APPLICATION OF ARRESTER TO DOUBLE CIRCUIT TRANSMISSION LINE TO ENHANCE LIGHTNING PERFORMANCE AND INTRODUCTION ABOUT THE OBTAINED LIGHTNING WAVEFORMS BY MONITERING SYSTEMS

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1. INTRODUCTION

Lightning have caused more than 66.0 percent of faults occurred, as shown in Fig. 1, in transmission lines of a Korean electric utility company, KEPCO. As sensitive loads and reliance on electric power increase year by year, it is getting more focus on stable and high quality of power supply. It is getting bigger in more competitive market of power industry. A nine year record from 1996 to 2004 shows that double circuit outages, most of transmission lines are multi circuit more than double circuit in Korea, account for 33.7 percent of total lightning caused faults.

![Figure 1. Lightning faults in the KEPCO transmission lines](image-url)

Even though transmission fault might be cleared shortly by protective system, it could deteriorate the power quality accompanied with sag or flicker. Moreover, simultaneous double circuit fault could make the situation bad, for instance, blackout.

General solutions for transmission line against lightning include increasing of insulation distance, reduction of tower footing resistance, adoption of overhead ground wire or multiple overhead ground wires and unbalanced insulation of multi circuit transmission line. But these would not be appropriate in every situation. In mountain area where the soil resistivity is often high, the effectiveness of this method could be deteriorated or even not practical one because of high construction cost. Overhead ground wire diversify lightning current path to suppress the potential rising of tower. It also protect phase conductor from direct stroke and reduce the probability of back flashover and shielding failure. Unbalanced insulation of the double circuit line was proposed as another, especially for suppression of double circuit fault.

With the advent of non-ceramic housed arrester, line arresters have appeared and been accepted as an alternative in transmission as well as distribution. There are two type of line arrester being used over the world. One is a gapless line arrester, which is the same kind of arrester used in substation. The other is a gap type with series air gap, which is designed to discharge lighting surge only.

In Korea, electric power occupies a major portion in the energy market and become to things indispensable to life with wide spread of information technology. As a result of restructuring of electric power industry in accordance with the growing social needs introduced competition to the industry. A transmission fault in the competitive market, may lead to sharpening conflicts between concerned companies, or a grid company and customers. In the changed circumstances, a unique electric utility of KEPCO tried to find more effective solutions, especially for suppression of simultaneous multi circuit trip.

This paper describes the surge arrester application study for transmission line in Koreea Electric Power Corporation. An unbalanced insulation method with line arrester was assumed as another countermeasure against
simultaneous double circuit trip of 154 kV transmission line due to lightning. The lightning performance of line with arresters was compared with conventional insulation concept using different insulation distances, and evaluated with some technical and economical restrictions. EMTP simulation and predictive calculation of lightning failure rate were carried out to evaluate the performance. A monitoring system had been installed at every tower to investigate the performance of line arrester. The monitoring system detected the lightning discharging current and proved the effectiveness of line arrester.

2. LIGHTNING PERFORMANCE

The KEPCO is operating 28,409 circuit kilometers of transmission line ranged from 66 kV, 154 kV, 345 kV and 765 kV. The 154 kV transmission lines take 65.9% as Table 1. It is more vulnerable to lightning attack because of shorter insulation distance compared to higher transmission voltage lines. As shown in Figure. 2, 75% of lightning caused faults have been taken place in 154 kV lines. Of attempts, an unbalanced insulation method with transmission line arrester was considered as another countermeasure against simultaneous double circuit trip of 154 kV transmission line by lightning stroke.

<table>
<thead>
<tr>
<th>Lines</th>
<th>Over-head</th>
<th>Under-ground</th>
<th>SUM</th>
<th>P[%]</th>
</tr>
</thead>
<tbody>
<tr>
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<td>662</td>
<td>0</td>
<td>662</td>
<td>2.3</td>
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<td>345kV</td>
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<td>220</td>
<td>7903</td>
<td>27.8</td>
</tr>
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<td>154kV</td>
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<td>1967</td>
<td>18723</td>
<td>65.9</td>
</tr>
<tr>
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<td>889</td>
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<tr>
<td>HVDC</td>
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<td>202</td>
<td>232</td>
<td>0.8</td>
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<tr>
<td>SUM</td>
<td>26018</td>
<td>2391</td>
<td>28409</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Table 1. Transmission facilities of KEPCO

2.1 Calculation of critical flashover current

Once lightning strikes the transmission tower or phase conductor, a voltage difference between conductor and tower body may abruptly rise. When the voltage exceeds the critical level, corresponding to the time to flashover characteristic of insulator string, fault current begin to flow to ground.

