A Study on the Application of SFCL on 22.9 kV Bus Tie for Parallel Operation of Power Main Transformers in a Power Distribution System

Abstract - This paper analyzed the application of Superconducting Fault Current Limiter (SFCL) on 22.9 [kV] bus tie in a power distribution system. Commonly, the parallel operations of power main transformers offer a lot of merits. However, when a fault occurs in the parallel operation of power main transformer, the fault currents might exceed the interruption capacity of existing protective devices. To resolve this problem, thus, the SFCL has been studied as the fascinating device. In case that, Particularly, the SFCL could be installed to parallel operation of various power main transformers in power distribution system of the Korea Electric Power Corporation (KEPCO) on 22.9 [kV] bus tie, the effect of the resistance of SFCL could reduce the increased fault currents and meet the interruption capacity of existing protective devices by them. Therefore, we analyzed the effect of application and proposed the proper impedance of the R-type SFCL on 22.9 [kV] bus tie in a power distribution system using PSCAD/EMTDC.

Key Words : SFCL, Bus tie, Parallel operation, Power main transformers, Circuit breaker, Power distribution system

1. Introduction

Recently as power demand is increased, the power distribution system is being more complex and a power main transformer (MTR) is required to change to larger power main transformer or to be operated in parallel by connecting bus tie. These days, it is proposed to the parallel operation of MTR which offers plenty of merits than to change to a larger MTR which is so expensive and required to additional space in substations [1-3]. However, in the condition of the parallel operation of MTR, due to the reduction of equivalent impedance, the fault currents might exceed the interruption capacity of protective devices such as circuit breakers (CB), reclosers (RC), fuses, and so on.

Therefore, the ways decreasing fault current are necessary to meet its interruption capacity, so there are some existing ways. For example, they might generate other problems such as increasing power losses, voltage drop and loss power system safety. Among these methods, now days, the novel way to solve these problems has studied in application of SFCL[4-6]. The application of SFCL is being now under examination as the most effective, economic and realistic method. In power distribution system with SFCL on 22.9 [kV] bus tie, the effect of the resistance of SFCL can limit the increased fault currents, which could meet the interruption capacity of existing protective devices.

In this paper, therefore, when applying the R-type SFCL on 22.9 [kV] bus tie for parallel operation of various power main transformers in a power distribution system, we analyzed the proper impedance value of the SFCL to meet the interruption capacity of CB using PSCAD/EMTDC.

2. Power Distribution System Configuration

2.1 Power Distribution System

Fig. 1 shows a configuration of a power distribution system with a R-type SFCL on 22.9 [kV] bus tie in 154 [kV] substation. The substation has the two power main transformers (MTR) and some feeders. Furthermore, to protect MTR, feeders and loads, diverse protective devices are installed such as CB, and RC. And there is a switch (S/W1) which could connect MTR1 to MTR2 and
normally closed. The SFCL is installed on 22.9 [kV] bus tie between MTR1 and MTR2. The capacity of MTR1 is fixed as 60 [MVA] and the one of MTR2 is various as 60 and 100 [MVA]. Recently, to meet the power demand, the KEPCO considers installing the 100 [MVA] power main transformers so this paper spills over these environments[7].

Table 1 Data of power distribution system

<table>
<thead>
<tr>
<th>Items</th>
<th>Data (Base 100 [MVA], 22.9 [kV])</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>154 [kV], j1.778 [\Omega]</td>
</tr>
<tr>
<td>MTR1</td>
<td>60 [MVA], j20 [%] (Self base 60 MVA)</td>
</tr>
<tr>
<td>MTR2</td>
<td>60, 100 [MVA], j20 [%] (Self base 60 and 100 MVA)</td>
</tr>
<tr>
<td>Line</td>
<td>Z1 : 3.86+j7.42 [%/km] Z0 : 9.87+j22.68 [%/km]</td>
</tr>
<tr>
<td>Load</td>
<td>3ø, 9 [MVA], p.f. 0.95 lag, Lumped loads</td>
</tr>
<tr>
<td>Fault type</td>
<td>Three phase ungrounded fault</td>
</tr>
</tbody>
</table>

2.2 Protective Devices Capacity

The Circuit breaker (CB) is an automatically-operated electrical switching device capable of making, carrying, and breaking currents under normal circuit condition as well as specified abnormal circuit conditions such as short circuit [7]. The CB can be tripped and closed manually within the one of rated capacity values such as symmetrical fault current. The typical capacity ratings for CB installed at outgoing point of feeder are noted in Table 2.

Table 2 Capacity ratings for circuit breakers at outgoing point of feeder

<table>
<thead>
<tr>
<th>Rated Voltage</th>
<th>Rated Interruption Current rms</th>
<th>Rated current rms</th>
<th>Making Current peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.8 [kV]</td>
<td>12.5 [kA]</td>
<td>600 [A]</td>
<td>31.5 [kA]</td>
</tr>
</tbody>
</table>

Fig. 2 shows waveforms of fault current for the condition of transformer operation at the fault point. Fig. 2(a) and 2(b) represent the fault current of the capability of 60 and 100 [MVA] power main transformers respectively.

