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25 YEARS

THEVA

HTS Cable Technology – a Chance for Addressing the Challenges of Energy Transition

Werner Prusseit
THEVA Dünnschichttechnik GmbH

Virtual CCA 2021
11.10.2021

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WHY HTS CABLES ?

The perspective of a grid operator

Our task: Reliable, uninterrupted power supply

Not our job: Making experiments in our grid

Why bother with HTS technology?

- Cool, disruptive technology 
- Energy efficiency — Only 6% grid losses - 1.5% at HV
- Cooling is reliable — No cooling even more
- Can transport lots of power — We have proven solutions
- HTS can be cheaper — Customer pays the bill

No incentive

External urge necessary

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The times they are changin'

Bob Dylan, 1963

Energy Transition: Challenge and Chance

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CLIMATE CHANGE IS THE BIGGEST THREAT FOR MANKIND

No combustion of fossil fuels – nowhere!

Better get ready for it

The world is getting fully electric

Protect your infrastructure

Make it resilient

against flooding, hurricanes, drought & fire, ice, overloads




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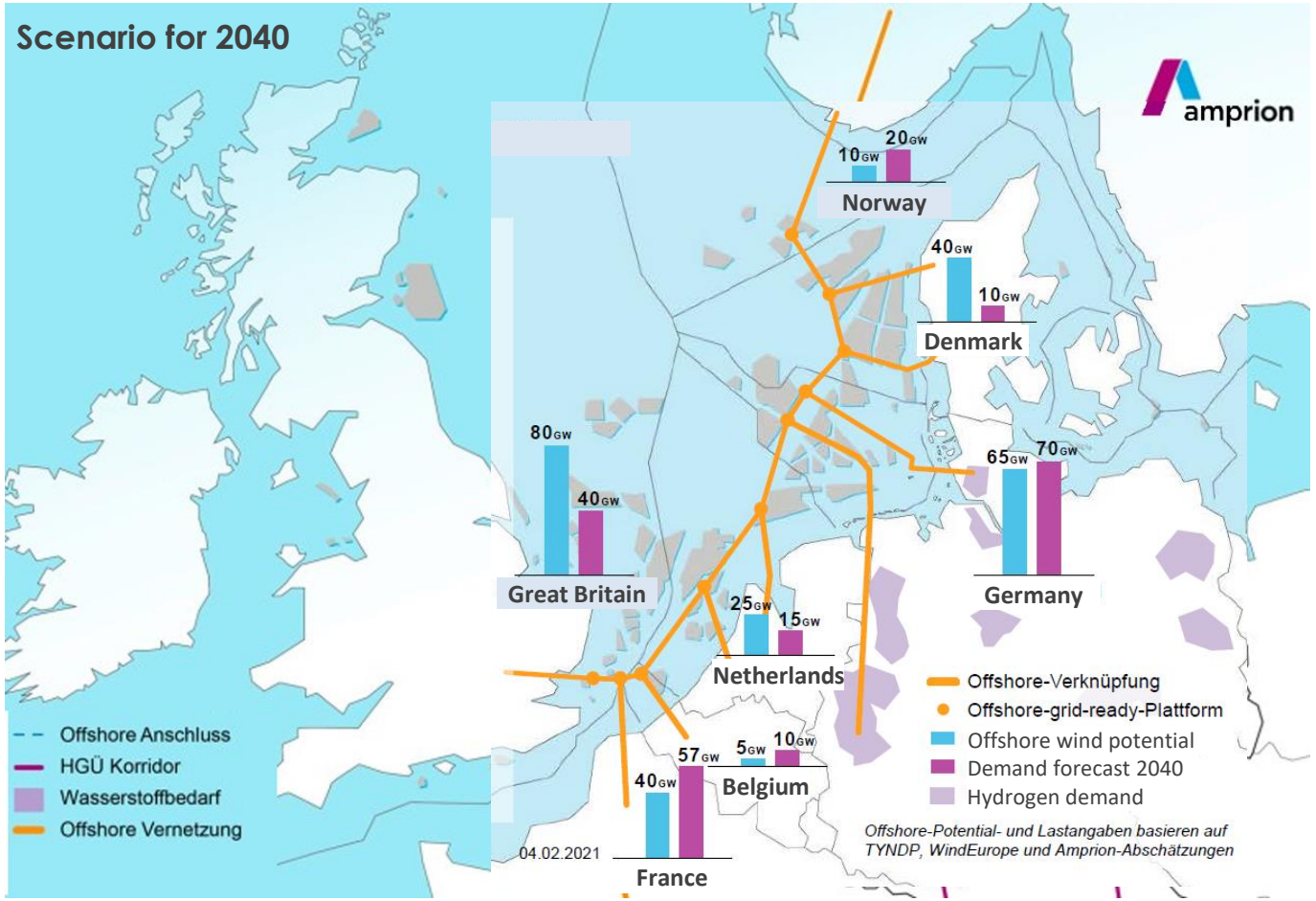
FACING EUROPEAN TRANSMISSION CHALLENGES

