Feasibility Analysis, Technical Challenges, and Potential Solutions for Cross-Country Multi-Terminal Superconducting DC Power Cables

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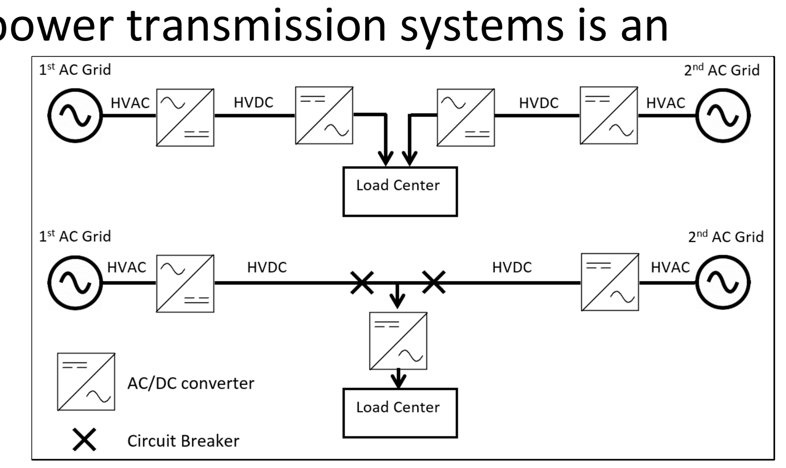
Introduction and Recent Trends

- DC power transmission was not totally ignored although the AC became the norm for power T & D since the end of the 19th century because it provides an efficient and effective interconnection for the AC grids to transfer power, besides adding rigidity
- The conventional solution to connect AC grids is the rotary converter, but the trend towards the solid-state solutions based B2B HVDC grids tying systems is growing recently
- The new trend of increasing reliance on renewable energy sources, which provide ample amounts of energy at remote locations, requires a very efficient method to transmit these large amounts of power to the urban demand centers
- The rapid development in power electronics has contributed in utilizing the HVDC, and making it feasible and controllable
- HVDC transmission is preferred over the HVAC when the power transmission distance exceeds the break-even point
- considering the MT-HVDC power transmission systems is an innovative solution to address the power sector challenges, and it allows full use of the technical and economic benefits



Need for Superconducting Cable Technology for the MT-HVDC Systems

- The MT HVDC system involves handling large amounts of power, on GW scale which can be handled by the HTS cable (up to 100 kA compared to few kA for conventional cables)
- No weather conditions
- Less complexity and size of the project, especially for urban areas
- For expansion, the HTS DC cables can be buried closer to each other because their magnetic field can be completely eliminated

AC Losses in Superconducting Cables Due to The Ripple and Harmonics from Converters

- DC Superconducting power cables does not suffer from AC losses
- For better efficiency and reduction of the required cryogenic cooling capacity, the AC small ripple losses are necessary to be eliminated it for long distance HTS DC cable systems
- The harmonics from reversing the power flows in HVDC based HTS cable systems can exist, but It has been reported that the parallel hybrid modular multilevel HVDC converter (MMC) design offers significant reduction in the extent of ripple in HVDC systems

Technical Challenges and Solutions for the MT-HVDC HTS Cables Technology

The superconduct Technology Challenges

- Cost
- Lack of standards and industry accepted test protocols

Cryogenic Systems Challenge to Support Long Distance Superconducting HVDC Systems

- the lack of reliable and economic cryogenic refrigerator systems.
- This challenge has recently been addressed by the industry through the development of large cryo-refrigerators based on Turbo-Brayton cycles with >150 kW cooling power at 70 K . These large cryogenic systems are significantly more efficient and require little maintenance compared to Stirling refrigerators and Gifford-McMahon cryocoolers.
- Turbo-Brayton cryocoolers have been used successfully for the HTS cable projects in Korea.
- Further new approaches are being investigated to reduce the complexity and costs of the cryogenic systems for large HTS systems.
- Further technical advancements are needed to improve the reliability and reduction of capital and operational costs of cryogenic systems and the interfaces between the room temperature components and cryogenic components at the terminals of MT-HVDC systems.

