Short Circuit Withstanding Capability of 22.9kV HTS Cable in Korea

Seungryul Lee†, Jaeyoung Yoon* and Byeong-mo Yang**

Abstract – In Korea, GENI(Green superconducting Electric power Network at the Icheon substation) project has been conducted since 2008. The objective of the GENI project is to install and operate a 22.9kV/50MVA High Temperature Superconducting (HTS) cable system and a 22.9kV/630A Superconducting Fault Current Limiter (SFCL) system in the Icheon substation located near Seoul. It is important to design specifications considering real power system conditions for a successful application of the HTS cable and SFCL system to a real grid. This paper proposes a design specification for the short circuit withstanding capability of the HTS cable to apply to Korean power distribution system, from the viewpoint of a protection system. The HTS cable system with the proposed specification has been operated in the Korean real grid of the Icheon substation since August, 2011.

Keywords: HTS cable, Short circuit withstanding capability, Protection system

1. Introduction

In a recent power system, the load density of the metropolitan area has been increased rapidly and the high density of the power load demands the large capacity of the power facility. However, there is a technical limitation on the increase of the transfer capacity of a conventional power line. Also, it is very difficult to secure an additional route for the installation of underground cables in an overcrowded city, because of the NIMBY (Not In My Back Yard) phenomenon and the high construction costs. In order to provide a solution to overcome the predicted shortage of future power network facilities and environmental problems, the use of HTS (High Temperature Superconductor) cables is now considered as an alternative. The capacity of the HTS cable is several times larger than that of a conventional cable at the same voltage level. The HTS cable has low losses and is environmentally friendly. These advantages led to many R&D projects of the HTS cables in the world [1-4]. In Korea, there are two representative R&D projects of the HTS cable system since 2001 [5]. The first one is DAPAS (Development of Advanced Power system by Applied Superconductivity technologies) program funded by the Ministry of Education, Science and Technology. In this project, LS Cable Ltd. (LSC) and Korea Electrotechnology Research Institute (KERI) jointly developed a 22.9 kV, 50 MVA, 3 phase, 100 m HTS cable using 1G HTS wire in 2006. The HTS cable system has been tested in a power test center of Korea Electric Power Corporation (KEPCO). Encouraged at the result of DAPAS project, a new project, GENI (Green superconducting Electric power Network at the Icheon substation) project was launched in 2008. In this project, LSC developed a 22.9 kV, 50 MVA, 500 m HTS cable system using 2G HTS wire [6, 7]. This HTS cable system has been working at the Icheon substation in the live Korean grid since August, 2011. In order to operate successfully the HTS cable system without the any damage in the real power grid, it is necessary to design it considering the power system conditions, such as a power protection system. In DAPAS program, the short circuit withstanding capability of the HTS cable was proposed as 25 kA, 15 cycles, but the specification is not sufficient for the Korean power distribution system. This paper describes a study on the short circuit withstanding capability of the 22.9 kV HTS cable system considering a protection coordination of the Korean power distribution system. The proposed specification is reflected in the HTS cable system which has been operated at a live power system of the Icheon substation for GENI project.

2. HTS cable of GENI project

GENI project is the first demonstration of the HTS cable application to a real power grid in Korea. The application site is the Icheon substation located in Gyeonggi-do, South Korea. Fig. 1 illustrates the location and foreground of
Icheon substation.

Fig. 1. Location and foreground of Icheon substation.

The ratings of the HTS cable system are 22.9 kV, 50 MVA, 1.26 kA. LSC developed the HTS cable system, using 2G HTS wire, 344B manufactured by American Superconductor (AMSC). The installation location is the secondary side of the fifth main 154 kV / 22.9 kV transformer. Fig. 2 shows the one-line diagram and the layout for the application of the HTS cable at the Icheon substation. KEPCO has been operating the HTS cable system since August, 2011.

