A Study for Control Power System Load Flow by Shield Control of High-TC Superconducting Cable

Hyun-Chul Lee¹, Yong-Gi Roh¹ and Byoung-Jo Jung²*

¹Department of Electricity System Control, JHRDI, 119 Dongjansan-ro Gunsan-si Jeollabuk-do – 54004, Korea; oneye12@gmail.com, ygroh@korcham.net

²Department of Lift Engineering, Korea Lift College, 120 Unjeong 1-gil Geochang-gun Gyeongsangnam-do – 501141, Korea; bjjung@klc.ac.kr

Abstract

Objectives: HTS cable was shown high temperature characteristic of the superconducting tape by sharp increase resistance on fault state. This paper proposes by controlling the HTS shield part to stable transmission in power system.

Methods/Statistical Analysis: HTS cable was divided mainly three parts that was former, conductor, and shield part. To be performance the HTS cable designed by comparison low error value with real HTS cable property and, developed by controlling shield parts by using mutual inductance change. Findings: The HTS power cable was controlled load flow by adjusting the shield part. Improved the HTS cable was limited current above 64% better than HTS cable in installed the fault current limiter. Therefore, HTS cable could be improved power stability in the power system.

Improvements/Applications: The HTS shield control might be controlled power flow and limited fault current. It wasn’t necessary for installing other device by controlling HTS cable shield part. So, proposed the HTS cable model was applied in economic and effective device in power system.

Keywords: Fault Current Limit, HTS Cable, HTS Shield Control, Load Flow, Power System

1. Introduction

Supply of electric power should be always satisfied power demands in power system. Recently, the power system has been requested high density power in high-rise building and urbanism. The power system has being saturated transmission capacity. However, conventional power cable is difficult to transfer large capacity. The HTS (High-Temperature Superconducting) cable has transmission ability of 3~5 times in the same voltage level and size than conventional cable in underground transmission lines. So, the HTS cable has been progressed a lot of research about usable means in high-density metropolitan area. The HTS cable has been characterized to be transferred large current by low loss in zero resistance on steady state. The HTS cable has shown the sharp change resistance by passing transmission current above critical current on transient state. It was raised the superconducting tape temperature by occurring resistance on above critical current in the HTS cable. This mechanism is restricted to the fault current by sudden resistance occurrence of transmission line in the HTS cable fault state. Generally, the HTS cable was designed for stable protection in the cable fault state.

This study focused on control method in power system by using the HTS cable modeling. The HTS cable was modeled as electrical characteristic by using BISSCO type (1st generation superconducting tape). Conformity to the simulation model was proved through test result by comparing HTS cable model data with demonstration data. Proven the HTS cable model was reviewed about applied method by installing HTS cable on the power system. This test was protected the HTS cable through current magnitude in superconducting tape according to steady/transient state. This paper proposes to controlled mutual impedance in the shield part.

*Author for correspondence
of HTS cable. The cable was presented fault impedance when it was appeared transmission current above critical current on transient state in power system. The HTS cable was protected power system by changing the superconducting tape resistance. However, HTS cable was damaged by rising the superconducting tape temperature according to large fault current. So, this paper was simulated with use the variety protection method for limiting current. First, installed the FCL (Fault current limiter) devices. Second, installed the thyristor switch for changing impedance by adjusting the control switch angle. For protecting the HTS cable, using to the FCL and CB (Circuit Breaker). The proposed the HTS cable wasn't needed to installed FCL devices because it was protected the fault current by controlling the shield line impedance of the HTS cable. Simulation result, the power stability was improved to control power flow of HTS cable in power system. HTS cable was applied from the design plan in order to protect and operate in the power system.

1.1 Model of the HTS Cable

The HTS cable structure was showed cross section in Figure 1. Conductor part was transferred the current on the superconducting tape. Shield part cable was occurred current of same magnitude the conductor part as 180 degree phase shift by electron induction. Former and stabilization part were protected conductor and shield part when the steady state was maintained the figuration of HTS cable, and the transient state was passed the fault current. Superconducting tape was lost the superconducting state to variation of resistance characteristic by changing temperature and current.