EUROBAR

- **European Offshore Grid**
  Sharing offshore wind and making it base load capable
- **Trans-European Network**
  DE: in 33 TWh; out 50.5 TWh (10%)
  Net export 2020: 17.5 TWh
- **Integration of Power to Gas**
  Hydrogen infrastructure
- **Strengthening domestic transmission grid**
  from coast to consumer



Amprion: major TSO in Europe

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ENERGY TRANSITION IN GERMANY

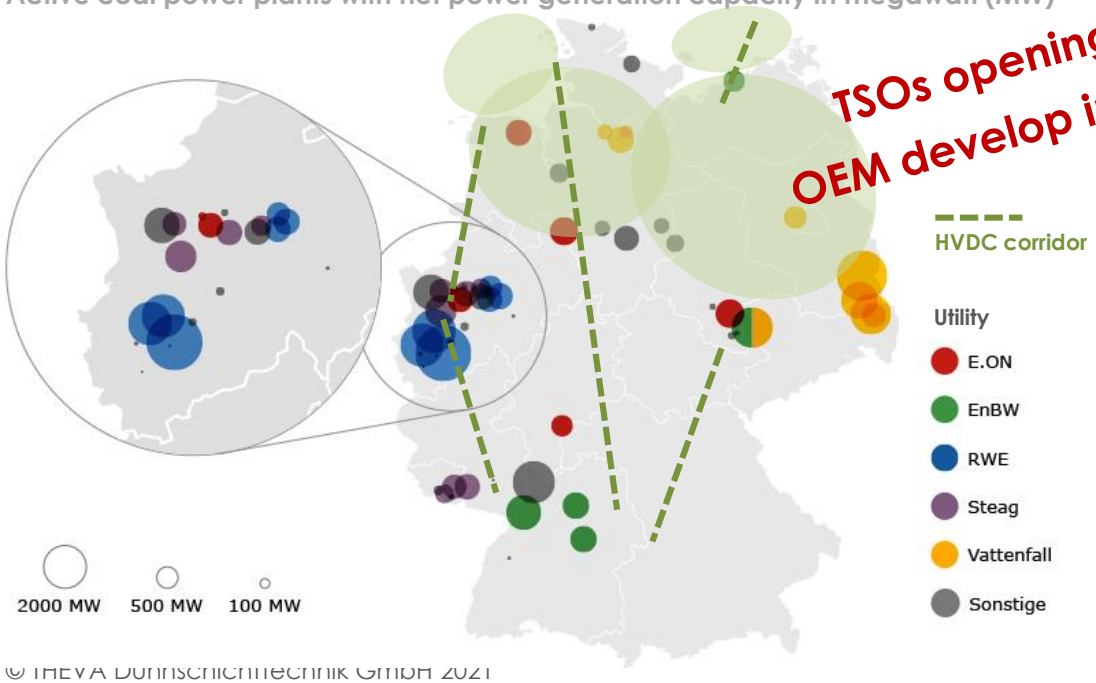
Phasing out nuclear power by 2022: 11 GW balanced by redundancy & renewables

but, the main challenge is yet to come ◀ **Political urge**

Phasing out coal power plants by 2038: 50 GW requires renewables **plus strongly enhanced grid**

Coal power plants in Germany

Active coal power plants with net power generation capacity in megawatt (MW)



TSOs opening for innovation

OEM develop innovative solutions

Long distance transport: HVDC

- New development: 525 kV_{DC} XLPE cables
- 800 km from north to south (new routes)
- Point to point connections
- Huge, expensive converter stations

