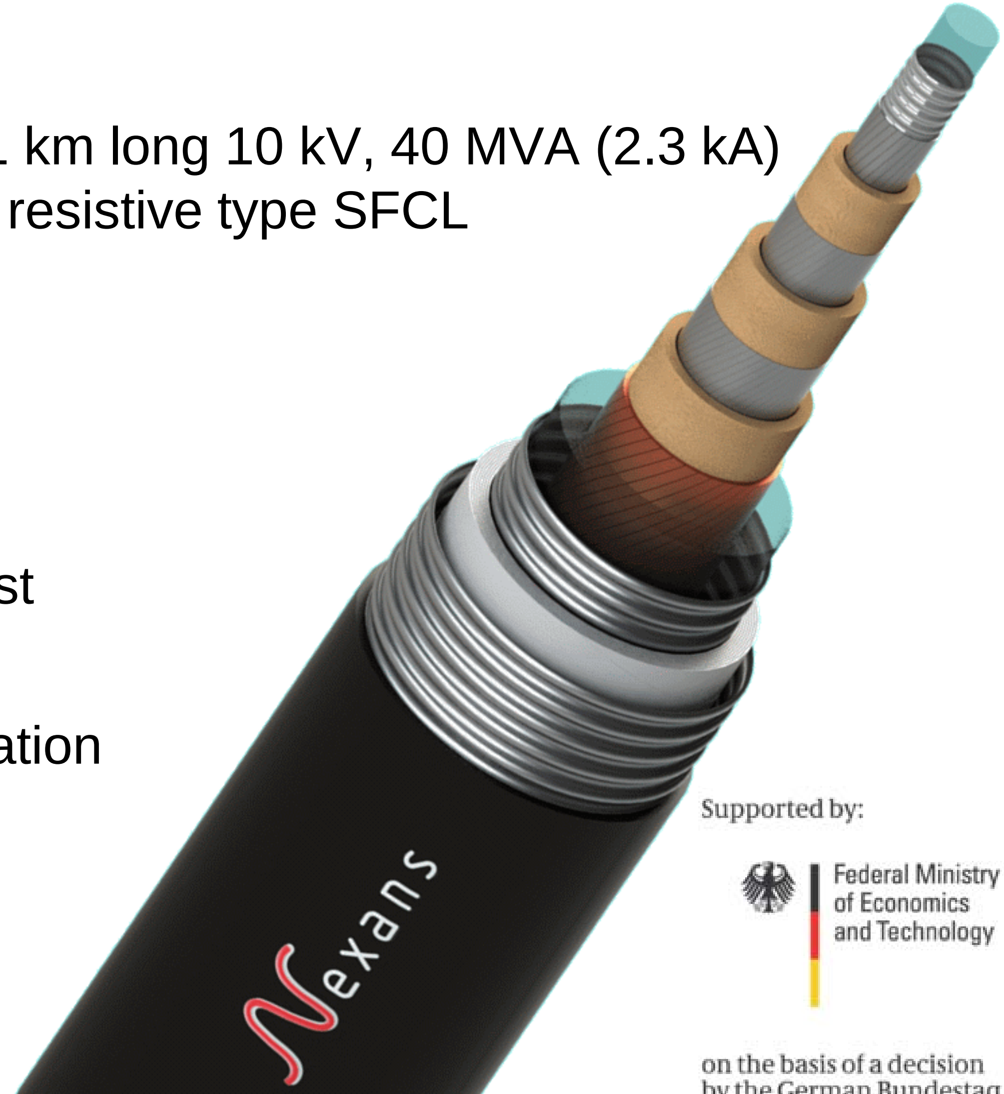
Project partners

- RWE – Specification and field test
- Nexans – HTS cable and FCL
- KIT – HTS tests and characterization

VORWEG GEHEN

Nexans

KIT Karlsruhe Institute of Technology



Supported by:

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Installation in Downtown Essen

- 10 kV bus connection of two substations with HTS system (cable + SFCL)
- Approximately 1 km cable system length with one joint
- Installation in Q4/2013, afterwards at least two year field test in grid

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Conclusions

- HTS systems attractive alternatives to conventional systems
  - Replacing HV cable systems with MV HTS cable systems
  - Reduction of inner city transformer substations
- Concentric HTS cable systems for MV applications
  - Very good electromagnetic behavior
  - Thermally independent from environment
  - Small right of way and reduced installation costs
- Enabling new grid concepts for urban area power supply
- Ampacity project in Germany started (HTS cable and SFCL)