It was showed the HTS cable electrically equivalent model in Figure 2. Conductor part was consisted two superconducting layers, and shield part was consisted one superconducting layer. The former and stabilizer was used copper to protect each superconducting.

\[
R_{\text{HTS}} = \frac{V_{\text{HTS}}}{I_{\text{HTS}}} = r_c \left( \frac{I_{\text{HTS}}}{I_{\text{cHTS}}} \right)^{n-1}
\]

(1)

Here, \( R_{\text{HTS}} \) was operation resistance, and \( r_c \) was critical resistance in HTS cable. Critical current was about experiment equation by changing the HTS cable temperature, as (2).

\[
I_{cHTS} = \alpha T_{\text{oper}}^2 + \beta T_{\text{oper}} + \gamma
\]

(2)

Here, \( T_{\text{oper}} \) was the operation temperature in HTS cable. \( \alpha, \beta, \) and \( \gamma \) were temperature parameter in HTS cable as shown in Table 1.

1.2 Compared Demonstrated Test with Simulation Test of the HTS Cable

The HTS cable has been tested to 2/3 of rated current (800Arms) that was measuring and simulation current value as shown in Table 2. Each measuring data was the conductor and shield part current. The current of HTS cable

![Figure 2. Electrical Model of the HTS cable.](image)

![Figure 1. Cross section and cable core of the HTS cable structure.](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha )</td>
<td>0.001617</td>
</tr>
<tr>
<td>( \beta )</td>
<td>-0.30584</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>19.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Current [( A_{\text{rms}} )]</th>
<th>Conductor Part</th>
<th>Shield Part</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demonstration</td>
<td>800</td>
<td>744</td>
<td>93%</td>
</tr>
<tr>
<td>Simulation</td>
<td>812</td>
<td>739</td>
<td>91%</td>
</tr>
<tr>
<td>Model error</td>
<td>1.5%</td>
<td>0.7%</td>
<td></td>
</tr>
</tbody>
</table>
was showed errors between demonstration and simulation value that was 1.5 %( conductor part) and 0.7 % (shield part), respectively. These errors were considered as the heat characteristic and AC loss effects in the HTS cable.

The HTS cable current wave was shown compare with demonstration and simulation result in Figure 3.

1.3 The HTS Cable on Three Phase Unbalanced

The HTS cable has been tested the simulation result to compare with each part as shown in Table 3. It was transferred the unbalanced current (unbalanced ratio 30%). The error between the demonstration and the simulation value of the shield part was larger relatively than that of the conductor part (the maximum error 6.5%) show in Figure 4 and Figure 5.

2. Proposed Work

A Protection relay or over-current limit devices were needed in order to control within the critical current on transient state of the HTS cable. The HTS cable has been based on protecting the quench limit characteristic curve by using calculation for each transmission line parts of calculated from thermal balance equation.

The HTS cable was transferred to large current than conventional cable. Fault state of the HTS cable was appeared more large current than steady state. So, HTS cable was used the FCL (Fault Current Limiter) device to reduce the fault current. This paper proposes another method to control HTS cable impedance by using thyristor switch in shown Figure 6. Simulated test has been measured for current and temperature of the superconducting tape. Fault current of HTS cable was limited under critical current. Proposed method has been shown similar characteristic with FCL device.

The HTS cable was implanted the power system shown in Figure 7. It was indicated the HTS cable specification as shown in Table 4.

<table>
<thead>
<tr>
<th>Conductor [A]</th>
<th>Shield [A]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td>Simulation</td>
</tr>
<tr>
<td>W phase</td>
<td>795</td>
</tr>
<tr>
<td>R phase</td>
<td>636</td>
</tr>
<tr>
<td>B phase</td>
<td>636</td>
</tr>
</tbody>
</table>

Table 3. Compared with the demonstration and simulation value in each parts

Figure 3. Demonstration I test and simulation results. (a) was demonstration test, and (b) was simulation result.

Figure 4. Demonstration test and simulation results. Figures were current waveform on HTS cable conductor part of each phase. Unbalanced ratio was 30%. (a) was demonstration test, and (b) was simulation result.

Figure 5. Demonstration test and simulation results. Figures were current waveform on HTS cable shield part of each phase. Unbalanced ratio was 30%. (a) was demonstration test, and (b) was simulation result.

Figure 6. Simulated test result of HTS cable. Case 1 was not used other equipment. Case 2 was protected HTS cable by applying SFCL (Super-conducting Fault Current Limiter). Case 3 was protected HTS cable by controlling impedance. (a) was fault current magnitude of HTS cable, and (b) was heat characteristic of HTS cable.
Case 1 for the HTS simulation wasn’t protection devices in fault state that was shown the large current and temperature shown in Figure 8.