The value of fault current for 60 [MVA] transformer is smaller than for 100 [MVA] one. Because, according to a base capability of 100 [MVA], the equivalent impedance of their own is different and that of 60 [MVA] is bigger than 100 [MVA]. The symmetrical fault current rms is 7.18 [kA] for 60 [MVA] one and 11.59 [kA] for 100 [MVA] one. These values are lower than the rated interruption current of CB in Table 2.

3. Parallel Operation of Power Main Transformers

Usually, the parallel operations of power main transformers (MTR) offer a lot of merits. For example, it is that expandability of power, higher efficiency, improved reliability, redundancy implementation, and easy maintenance. However, in the condition of the parallel operation for MTRs, the fault currents could be increased and this problem is becoming more serious in a power distribution system. Therefore, in this paper, we analyzed...
the fault current for parallel operations considering various cases shown in Table 3.

Table 3 Data for parallel operation of MTRs

<table>
<thead>
<tr>
<th>Case</th>
<th>MTR 1 (MVA, Self Base)</th>
<th>MTR 2 (MVA, Self Base)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>60, j20 %</td>
<td>60, j20 %</td>
</tr>
<tr>
<td>Case 2</td>
<td>60, j20 %</td>
<td>100, j20 %</td>
</tr>
<tr>
<td>Case 3</td>
<td>100, j20 %</td>
<td>100, j20 %</td>
</tr>
</tbody>
</table>

If the fault occurs in parallel operation of MTRs at the fault point, the fault currents to feeder ($I_{\text{fault,feeder}}$) are flowing from MTR1 and MTR2, which is calculated by the following equation (1)[10].

$$I_{\text{fault,feeder}} = \frac{1}{Z_{\text{total}}} I_f$$

$$Z_{\text{total}} = Z_S + Z_{\text{T1,parallel}} + Z_{\text{fault}}$$

$$= R_S + jX_S + \frac{jX_{\text{T1}}jX_{\text{T2}}}{jX_{\text{T1}}+jX_{\text{T2}}}$$

$$+ R_{\text{fault}} + jX_{\text{fault}}$$

Where:
- $I_f$ : the rating load current
- $Z_{\text{total}}$ : the total impedance from a source to the fault point
- $Z_S$ : the total impedance of source
- $Z_{\text{T1,parallel}}$ : the total impedance of transformer in parallel
- $Z_{\text{fault}}$ : the total impedance of fault point
- $R_S$ : the resistance of source
- $X_S$ : the reactance of source
- $X_{\text{T1}}$ : the reactance of MTR1
- $X_{\text{T2}}$ : the reactance of MTR2
- $R_{\text{fault}}$ : the resistance of fault
- $X_{\text{fault}}$ : the reactance of fault

The unit is per-unit (P.U.)

We assumed that the impedances of MTR 1 and 2 are most reactance value, because the reactance value is generally much bigger than the resistance value in the transformers ($X_{\text{Tr}} >> R_{\text{Tr}}$) [11]. Thus we neglect the resistances of MTR 1 and 2.

Fig. 3 shows the waveform of fault currents for case 1 which is the parallel operation with both 60 [MVA] MTRs. Fig. 3(a) notes the fault currents of the feeder at fault point. This value is added by the fault currents from MTR1 and MTR2. The fault current consists of A, B, C phase currents and is divided by asymmetrical and symmetrical ones. Generally, the capacity of the rated interruption current for the CB is determined by the symmetrical fault current rms. Therefore, we considered the value of the symmetrical fault current rms.

Fig. 3 Waveform of fault current for case 1. (a) fault current, (b) symmetrical fault current.

Fig. 3(b) shows the symmetrical fault currents for Fig. 3(a). The feeder current of B phase is summed by the B phase fault current from MTR1 and MTR2. A symmetrical fault current rms to feeder is 13.68 [kA] and it is increased due to the reduced equivalent impedance of parallel operation for MTRs and the summed fault current. Furthermore, due to the same capacity of two MTRs and %Z, the fault currents which flow from MTR1 and MTR2 are the same value. Also, this value of feeder exceeds the rated interruption current of CB, thus which might malfunction for breaking fault current.

Fig. 4 shows the waveform of fault currents for case 2 in parallel operation of 60 and 100 [MVA] MTRs.

Fig. 4 Waveform of fault current for case 2. (a) fault current, (b) symmetrical fault current.

Fig. 4(a) notes the fault currents of the feeder at fault point. The fault currents are totally increased than case1. Fig. 4(b) shows the symmetrical fault currents for Fig. 4(a). Because of the reduced equivalent impedance for 100 [MVA] MTR2, the fault currents are increased. The symmetrical fault current to feeder could exceed the
capacity of CB and malfunction for breaking operation.

Fig. 5 represents the waveform of fault currents for case 3 in parallel operation of 100 and 100 [MVA] MTRs. Fig. 5(a) shows the fault currents of the feeder at fault point. The fault currents are the biggest in these cases. Fig. 5(b) shows the symmetrical fault currents for Fig. 5(a). Because of the reduced equivalent impedance for 100 [MVA] MTR1 and 2, the fault currents are increased. The symmetrical fault current to feeder could generate the problem of capacity excess for CB and might expand the fault area due to malfunction for one.

