Recent Progress and Research Activities on HTS Power Cable Application in KEPCO

Mr. LEE, Chulhyu, KEPCO
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- The 1st Commercial Project
- Paradigm Shift of Power System
- The 23kV Tri-axial HTS Cable
- The Economic Evaluation
History of HTS Cable Projects

R&D  Demo (in grid)  D/B

- **DAPAS**
  - 22.9kV 50MVA
  - 154kV 1GVA

- **KEPRI**
  - 22.9kV Cable Operation & Long term evaluation


**22.9kV 50MVA 410m**
**22.9kV 120MVA 100m**

**Fault diagnosis method**
**Long term operation**

**Icheon Project (08.11~13.10)**
**Icheon II (14.06~17.10)**

**JeJu Project (11.07~16.10)**
- AC 154kV Cable, 1km
- DC 80kV Cable, 0.5km

**80/154kV Class Demo.**

**IEEE CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), February 2019.**
23kV HTS Cable Demonstration in Icheon

Icheon Substation
AC : 22.9kV, Capacity: 50MVA, Length: 410m

Control Center
SFCL
Joint
Snake Installation
Termination
Cooling System
Ground Offset
The demonstration project to install 154kV HTS cables was conducted at Jeju HVDC and Superconductivity Test Center. DC 80kV HTS cable was also installed to test the performance on the same place.
Development of HTS Cable Cooling System

R&D

3kW@66.4K, 2006~2008

Decompression System

- Icheon 22.9kV 50MVA
- (6.5kW@69K, 2011)

DEMO

6kW@66.4K, 2008~2012

Decomp.+ Stirling System

- Icheon 22.9kV 120MVA
- (6kW@69K, 2013)

[DC] 3kW@69K 2008~2012

[AC] 12kW@69K 2013~2016

Stirling + Brayton Sys.

- JeJu DC80kV (6kW@69K, 2014)
- JeJu AC154kV 600MVA (12kW@69K, 2016)
Korea began research on the development of superconducting cables in the early 2000s. The development and verification tests of the HTS cables for AC and DC from 23kV to 154kV have been very successful through the various demonstration projects.
KEPCO declared to lead the industrialization of HTS in an opening ceremony in Mar. 2016.

The 1st commercial application of HTS cables, “SHINGAL Project” was developed with the support of high executive levels.
“Shingal” Project: 23kV HTS Cable Installation

23k HTS Cable Layout between two substations

154kV Heungdeok S/S

154kV Shingal S/S

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“Shingal” Project : 23kV HTS Cable Installation


System : AC HTS 23kV 50MVA 1km-cct

Cooling : 7.5kW @69K
- LN₂ Circulation cooled by Turbo-brayton Cryo-cooler and Decompression type refrigerator

Budget : USD 15M (100% funded by KEPCO)

Purpose : Sharing power supply capacity by connecting 23kV HTS cable between two substations
**“Shingal” Project : 23kV HTS Cable Installation**

The type test of the 23 kV HTS cable system is underway at the Gochang test center of KEPCO
- **Duration** : Aug. 2018 ~ Nov. 2018
- **Based on CIGRE TB 538 (2013)**
  IEC 60840, and IEC 61462, KEPCO has established its own type test guidelines; KEPCO GS 6145-0088

**bending test**
### “Shingal” Project: Type Test

<table>
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<tr>
<th>Items</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
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Currently, The thermal cycle test is underway
Paradigm Change of Power System

Which came first?

Less expensive
HTS first

or

HTS
Market
First

Ref. : Hashtag3r.com
Paradigm Change of Power System

- Pumped
- AC
- 765kV
- ESS
- HVDC
- HTS
Paradigm Change of Power System

- The HVDC connection with North Korea will be necessary considering the national security and the reliability of power system issues among others.
- This peaceful scenario will be able to envision a Super Grid which connects Korea with its neighboring big countries, such as China, Russia, and Japan.