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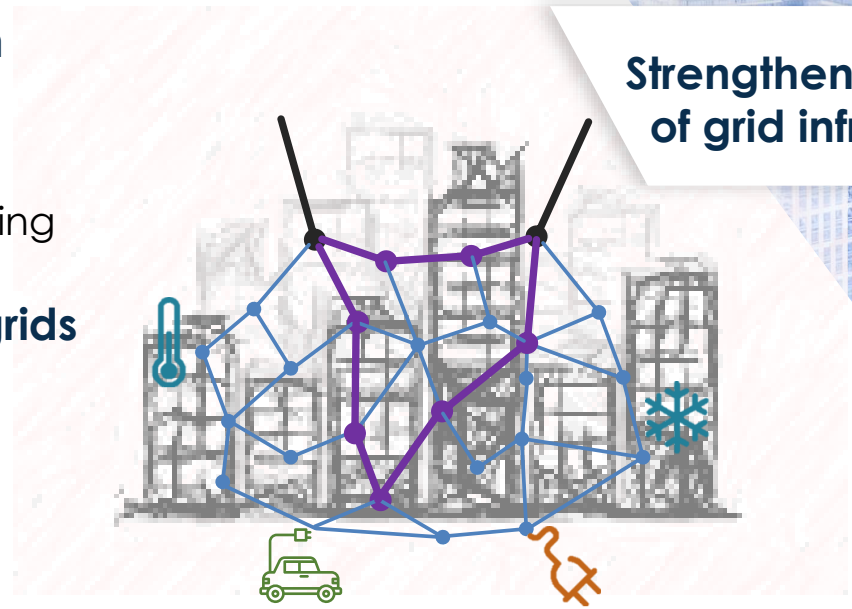
The Distribution Challenge – Getting Gigawatts in Congested Areas

Fossil fuel substituted by electric energy

- Mobility
- Heating
- Industrial processes

Increasing energy consumption

- Increasing city population
- Demographic change
- IT, communication, air-conditioning



Strengthening and renewal of grid infrastructur necessary

Bottleneck existing distribution grids

- Aging infrastructure
- Design / capacity
- Losses ⇒ CO_2

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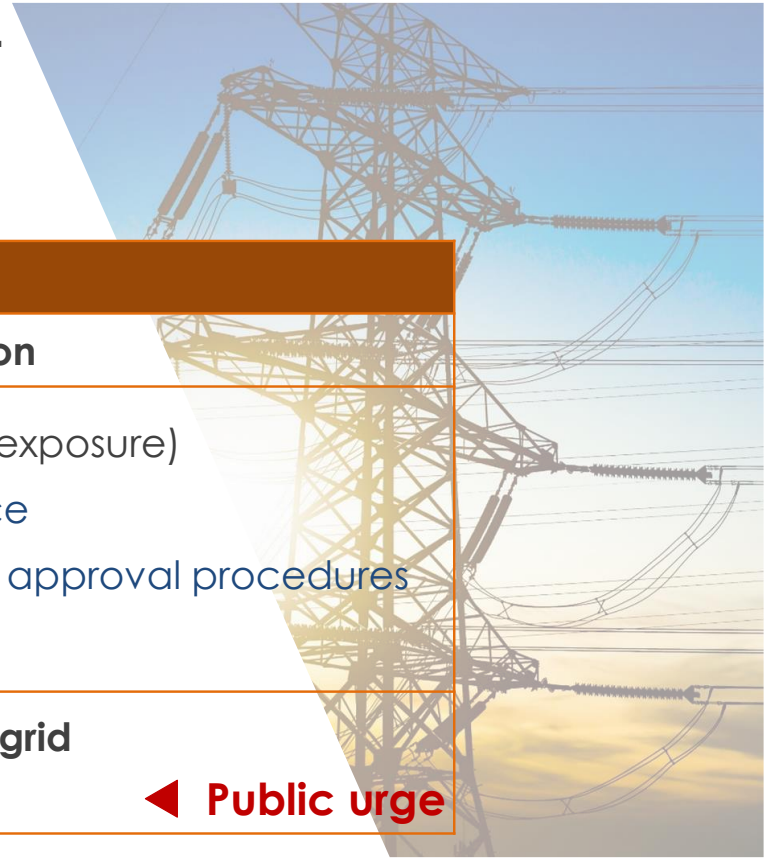
How Would a TSO Prefer to Transport Gigawatts ?

The standard solution – AC transmission in OHL

AC allows easy transformation between voltage levels
from long range EHV to short range MV and LV



Overhead Lines (OHL)	
Pro	**Con**
▪ Cheapest and easiest solution ▪ Accessibility ▪ No capacitive reactive power P_X ▪ Long distances without compensation	▪ High risk of damage (exposure) ▪ No public acceptance ▪ Long legal disputes & approval procedures

Historically, OHL constitute 90+% of our transmission grid

Today – practically no new OHL feasible ◀ **Public urge**

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INVISIBLE TRANSPORT AND DISTRIBUTION OF HIGH POWER?