Further, in case 3, the parallel operation of 100 and 100 [MVA] MTRs, the symmetrical fault currents exceed that within about 1.5 [km].

4. Application of SFCL on 22.9 kV Bus Tie in a Power Distribution system

To solve these problems, we proposed to apply the SFCL on 22.9 [kV] bus tie in a power distribution system. When the fault occurs in parallel operation of MTRs with the SFCL at the same point, the fault currents to feeder (Ifault_feeder_SFLC) are flowing from MTR1 and MTR2. Here, the fault current from MTR2 is limited by the R-type SFCL’s effect expressed as the limited fault current (Ifault_MTR2_SFLC) in Fig. 7 and is calculated by the following equation (2). The unit is per-unit (P.U.)

Fig. 5 Waveform of fault current for case 3. (a) fault current, (b) symmetrical fault current.

Fig. 6 shows the profile of symmetrical fault current for fault locations by case 1, 2, and 3. The symmetrical fault currents to parallel operation are usually increased and these values are different as well as exceed the rated interruption current of CB in case by case.

Here, in case 1, the parallel operation of 60 and 60 [MVA] MTRs, the symmetrical fault currents exceed the rated interruption current of CB within about 0.5 [km]. In case 2, the parallel operation of 60 and 100 [MVA] MTRs, the symmetrical fault currents go beyond the rated interruption current of one within about 1 [km].

Fig. 6 Profile of symmetrical fault for fault locations by case 1, 2, and 3

Fig. 7 Flow of fault current with SFCL

\[
I_{\text{fault, feeder, SFCL}} = \frac{1}{Z_{\text{total, SFCL}}} I_n
\]  \hspace{1cm} (2)

Where:
- \(Z_{\text{total, SFCL}}\) : the total impedance from a source to the fault point with R-type SFCL
- \(Z_{\text{parallel, SFCL}}\) : the total impedance of transformer in parallel with SFCL
- \(R_{\text{SFCL}}\) : the resistance of R-type SFCL

Fig. 8 shows waveforms of symmetrical fault currents for case 1, 2 and 3 in parallel operation of the MTRs with the SFCL on 22.9 [kV] bus tie. The SFCL at bus tie limit the fault current flowing from MTR2 to meet the rated interruption capacity of CB. Thus, we controlled the SFCL’s condition which is the impedance of R-type SFCL. Fig. 8(a) represents the symmetrical fault currents
with SFCL’s impedance $1.1 \, [\Omega]$ for case 1. The limited symmetrical fault current rms to feeder ($I_{\text{fault\_feeder\_SFCL}}$) is $12.39 \, [kA]$ and it could meet the rated interruption capacity of CB. Fig. 8(b) and 8(c) note the symmetrical fault currents with the SFCL’s impedance $1.4 \, [\Omega]$ for case 2 and $4.2 \, [\Omega]$ for case 3 respectively. The reduced symmetrical fault current rms to feeder are $12.35 \, [kA]$ for case 2 and $12.48 \, [kA]$ for case 3. These values are to meet the rated interruption capacity of CB. Furthermore, it is that the higher SFCL’s impedance, the greater applying the capacity of MTR to parallel operation.

Fig. 8 Waveforms of symmetrical fault current in parallel operation of the MTRs with SFCL on bus tie. (a) case 1, (b) case 2, (c) case 3.

Fig. 9 shows the graph of symmetrical fault current rms with the SFCL’s impedance in parallel operation of the MTRs for case 1, 2, and 3. Here, when the SFCL’s impedances apply over $1.1, 1.4,$ and $4.2 \, [\Omega]$ for case 1, 2, and 3 respectively, the symmetrical fault current rms to feeder could be limited under the rated interruption current of CB at outgoing point. Therefore, we proposed to apply the SFCL on $22.9 \, [kV]$ bus tie in a power distribution system and consider the divers conditions of parallel operation for MTRs. In result, it could be limited lower than the rated interruption current of CB and the value of increased fault currents by controlling the SFCL’s impedance should be selected to meet the rated interruption current of CB considering various environments.

5. Conclusion

In this paper, we analyzed the application of SFCL on $22.9 \, [kV]$ bus tie for parallel operation of power main transformers in a power distribution system using PSCAD/EMTDC. There are some advantages to parallel operation of MTRs, but the increased fault current could over the rated interruption current of CB at outgoing point of feeders about symmetrical fault current, $12.5 \, [kA]$. To solve this problem, Therefore, we proposed to apply the SFCL on $22.9 \, [kV]$ bus tie in a power distribution system and consider the divers conditions of parallel operation for MTRs. In result, it could be limited lower than the rated interruption current of CB and the value of increased fault currents by controlling the SFCL’s impedance should be selected to meet the rated interruption current of CB considering various environments.

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References


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발전계통에 전력용 변압기 병렬운전시 22.9 kV SFCL Bus Tie 적응방안에 관한 연구

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