The HTS cable power system was setup the SFCL device for protect fault state. Case 2 was added the SFCL in the HTS cable power system shown in Figure 9. The SFCL impedance was calculated, as (3). It was appeared the zero impedance in steady state. Fault state was limited fault current by generating impedance.

\[
Z_{sc}(\tau) = Z_s \left[1 - \exp\left(-\frac{t_0 - t}{\tau_s}\right)\right]
\]  

(3)

It has been applied the SFCL in the power system shown in Figure 10. Case 2 was simulated to examine current and heat fault state of HTS cable with SFCL.

Power flow was controlled the thyristor phase by using the mutual impedance between conductor and shield. It has been using the thyristor device for protecting the HTS cable power system shown in Figure 11.

The current waveform and heat was superconducting tape by switching thyristor 0 degree shown in Figure 12. The thyristor switching time was 1.01 sec.

Table 4. Specification in the HTS cable

<table>
<thead>
<tr>
<th>Items</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Voltage</td>
<td>22.9 kV</td>
</tr>
<tr>
<td>Rated Current</td>
<td>1,250 A</td>
</tr>
<tr>
<td>Capacity</td>
<td>50 MVA</td>
</tr>
<tr>
<td>Length</td>
<td>500 m</td>
</tr>
<tr>
<td>Cable Type</td>
<td>3 cores in one cryostat</td>
</tr>
<tr>
<td>Dielectric Type</td>
<td>Cold dielectric</td>
</tr>
</tbody>
</table>

Figure 7. Installed HTS cable in the power system.

Figure 8. Dynamic characteristic of HTS cable system. Fault duration for simulation was 0.5[sec]. (a) was current wave form of the superconducting tape (b) was heat of the superconducting tape.

Figure 9. Model to protect HTS cable by using SFCL. (a) was model for current limit device, and (b) was HTS cable power system to apply the SFCL.

Figure 10. Dynamic characteristic of HTS cable system by applying SFCL. Fault duration for simulation was 0.5[sec]. (a) was current wave form of the superconducting tape, and (b) was heat of the superconducting tape.

Figure 11. Proposed HTS cable simulation model. (a) was electrical characteristics between the conductor and shield, and (b) was controlled the line impedance in the HTS cable.

Figure 12. Dynamic characteristic of HTS cable system by controlling shield superconducting through thyristor switching. Fault duration for simulation was 0.5[sec]. (a) was current waveform of the superconducting tape, and (b) was heat of the superconducting tape.
Hyun-Chul Lee, Yong-Gi Roh and Byoung-Jo Jung

Indian Journal of Science and Technology

Vol 9 (48) | December 2016 | www.indjst.org

4. References


3. Conclusion

HTS cable was transferred with large current in power system. This paper was examined for using the HTS cable as follows.

1. Install the HTS cable 22.9kV, 50MVA, 500m
2. Compare demonstrated test and simulation test of HTS cable
3. Simulate to protect the HTS cable by SFCL
4. Improve the HTS cable by using thyristor switching

The HTS cable model was applied the 22.9kV HTS cable. This cable was operated in the domestic substation. HTS power system data was compared with the simulation model for verifying simulation. Temperature was changed under the critical temperature in the superconducting tape. Simulation result was showed almost similar characteristic within real result. Using this model, it was applied as power system. In case of fault state, HTS cable could be damaged the superconducting tape. So, it used the SFCL device for protecting HTS cable. This paper was proposed to protect HTS cable by controlling shield part of HTS cable. SFCL and developed HTS cable were reduced the fault current. It was controlled to be 60% of the rated current in case of the steady state, and it was limited within 80% of the critical current in case of the abnormal state. Fault current limit was controlled shield line of HTS cable to indicate the similar effects to use SFCL. HTS cable could be controlled the power flow and limited fault current. It wasn’t necessary for installing other device by controlling HTS cable shield line. So, this model was applied in economical and effective device in power system. Improved HTS cable was considered application for the power system in future.

Figure 13. Dynamic characteristic of HTS cable system by controlling shield superconducting through thyristor switching. Fault duration for simulation was 0.5[sec]. (a) was current waveform of the superconducting tape, and (b) was heat of the superconducting tape.

The current waveform and heat was superconducting tape by switching thyristor 90 degree in shown Figure 13. The thyristor switching time was 1.01 sec.

Vol 9 (48) | December 2016 | www.indjst.org

Indian Journal of Science and Technology | 5