3. Short circuit withstanding capability

The short circuit withstanding capability is not tested for 22.9 kV conventional cables in Korea. If we calculate the short circuit withstanding capability based on IEC-60949, we can know that the rated short-circuit current of 25 kA can flow through the cable during several seconds. This means that the short circuit test is pointless because the short circuit withstanding capability is very strong in the 22.9 kV conventional cables. However, we need to test the short circuit withstanding capability for the HTS cable because it depends on a design of the HTS cable. In DAPAS program, the 22.9 kV HTS cable was developed in order that a fault current of 25 kA can flow through the cable during 15 cycles. This is not suitable for the Korean power distribution system. So, we conducted the detailed study on the short circuit withstanding capability of the 22.9 kV HTS cable in the Korean power system, considering some conditions such as fault current levels and the protective coordination system.

4. Specifications of the 22.9kV HTS cable

4.1. Rated short circuit current of the HTS cable

The short circuit withstanding capability is related to a short circuit test. Standards of circuit breakers and transformers adopt 25 kA or a maximum short circuit current as a rated short circuit current [8, 9]. We proposed two criteria to decide the rated short circuit current of the HTS cable. The first criterion is to choose it considering fault currents of the present Korean power distribution system. In the 22.9 kV power system of the Icheon substation, the maximum 3-phase short circuit fault current is less than 8kA. 1-phase-to-ground fault current is about 7 kA in the power system with a Neutral Ground Reactor.
(NGR), and 10kA without the NGR. In general, a maximum fault current is below 12.5 kA in Korean power distribution system, even when renewable sources are applied to the power system. So we propose 12.5 kA as the rated short circuit current of the 22.9 kV HTS cable for the present power distribution system. The other criterion is conservatively to decide it for the future power system. In the future, it is possible that a fault current is over 20 kA, when the system operators apply a main transformer with a large capacity of 100 MVA or two main transformers of 45/60 MVA operated in parallel. In this case, we have to choose 25 kA as the short circuit current. The proposals of this study are as follows.

- 12.5 kA in the present power distribution system (e.g. Icheon substation) = Maximum fault current of the present power distribution system + Margin

- 25 kA in the future power system = Rated short circuit current of 25.8 kV circuit breakers = Maximum fault current of the future power distribution system + Margin

4.2. Short circuit current withstanding time

The worst scenario of fault events is that the protective relays and circuit breakers of distribution lines are not worked, and the backup protective relay of a 154 kV / 22.9 kV main transformer works. The backup protective relay is the Over Current Relay (OCR). In this case, a fault current may flow during 78 cycles, considering an OCR pickup time of 70 cycles, an OCR operating time of 3 cycles, and a circuit breaker trip time of 5 cycles. This means the minimum withstanding time is about 78 cycles in the Korean power distribution system. It is reasonable that the withstanding time is decided as 100 cycles considering some margin.

- Short circuit current withstanding time for the HTS cable = 100 cycles = 70 cycles (Pickup time of a backup protective relay for a 154 kV / 22.9 kV main transformer) + 3 cycles (Operating time of the relay) + 5 cycles (Trip time of a circuit breaker) + Margin

4.3. Short circuit withstanding capability of the HTS cable

The short circuit withstanding capability for the 22.9 kV HTS cable of DAPAS program is 25 kA, 15 cycles. Energy relation is presented in equation (1), depending on the fault current levels. Table 1 shows the calculation of the fault current flowing time by fault current levels, using the equation (1).

\[
(25kA)^2 \times Z \times 15 \text{cycles} = (IF)^2 \times Z \times TF
\]

\[
\rightarrow TF = \left( \frac{25kA}{IF} \right)^2 \times 15 \text{cycles}
\]

Where, Z is the impedance of the HTS cable

IF is a fault current

TF is a fault current flowing time

A maximum fault current of the Icheon substation is slightly over 10 kA, even when the NGR is not installed. So, we can assume that the maximum fault current is 11 kA. Table 1 shows that the HTS cable of DAPAS project can withstand the fault current of 11 kA during 77.5 cycles. This cannot satisfy the minimum withstanding time of 78 cycles proposed in chapter 4.2. This means that the specification of the HTS cable has to be re-determined through more detailed study considering a protection system.

