Protection against the ground fault for 275 kV HTS cable and experiment

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Content of this presentation

1. About experiment
   - Ground fault accidents for HTS cables
   - Samples of the standing style
   - Results of the samples without protection

2. Protections against the ground fault
   - Behavior of the current and voltage
   - Protection for the cable core and cryostat pipe

3. Effects of protections
   - Results of the samples with protection
Single core is stored into a cryostat pipe. => 3 set are needed for three-phase AC system.
Ground fault accident

Three-phase AC

225 kV (= $275 \times \sqrt{2} / \sqrt{3}$)

~ 3 cycles (0.06 second for 50 Hz)

Until the main circuit breaker will run

275 kV HTS cable (Three-phase)

Voltage

Time

Ground

Cryostat pipe

Cable-core

Outer refrigerant

Outer pipe

MLI

Inner pipe

Copper shield

HTS shield

Insulation

HTS conductor

Copper former
Purpose of our research

Current (or Energy) at the ground fault accident

High

~ 63 kA (actual result ~ 50 kA) for 275 kV cables

Outer pipe is vented.

Outer pipe is not vented.

Low

275 kV HTS cables in a tunnel

$\text{LN}_2$ leaked

- Damages to the neighbors
- Lack of oxygen
- High pressure of the refrigerant

$\text{LN}_2$ not leaked

Where is this border?

$\Rightarrow$ Can this be possibly lifted up?

This presentation’s theme
Sample style to examine

We have an HTS cable system to examine.

But it is too expensive to burn out....

=> We adopted the standing style.
Sample of standing style

Electrode

1 m for length

Artificial ground fault point

To short-cut with an iron pin in a drilled hole

Setting

Electrode to conductor

Electrode to shield

Electrode to inner pipe

Electrode to outer pipe

Cryostat pipe

LN$_2$

To form MLI

10 cm
Current: <AC20kA
Voltage: <12kV
Frequency: 50Hz

Electrode
Cu-Former & conductor
Shield
Inner pipe
Outer pipe
Ground fault point (An iron pin)
Cable core
Results (w/o protection)

- Core
  - Size of the original hole
  - Carbon papers (originally black)

- Pipes
  - Inner pipe; w/o MLI
  - Outer pipe

- AC 10 kA – 3 cycles
Current & Voltage

Current
- Current flowed in all 3 paths, the shield and both of the cryostat pipe. Their amount equals to the source current.
- Current flowed in the shield at first, and in the outer pipe at last.

Voltage
- Voltage rose abruptly in around 1ms, and was relatively stable.
- Amount of the energy was approximately 0.3 MJ for 3 cycles.
Protection for core and inner pipe

**Sample A**
- Protection on core
- Cryostat pipe
  - Outer pipe MLI
  - Inner pipe
- Outer refrigerant
- Copper shield
- HTS shield
- Insulation
- HTS conductor
- Copper former

**Sample B**
- Protection on inner pipe
- Conventional
- Sample B

<table>
<thead>
<tr>
<th>Structure</th>
<th>Diameter [mm]</th>
<th>Sample A</th>
<th>Sample B</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTS conductor</td>
<td>35.4</td>
<td>35.4</td>
<td></td>
</tr>
<tr>
<td>HTS shield</td>
<td>88</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>Whole core</td>
<td>112</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>Inner pipe w/ MLI et al.</td>
<td>Bore</td>
<td>127</td>
<td>106</td>
</tr>
<tr>
<td>Outer pipe</td>
<td>Bore</td>
<td>200</td>
<td>155</td>
</tr>
<tr>
<td>Outside</td>
<td>168</td>
<td>144</td>
<td></td>
</tr>
</tbody>
</table>

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Results (w/ protection)

AC 10 kA – 3 cycles
Conductor
Shield
Inner pipe
Outer pipe

AC 20 kA – 3 cycles
Conductor
Shield
Inner pipe
Outer pipe

w/o protection

w/ protection

Sample A, similar to B

Outer pipe kept its soundness
NOT reached by arc discharge
Effect of protections

The protection on the cable core was severely damaged, as well as the core itself.

The protection on the inner pipe was damaged thermally, in spite of its outer soundness. (common to sample A and B)
Summary

- Ground fault examinations for 275 kV HTS cable were conducted.
  AC 10 ~ 20 kA, 3 cycles for samples of the standing style.

- Protection for the core and inner pipe was provided.
  => Successfully kept the soundness of the outer pipe.
  The arc discharge to outer pipe was interrupted,
  regardless of the protection on the core.

- Protection on the inner pipe remained,
  despite that on the core damaged severely.
  Protection on the core may worthless for 275 kV cable.

ACKNOWLEDGMENT
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## Sample list and details

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>No.1</td>
<td>1.5</td>
<td>0.5</td>
<td>0.006</td>
<td>No damage</td>
</tr>
<tr>
<td>No.2</td>
<td>3</td>
<td>0.5</td>
<td>0.017</td>
<td>Inner pipe vented</td>
</tr>
<tr>
<td>No.3</td>
<td>5</td>
<td>0.5</td>
<td>0.033</td>
<td>Outer pipe vented</td>
</tr>
<tr>
<td>No.4</td>
<td>5</td>
<td>0.5</td>
<td>0.030</td>
<td>Inner pipe vented</td>
</tr>
<tr>
<td>No.5</td>
<td>7.5</td>
<td>v</td>
<td>0.214</td>
<td>Outer pipe vented</td>
</tr>
<tr>
<td>No.6</td>
<td>10</td>
<td>v</td>
<td>0.245</td>
<td>Outer pipe vented</td>
</tr>
<tr>
<td>No.7</td>
<td>10</td>
<td>v</td>
<td>0.325</td>
<td>Outer pipe vented</td>
</tr>
</tbody>
</table>

The arc did not revive with the voltage of 12 kV.

Inner pipe (MLI removed)