Is High Temperature Superconductivity the Future of Energy Transport
Content

- Basics of Superconductivity
- High Temperature Superconducting Power Cables
- Lipa High Voltage Superconducting Power Cable
- Benefits of HTS Cables
- DC Superconducting Cables
Below the critical Temperature ($T_c$) the electrical resistance drops to zero.
Boundaries of the Superconducting State

Superconductivity only possible within the operating area given thorough the limits of $J$, $B$ and $T$.
Definition of the critical current of a superconductor given by the voltage drop of 1 µV/cm
Materials showing Superconducting Behavior

**High Temperature Superconductors (HTS) can be cooled with Liquid Nitrogen (LN$_2$)**
Superconducting Wire

- **Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_{10}$ (Bi-2223)**
  - First generation superconducting wire (1G)
  - Commercially available in km lengths
  - Single wire with $I_c$ up to 180 A
  - Used within the Lipa development project
  - Typical dimensions 4.3 mm width, 0.4 mm thickness

- **YBa$_2$Cu$_3$O$_7$ (Y-123)**
  - Second generation superconducting wire (2G)
  - Different manufacturing process
  - Believed to be much cheaper than 1G in the future
  - Critical current around 100 A per tape
Components of an HTS Cable System

- Superconducting Cable System
  - Cable 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
High Voltage HTS Cable Design

- Outer Cable Sheath
- LN\textsubscript{2} Coolant
- HTS Tape
- Former
- High Voltage Dielectric
- HTS-Shield
- Copper Shield Stabilization
- Outer Cryostat Wall
- Inner Cryostat Wall

3 phases in 3 separate conduits
Accessories for HTS Cables

- **Terminations**
  - Transition from HTS to normal conductor
  - Transition from 77K to roomtemperature
  - Interface to grid
  - Interface to cooling system

- **Joint**
  - Low loss connection of two superconducting cables
  - Optional interface to intermediate cooling system (for longer lengths)

- **Challenges of accessories for high voltage HTS systems**
  - Higher dielectric withstand values
  - Larger wall thicknesses of materials
  - Thermomechanical design much more complex
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 $\delta$ 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 \((10^{-5} \text{ mbar})\)
  - 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 is the world leader in flexible cryostats
No separate return line required in case of individual cryostats
LIPA Superconducting Power Cable

- Long Island Power Authority (LIPA) – Holbrook Substation
- 600 m cold dielectric cable system
  138 kV, 2,4 kA ~ 574 MVA
- Specified fault current – 51 kA for 200 ms
- 600 m cable pulled in HDPE pipe
- DOE funded project with several project partners

*Worlds first HTS cable operating at transmission voltage level*
Cable Energization

- AC-High Voltage test completed successfully
  - $1.5 U_0$ applied at each phase for one hour
  - PD measurement completed
    No partial discharge detected

- 24 hour dielectric soak test completed successfully
  - Cable connected to LIPA grid at one end

- Cable connection at both ends completed on April 22$^{nd}$, 2008
  - Operation with parallel over-head line for 24 hours

- Operation without parallel path afterwards
Same Voltage, More Power

- Greatly increased power transfer capacity at any voltage level

Same Power, Lower Voltage

- New MV versus HV Siting Opportunity
  - “MV Transmission”
  - Ideal for NIMBY & ROW sparse environments

HTS cables provide transmission-level power transfer capability at medium voltage

* XLPE cable ratings for 5-10 km, single circuit, direct buried.
  HTS cable rating based on conventional 4000 A breaker rating.
Example: 138 kV, 575MW Capacity

- Self contained thermal envelope
  - No thermal derating
- Minimal magnetic field
  - No parallel line derating

Superconductor Cable inside PE duct
Main Benefits of Cold Dielectric Superconducting Cables

- Very high power transmission capacity
  - Transmit the same power at lower voltage levels

- Very low impedance
  - HTS cable take load from parallel overloaded paths In the grid

- No outer magnetic field due to the superconducting screen
  - Not impacting other parallel cables

- No thermal impact to the environment
  - No maximum laying depth, no thermal backfill required
Line loading, equipment & operational limitations can lead to grid congestion.
Utility HV System with Superconductor Cable

Superconductor Cable instead of OHL

Reduced Load Current

Total Losses: 2.8 MW (-54 %)

Improved Bus Voltages

Alleviation of grid congestion, reduced loading and losses on other assets
Today’s Key Energy Challenge: Carrying 100’s of Gigawatts of Green Power to Market

Many Issues
- Multiple Sources
- Multiple Destinations
- Siting
- Transmission Across Interconnections
- Losses

Source: AWEA and SEIA: “Green Power Superhighways” - February 2009

The challenge of moving renewable power long distances needs another option
Overall losses 2.75% for 5GW @1000 miles (2.4% for 10GW)
Underground installation addresses public and environmental concerns
Conclusion and Outlook

- HTS power cables are technically feasible as demonstrated in the Lipa project.

- Main advantages of HTS power cables are:
  - Very high power transmission capacity
  - Very low impedance
  - No thermal and electromagnetic impact on the environment

- HTS power cables are a powerful tool to address:
  - Grid congestion issue
  - Overall efficiency
  - Siting constraints

- HTS DC cables will solve current and future power transmission issues of high power over long distances while improving efficiency compared to conventional solutions.

*Superconducting cables will play a role for future transmission of electrical power.*
Thank you for your attention