The MT HVDC Systems Technology Challenges

- DC fault protection
  HTS cables can be designed to operate as Fault Current Limiting (FCL) cables
- Control of the power flow for the meshed DC system with different kinds of converter types.

The Challenge of Establishing Research and Development Centers

- It is still a challenge for the MT HVDC based HTS cable systems.
- The large DC power sources for testing MT-HVDC systems is a major challenge, especially coupled with the need for collocating the large cryogenic systems in the laboratories and research facilities.
- The conventional cables' laboratories and testing facilities lack for the existence of cryogenic cooling systems.
- It needs to be addressed by making the necessary investments, which will accelerate the development and implementation of this game changing technology.
- Modelling and analysis using simulations are needed, and the real-time simulation for these systems is very important
- The simulations are also important due to the fact that the DC system stability and dynamics are much faster compared to the corresponding AC systems

The System Components

The Converters

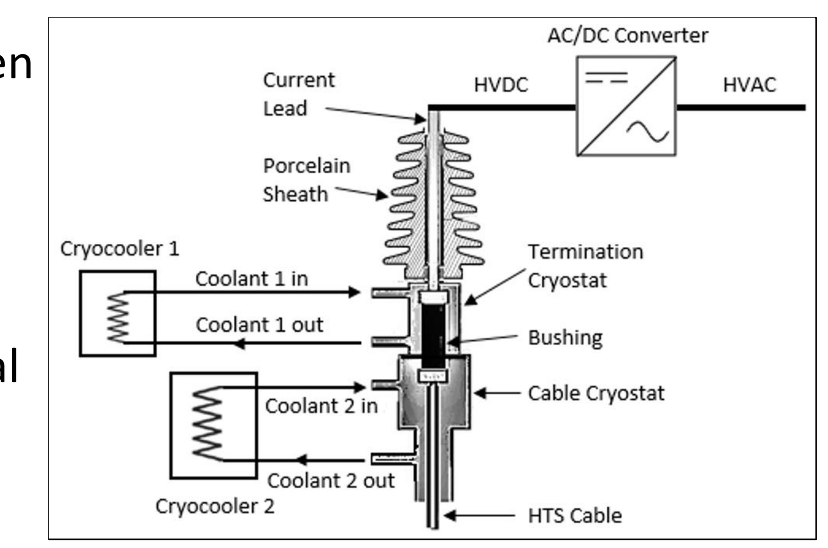
. Load Commutated Converter (LCC).
. Self Commutated Converter (SCC).
. Modular Multilevel Converter (MMC).

The HVDC HTS Cables

. The Warm, the Cold and the Two Stage Dielectric HTS cable layout
. the insulation tapes wrapping and submerging in the cryogenic coolant are used (no successful extruded insulation)
. Pressurizing and Subcooling are used
. smooth pipes are proposed (instead of corrugated cryostat pipes)

The HTS Cables Terminations

- Handle the interface between the room temperature components and the cryogenic components
- Handle the thermal, the mechanical and the electrical stresses



The System Configuration

. The radial configuration for the Cross-Country MT-HVDC since it spans long distances
. To calculate the distance between any two cooling stations

$$Q = \dot{m}\, Cp\, \Delta T$$

. Liquid Nitrogen (LN2) is used with the operating temperature range (ΔT) of 68 to 78 K, a mass flow rate ($\dot{m}$) of 200 (g/s), and specific heat capacity of (Cp) of 2 (kJ/kg/K), then the maximum heat load of the cable section (Q) between the cooling stations can be up to 4 kW. Considering 1 W/m of the heat flux for the HTS cable will give us 4 km, which is the maximum length that the HTS cable can go between the cooling station