AC cables	DC cables
▪ **Dominating in urban distribution (LV, MV, HV)** ▪ High power transport: only few, **short** EHV intermediate connections (380 kV, < 25 km)	▪ **High power, long distance transport** ▪ **Submarine cables** connecting countries/wind farms ▪ Germany: South-Link: 525 kV, 800 km
▪ Expensive (civil engineering) ▪ High capacitive reactive power ($\propto U_{\perp}^2$) ▪ Limited length w/o compensation (380 kV, 25 km)	▪ No reactive power, no length limit ▪ Point to point connections – no grid ▪ Huge, expensive converter stations

Cables are used where space, public and environment don't allow OHLs
Long distance and submarine connections only by DC cables




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UNIQUE SELLING PROPOSITIONS OF HTS CABLES

- **Current instead voltage** — transport of high power at lower voltage level
  low reactive power, long length without compensation
- **High power density – small footprint** — compact laying, reduced cost and obstruction
- **No environmental impact** — no warming, EM-emissions, interference

Public acceptance

2 GVA power transport options			
Spec	**HVAC-XLPE**	**HTS - AC**	**HVDC-XLPE**
Voltage (kV)	380	110	±525
Current (A)	1600	5,250	1900
Max. length (km)	25	200+	no limit
Cable system	2 × 3 = 6	2	2
Width: OP/(Constr.) (m)	10 (25)	1 (5)	5 (10)

EHV needs much space

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What needs to be done?

- **Proof of compactness: 500+ MW in Ø15 cm**
- **Demonstrate long (10+ km) distance cooling**

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SuperLink Project

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

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SUPERLINK PROJECT TEAM

Stadtwerke Munich	Utility for 400 V – 400 kV urban infrastructure
NKT Cables Group	HTS cable system manufacturer
Linde Group	Technical gases cryogenics and cryogenic systems
THEVA	HTS tape manufacturer project development
Univ. of Appl. Science South Westfalia	High voltage and cable testing
Karlsruhe Institute of Technology	Power systems electromagnetic and thermal modelling

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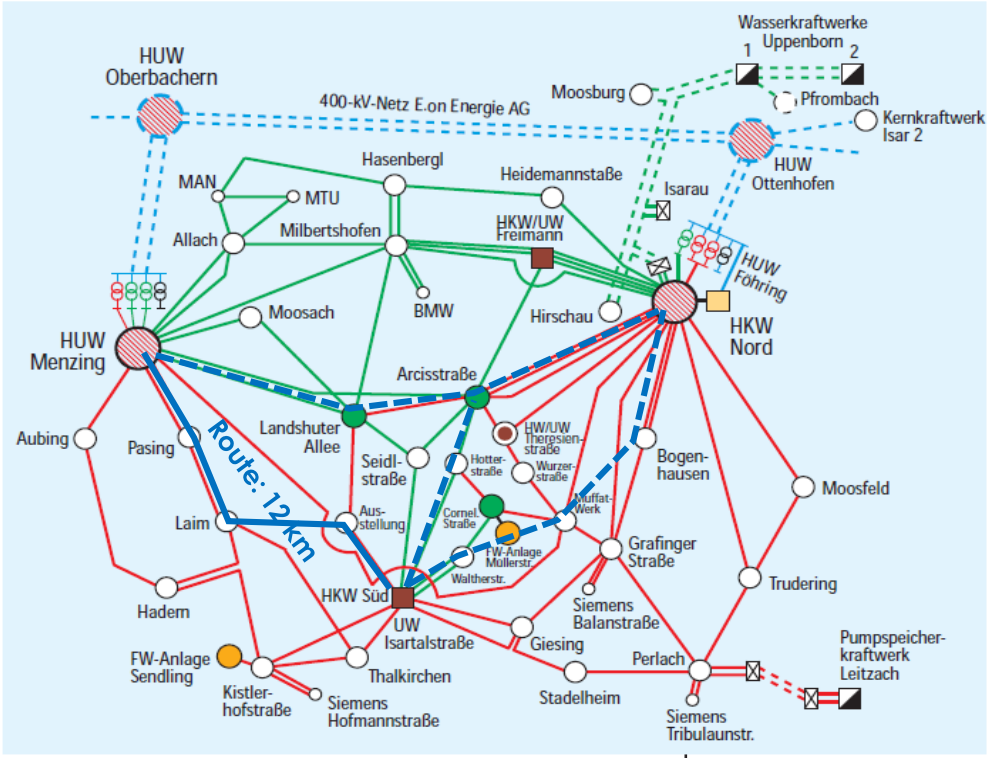
URGING PROBLEM OF THE CITY ULITLITY

