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

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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
- Cooling is reliable
- Can transport lots of power
- HTS can be cheaper

Only 6% grid losses - 1.5% at HV
No cooling even more
We have proven solutions
Customer pays the bill

No incentive
External urge necessary

Invited presentation TC-1 was given at the virtual CCA 2021, October 11-15, 2021.
The times they are changin’

Bob Dylan, 1963

Energy Transition: Challenge and Chance
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
**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

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)

Phasing out coal power plants by 2038: 50 GW

requires renewables plus strongly enhanced grid

Long distance transport: HVDC

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

TSOs opening for innovation

OEM develop innovative solutions

Political urge
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

Bottleneck existing distribution grids

• Aging infrastructure
• Design / capacity
• Losses ⇒ CO₂

Strengthening and renewal of grid infrastructure necessary
# 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)

<table>
<thead>
<tr>
<th>Pro</th>
<th>Con</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheapest and easiest solution</td>
<td>High risk of damage (exposure)</td>
</tr>
<tr>
<td>Accessibility</td>
<td>No public acceptance</td>
</tr>
<tr>
<td>No capacitive reactive power $P_X$</td>
<td>Long legal disputes &amp; approval procedures</td>
</tr>
<tr>
<td>Long distances without compensation</td>
<td></td>
</tr>
</tbody>
</table>

Historically, OHL constitute 90+% of our transmission grid

Today – practically no new OHL feasible

Public urge
### Invisible Transport and Distribution of High Power?

<table>
<thead>
<tr>
<th>AC cables</th>
<th>DC cables</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Dominating in urban distribution (LV, MV, HV)</td>
<td>▪ High power, long distance transport</td>
</tr>
<tr>
<td>▪ High power transport: only few, short EHV</td>
<td>▪ <strong>Submarine cables</strong> connecting countries/wind farms</td>
</tr>
<tr>
<td>▪ Intermediate connections (380 kV, &lt; 25 km)</td>
<td>▪ Germany: South-Link: 525 kV, 800 km</td>
</tr>
<tr>
<td>▪ Expensive (civil engineering)</td>
<td>▪ No reactive power, no length limit</td>
</tr>
<tr>
<td>▪ High capacitive reactive power (\alpha U_0^2)</td>
<td>▪ Point to point connections – no grid</td>
</tr>
<tr>
<td>▪ Limited length w/o compensation (380 kV, 25 km)</td>
<td>▪ Huge, expensive converter stations</td>
</tr>
</tbody>
</table>

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

### 2 GVA Power Transport Options

<table>
<thead>
<tr>
<th>Spec</th>
<th>HVAC-XLPE</th>
<th>HTS - AC</th>
<th>HVDC-XLPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (kV)</td>
<td>380</td>
<td>110</td>
<td>±525</td>
</tr>
<tr>
<td>Current (A)</td>
<td>1600</td>
<td>5,250</td>
<td>1900</td>
</tr>
<tr>
<td>Max. length (km)</td>
<td>25</td>
<td>200+</td>
<td>no limit</td>
</tr>
<tr>
<td>Cable system</td>
<td>2 × 3 = 6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Width: OP/(Constr.) (m)</td>
<td>10 (25)</td>
<td>1 (5)</td>
<td>5 (10)</td>
</tr>
</tbody>
</table>


Invited presentation TC-1 was given at the virtual CCA 2021, October 11-15, 2021.
What needs to be done?

- Proof of compactness: 500+ MW in Ø15 cm
- Demonstrate long (10+ km) distance cooling
SuperLink Project
## SuperLink Project Team

<table>
<thead>
<tr>
<th>Organization</th>
<th>Role Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stadtwerke Munich</td>
<td>Utility for 400 V – 400 kV urban infrastructure</td>
</tr>
<tr>
<td>NKT Cables Group</td>
<td>HTS cable system manufacturer</td>
</tr>
<tr>
<td>Linde Group</td>
<td>Technical gases cryogenics and cryogenic systems</td>
</tr>
<tr>
<td>THEVA</td>
<td>HTS tape manufacturer project development</td>
</tr>
<tr>
<td>Univ. of Appl. Science South Westfalia</td>
<td>High voltage and cable testing</td>
</tr>
<tr>
<td>Karlsruhe Institute of Technology</td>
<td>Power systems electromagnetic and thermal modelling</td>
</tr>
</tbody>
</table>
URGING PROBLEM OF THE CITY UTILILITY

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)
**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

<table>
<thead>
<tr>
<th>Criteria</th>
<th>400 kV XLPE</th>
<th>400 kV OHL</th>
<th>Multiple 110 kV</th>
<th>110 kV HTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum space</td>
<td>😞</td>
<td>😞</td>
<td>😞</td>
<td>😊</td>
</tr>
<tr>
<td>Public acceptance</td>
<td>😞</td>
<td>😞</td>
<td>😞</td>
<td>😊</td>
</tr>
<tr>
<td>Economic feasibility</td>
<td>😞</td>
<td>😊</td>
<td>😞</td>
<td>😊</td>
</tr>
<tr>
<td>Technical maturity</td>
<td>😊</td>
<td>😊</td>
<td>😊</td>
<td>😞</td>
</tr>
<tr>
<td>City grid integration</td>
<td>😞</td>
<td>😞</td>
<td>😊</td>
<td>😊</td>
</tr>
<tr>
<td>Power density</td>
<td>😊</td>
<td>😊</td>
<td>😞</td>
<td>😊</td>
</tr>
<tr>
<td>Low loss</td>
<td>😞</td>
<td>😞</td>
<td>😞</td>
<td>😊</td>
</tr>
</tbody>
</table>

The HTS option is very attractive – but needs development
**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 $\frac{1}{3}$ of all HV cables
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
**SUPERLINK CABLE DESIGN**

**Cable design**
- 3 phases in one cryostat
- Superconducting phases and screens
- 110 kV, 500 MVA, 2.6 kA\(_{\text{rms}}\)
- 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
**Distributed Cooling System**

- **Subcooled Liquid nitrogen (LN)**
- **Main cooling station**
- **Intermediate cooling station**
- **Terminal cooling station**
- **Refrigeration**

**Cryo distribution**

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

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**Liquid nitrogen supply (LN)**

1. Cool down

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Economic Efficiency of HTS Cables
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 ($\eta > 50\%$)
  Moderate load profile / fluctuations ($d\eta/dt$)
- 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“)

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**COST ASSESSMENT – COMPARING STANDARD XLPE TO HTS CABLES**

Higher HTS cable costs need to be balanced by other savings

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**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
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
Why HTS Cables?

Why bother with HTS technology?

Because you will need it!
Thank you!

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