<table>
<thead>
<tr>
<th>IF [kA]</th>
<th>TF [cycle]</th>
<th>TF [sec]</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0</td>
<td>191</td>
<td>3.19</td>
<td>Level of 1-phase-to-ground fault current in the present power distribution system with NGR</td>
</tr>
<tr>
<td>7.5</td>
<td>16</td>
<td>2.78</td>
<td>Level of 3-phase short circuit fault current in the present power distribution system</td>
</tr>
<tr>
<td>8.0</td>
<td>146</td>
<td>2.44</td>
<td>Level of 1-phase-to-ground fault current in the present power distribution system without NGR</td>
</tr>
<tr>
<td>10</td>
<td>93.8</td>
<td>1.56</td>
<td>Level of 3-phase short circuit fault current in case of connecting two 45/60 MVA main transformers</td>
</tr>
<tr>
<td>11</td>
<td>77.5</td>
<td>1.29</td>
<td>Level of 1-phase-to-ground fault current in case of applying a 100 MVA, 15% main transformer</td>
</tr>
<tr>
<td>12.5</td>
<td>60</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>41.7</td>
<td>0.69</td>
<td>Level of 3-phase short circuit fault current in case of connecting two 45/60 MVA main transformers without NGR</td>
</tr>
<tr>
<td>16</td>
<td>36.6</td>
<td>0.61</td>
<td>Level of 3-phase short circuit fault current in case of applying a 100 MVA, 15% main transformer</td>
</tr>
<tr>
<td>20</td>
<td>23.4</td>
<td>0.39</td>
<td>Level of 1-phase-to-ground fault current in case of connecting two 45/60 MVA main transformers without NGR</td>
</tr>
<tr>
<td>21</td>
<td>21.3</td>
<td>0.35</td>
<td>Level of 1-phase-to-ground fault current in case of applying a 100 MVA, 15% main transformer without NGR</td>
</tr>
<tr>
<td>25</td>
<td>15</td>
<td>0.25</td>
<td>Design of the HTS cable in DAPAS project</td>
</tr>
</tbody>
</table>

The 22.9 kV, 50 MVA HTS cable is most likely to be applied to the future power system with a large capacity transformer. A fault current can increase to 20 kA in the future Korean power distribution system, if the HTS cable is applied with a large capacity transformer or two 45/60 MVA transformers operated in parallel. In conclusion, the
short circuit withstanding capability of 25 kA and 15 cycles is not suitable for the Korean power system, if we consider conditions of the present and future power system.

So, this study proposed the short circuit withstanding capability of the 22.9 kV HTS cable, considering fault current levels, the protective coordination time, and some margin in the real Korean distribution power system. The proposed specifications of the 22.9 kV HTS cable by the power conditions are as follows.

• 12.5 kA / over 100 cycles (≒ 25kA / over 25 cycles) for the present power system with a 45/60MVA transformer (e.g. the Icheon substation)

• 25 kA / over 100 cycles for the future power system with a 100MVA transformer or two 45/60MVA transformers operated in parallel

5. Conclusion

For the successful application of HTS cables to real power system, it is very important to decide the specifications of the cable, considering real power system conditions. This paper proposed the specifications of the short circuit withstanding capability of the 22.9 kV, 50MVA HTS cable in the Korean real power distribution system. The results can be a little changed by the conditions of a power system, but the range of the change is expected to be small. The 22.9 kV HTS cable of GENI project is developed by LS cable, a Korean cable manufacturing company, reflecting results of this study. The final design specification is 25 kA, 30 cycles. The cable has been operated in the Icheon substation since August, 2011. In the future study, we will study on the specifications of 22.9 kV / 150 MVA and 154 kV / 600MVA HTS cables, which will be installed in Korea.

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References


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