Rebuilding the distribution grid and establish a 500 MVA connection across the city

- **Necessary change** in cable technology
  Non-availability of gas-pressure cables
- **Strong renewal pressure**:
  80+ % cables installed before 1980
  Enormous volume >90 HV cable sections
- **Connection of gas power station** in the south to transmission grid (NW) **across the city**
- **Avoidance of new 400/110 kV main substation** (space, cost)



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ALTERNATIVE SOLUTIONS

Transport of 500 MVA over 12 km

400 kV XLPE cable system

E.g. tunnel solution,
as in Berlin, London etc.

Same for GIL

400 kV overhead line

Not feasible in the city

Multiple 110 kV XLPE cable systems

5 systems & routes

Limited bending radii

Soil warming (spacing)

110 kV HTS cable

Novel technology

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ALTERNATIVE SOLUTIONS - ASSESSMENT

Transport of 500 MVA across 12 km in densely populated area

Criteria	400 kV XLPE	400 kV OHL	Multiple 110 kV	110 KV HTS
Minimum space	☹	☹	☹	☺
Public acceptance	☹	☹	😐	☺
Economic feasibility	☹	☺	☹	😐
Technical maturity	☺	☺	☺	😐
City grid integration	☹	☹	☺	☺
Power density	☺	☺	☹	☺
Low loss	☹	😐	☹	☺

The HTS option is very attractive – but needs development

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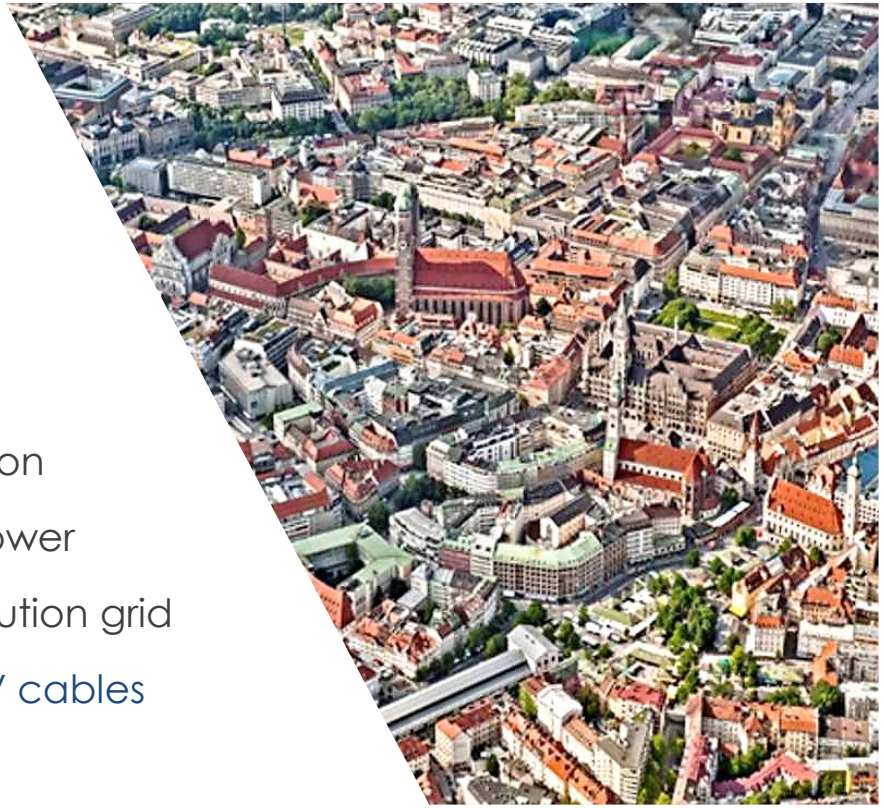
SW//M City Utility's Conclusion

HTS appears as unique & attractive solution

The 110 kV HTS cable solution …

- is the economically and technically most reasonable solution for the future urban power supply
- has minimum impact on environment, urban life and traffic
- minimizes obstruction of residents during construction and operation
- provides flexibility even at increasing consumption of electrical power
- improves the energy efficiency and carbon footprint of the distribution grid
- is an option for smart conversion of the city grid saving $^{1}/_{3}$ of all HV cables