Ref. http://www.toonpool.com
The left figure shows the conventional method used to install substations in urban areas, and the right figure illustrates the concept of a hybrid power system combined with 23kV HTS power cables.

The 23kV switching stations linked with HTS cables can perform the same tasks rather than constructing new substations that require a large-scale space.
Paradigm Change of Power System

No more High Voltage Cables
No more EMF
From a viewpoint of transmission planning, we have two issues for the broader application of the HTS cables to power systems.

One is the price reduction of HTS cables and the other one is the length of them.
Worldwide development and demonstration of HTS Cables

Ref. KEPCO & CNU
Development of Tri-axial HTS Cable

Research Project Overview

- Title: Development of 23kV Tri-axial Cable System and Business Model
- Period: Mar. 2017 ~ Feb. 2022 (5 years)
- Budget: $26 M (Funded by KEPCO)
- Target: (Before) 60 MVA 3 km (Present) 120 MVA 3 km
Development of Tri-axial HTS Cable

The main feature is that the LN$_2$ return path is configured separately to increase the length of the HTS cable up to 3 km.

<table>
<thead>
<tr>
<th>No.</th>
<th>Layer Function</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>Former</td>
<td>- Frame for attaching optimal number of superconducting tapes for each phase</td>
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<tr>
<td></td>
<td></td>
<td>- Fault current path for phase</td>
</tr>
<tr>
<td>2</td>
<td>Superconducting Conductor</td>
<td>- Rated current path for each phase</td>
</tr>
<tr>
<td>3</td>
<td>Electrical insulation</td>
<td>- Electrical insulation between phase-to-phase or phase-to-ground</td>
</tr>
<tr>
<td>4</td>
<td>Copper shield</td>
<td>- Shielding interior or exterior emission of electromagnetic field</td>
</tr>
<tr>
<td>5</td>
<td>Protective binder</td>
<td>- Binding and protecting cable core</td>
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<tr>
<td>6</td>
<td>LN$_2$ vessel</td>
<td>- Vessel for LN$_2$ flow</td>
</tr>
<tr>
<td>7</td>
<td>Thermal insulation</td>
<td>- Reducing radiation heat leak</td>
</tr>
<tr>
<td>8</td>
<td>Vacuum vessel</td>
<td>- Vessel for maintaining high vacuum in thermal insulation layer</td>
</tr>
<tr>
<td>9</td>
<td>Jacket</td>
<td>- Protecting the cable from external influences</td>
</tr>
</tbody>
</table>
Economics Evaluation of HTS Hybrid System

154kV Substation (Existing)  154kV Substation (New)  154kV XLPE Cable

154kV Substation (Existing)  23kV Switching station  23kV HTS Cable

[0.1M$]  [0.1M$]

HTS  Conventional (cable tunnel 20%)

Conventional (cable tunnel 50%)

Conventional (conduit)

Conventional (cable tunnel 50%)
Economics Evaluation of HTS Hybrid System

Before

154kV Cable Head

154kV Substation (New)

Load Center

154kV XLPE (Conduit)

23kV feeders (Cable Tunnel)

After

154kV Cable Head

154kV Substation (New)

Load Center

154kV XLPE (Conduit)

23kV HTS Cable (Conduit)
Economics Evaluation of HTS Hybrid System

Most importantly, there is a break-even distance even in this case where the investment costs of both conventional and the HTS hybrid method are the same.

The high investment cost of HTS cables can be offset by the effects of land acquisition, the cable tunnel construction, and the price reduction of the tri-axial HTS cable.
Will Moore’s law apply to HTS cables?

Moore’s law is the observation that # of transistors in IC doubles about every 2 years. Similarly, Swanson’s law says the cost of solar panels drops 20% for every doubling of cumulative production.

Why not to the HTS wires?

Source: Bloomberg New Energy Finance, Apr. 2015

Source: BNEF via Think Progress, Jul. 2016
Will Moore’s law apply to HTS wires?

Thank You for your Attention