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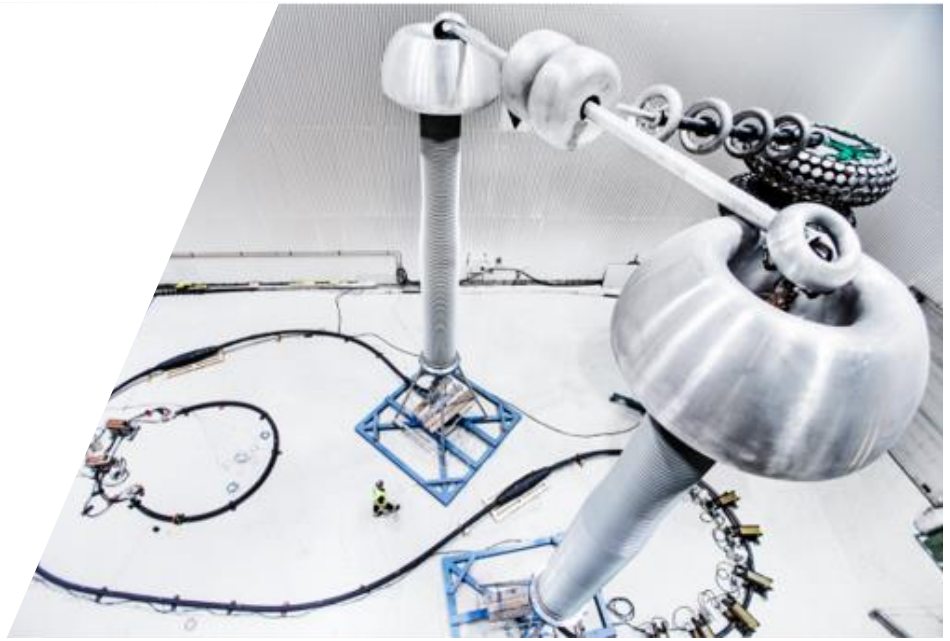
SUPERLINK CABLE PROJECT GOALS

Setting the stage for a long, high-power HTS cable connection in Munich

Development goals

- **Design concept** for a 12+ km long 110 kV cable line with all components and auxiliaries
- Capacity 500+ MVA in a **compact, single cable**
- **Closed cooling cycle & distributed cooling over 12+ km**
- **Development and type testing** of all components: cable, joints, terminals, efficient cooling substations
- In-grid testing of a **150 m long demo cable** in substation
- Project term: 10/2020 – 3/2023



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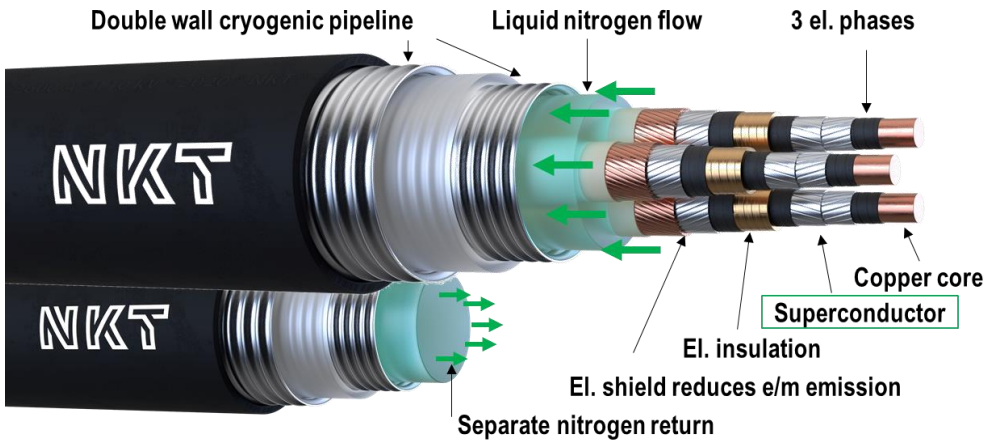
SUPERLINK CABLE DESIGN

Cable design

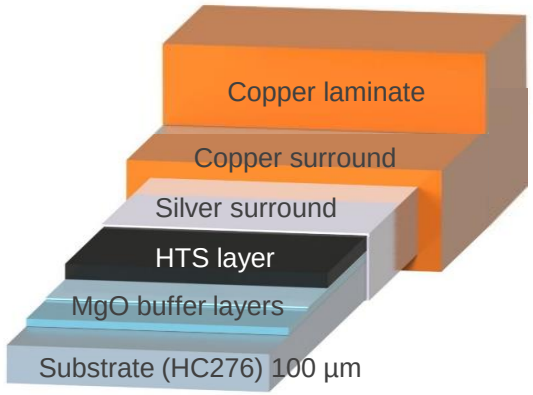
- 3 phases in one cryostat
- Superconducting phases and screens
- 110 kV, 500 MVA, 2.6 kA_{rms}
- Fault current resilient 40 kA for 1 s
- Black start capability
- Separate LN return pipe (single, one-way cable)



HTS conductor

Main manufacturing focus:

- ➢ Cost efficient production
- ➢ High yield processes (e.g. Laser-slitting)



- Robust, thick Cu-laminated conductor
- Width 3 mm to reduce AC-losses

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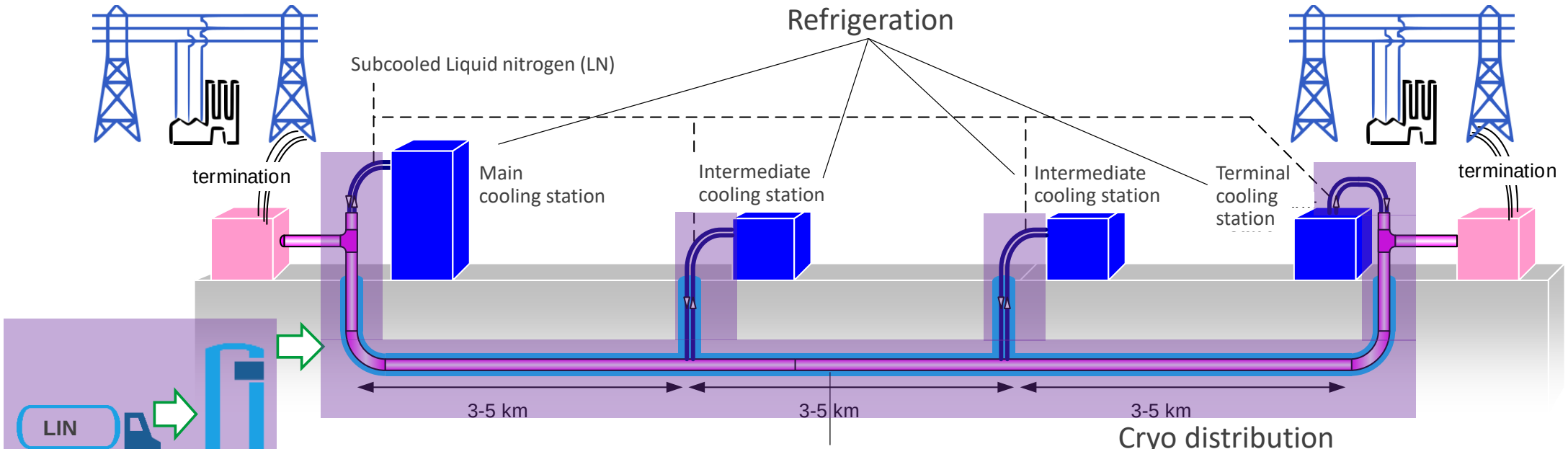
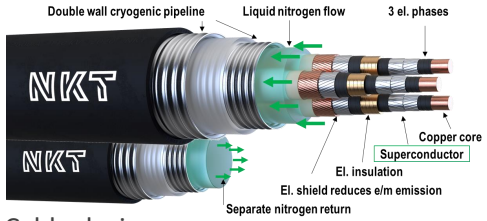
DISTRIBUTED COOLING SYSTEM



Cryo distribution



Cable design

Options for cryofluid:
- Nitrogen
- Nitrogen-oxygen mix (e.g. air)

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Economic Efficiency of HTS Cables

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INDICATIONS FOR FAVOURABLE ECONOMICS – A CHECK LIST

CAPEX

- **Transport at lower voltage level („Current instead Voltage“)**
  (HV instead EHV, MV instead HV)
- **Scarce underground space, reduced civil engineering**
  Urban retrofit (substitute gas pressure- or oil cables)
  Obstacles, crossings, difficult terrain

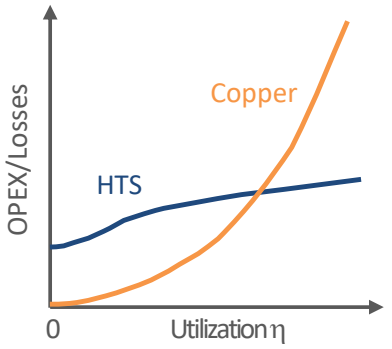
OPEX

- **High current, heavy duty** application
- **High load factor and utilization** (η > 50%)
  Moderate load profile / fluctuations ($d\eta/dt$)

Soft criteria

- Additional monetary benefits (e.g. cold gas, LN-pipeline)
  - Economic benefits (minimally invasive)
  - Resource efficiency (materials, construction, „ecological footprint“)
  - **Public acceptance** („not in my backyard“)

Narrow trench



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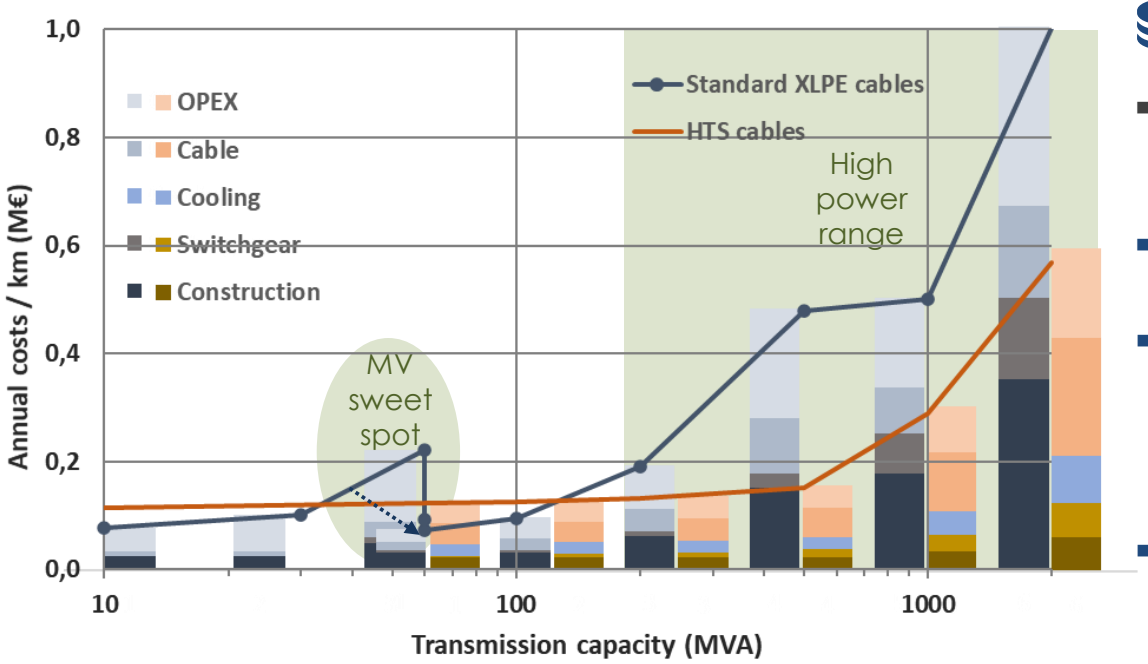
COST ASSESSMENT – COMPARING STANDARD XLPE TO HTS CABLES

Higher HTS cable costs need to be balanced by other savings



Business cases for HTS cables

- Higher HTS cable costs over-compensated by lower costs of civil engineering, switchgear etc.
- **OPEX lower**, when average **utilization > 50%**
- **Medium voltage sweet spot** at 40-80 MVA
  if HV level can be avoided (smaller towns);
  very HTS cost sensitiv
- **High power transport 200+ MVA**
  HTS competitive to multiple HV- or EHV-cables;
  smaller HTS cost sensitivity

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SUMMARY

HTS cables are a new tool to handle high power distribution in densely populated areas

- GVA distribution into metropolitan areas (e.g. Rhine-Ruhr area)
- Flexible cables fitting in city ducts with high current carrying capacity
- Reduced reactive power allows distances 100+ km without compensation
- Submarine cables and interconnects (under investigation)

The SuperLink project is a blueprint for a high power transmission cable

- High power in compact cable at distribution voltage level (instead of EHV)
- Distributed cooling over long distance

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WHY HTS CABLES ?

Why bother with HTS technology ?

Because you will need it !

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Thank you!

Supported by:

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