![Figure 3. Lightning stroke to top of tower](image)

![Figure 4. Calculated critical flashover currents](image)

Figure 4 summarize the calculated critical flashover current in four different insulation levels plus shielding failure. In tower with one ground wire and tower footing resistance of 15 ohms, back flashover may occur above lightning current of 51 kA. As in figure 4, the amplitude of the critical flashover current of tower with arrester increases from 51 kA to 68 kA. The critical currents increase with low tower footing resistances. The overhead ground wire helps to suppress voltage rising of tower body due to stroke. Line arrester with external air gap may also increase the critical value. When phase conductor is directly exposed to lightning exceeding about 5 to 7 kA, flashover due to shielding failure begins to appear in the 154 kV transmission line. This critical current also increases from 7 kA to 32 kA after the application of arrester to the tower.
2.2 Performance analysis of the line with arrester

Recently, the line arresters are considered as another solution for lightning fault, especially for prevention of simultaneous double circuit fault. One double circuit line for arrester application were chosen among candidate lines based on the historical susceptibility to lightning caused faults over seven years and surrounding topographical conditions. Its expected lightning performance was evaluated by predictive simulation and dedicated tools for lighting failure rate calculation, which is LORP 2002-2 developed by Central Research Institute of Electric Power Industry in Japan.

(a) 154 kV transmission tower model

<table>
<thead>
<tr>
<th>Items</th>
<th>non installed section</th>
<th>installed section</th>
</tr>
</thead>
<tbody>
<tr>
<td>length(m)</td>
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<td>12,816</td>
</tr>
<tr>
<td>altitude(m)</td>
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<td>34.83</td>
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<td>hd1(m)</td>
<td>30.16</td>
<td>30.05</td>
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<td>hd2(m)</td>
<td>25.66</td>
<td>25.73</td>
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<td>hd3(m)</td>
<td>21.66</td>
<td>21.86</td>
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<td>wd1(m)</td>
<td>7.40</td>
<td>7.44</td>
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<td>wd2(m)</td>
<td>9.60</td>
<td>9.60</td>
</tr>
<tr>
<td>wd3(m)</td>
<td>8.18</td>
<td>8.07</td>
</tr>
<tr>
<td>angle</td>
<td>hillside average angle of 10 in degree</td>
<td></td>
</tr>
<tr>
<td>kA</td>
<td>lightning current 26 (kA) (σ : 0.325)</td>
<td></td>
</tr>
</tbody>
</table>

(b) Input for lightning outage rate calculation

The basic data for lightning performance evaluation is shown in Figure 5. The double circuit line is 28.3 km long with one overhead ground wire. It delivers power from thermal power plant on western seashore to east through mountain area. Input data shown in (b) of Figure 5 is for the calculation in case of partial installation in 9.2 km section of entire 28.3 km line, respectively. The average hillside angle is assumed as 10 in degree, which is defined between the ground and the surface perpendicular to tower. Total lightning number per year is 829 times, which is extracted statistically from Kepco Lightning Detection & information Network. The phase conductor of the model line consist of two-bundled ACSR 410 mm² with overhead ground wire of ACSR 100 mm².

2.3 Unbalanced insulation of double circuit line

Let us assume that a double circuit transmission tower in which two circuits have the same insulation distance. When the tower is hit by lightning enough to break down the designed insulation, it is inferred that each circuit has the same probability of flashover. However, if they have different insulation level, the probability would be not identical any more. Figure 6 shows relationship between lightning outage rate and insulation distances in the 154 kV double circuit transmission line. It is the results of predictive calculation with the model in Figure 5. In this calculation, it is assumed that insulation distance of one circuit is varied from 1120 mm to 1568 mm, while the other of two circuits maintains a constant arcing horn gap of 1120 mm. The failure rate is not inversely proportion to insulation distance.

2.4 Line arrester with external air gap

The switching withstand voltage level defines the minimum distance of series air gap of gap type line arrester. It is required that expectable overvoltages due to normal switching should not interfere with normal line operation. The KEPCO design specifies it as 3.3 p.u. for the 154 kV line.
Figure 7. Switching surge flashover characteristic of gap type arrester

Figure 8. Lightning flashover characteristic of gap type arrester

Lightning flashover characteristic makes it possible to determine the maximum distance of the series air gap of line arrester. The flashover characteristic of the gap should be lower than that of arcing horn to guarantee the insulation coordination between them. Every time lightning overvoltage occur on the insulator string, it must be discharged through series gap of arrester. The series air gap of arrester is optimized between switching surge withstand capability and insulation coordination due to lightning. Considering the horn gap length of 1120 mm in Korean 154 kV transmission system, the arrester series gap was compromised as 630 mm.

Figure 9. Line arrester with series gap

2.5 Lightning performance with line arresters

In this study, total 90 transmission arresters, which covers about one third of the 28.3 kilometers line, have been installed since 2003. Because no failures have been observed during first two years, it might indicate that there were no severe problems with line arresters.

Figure 10. Lightning performance with arrester

Figure 11 Double circuit fault with arrester

For appropriate evaluation of the effectiveness, we devised a monitoring system for the arrester operation. Because of its additional cost, monitoring may not be necessarily in commercial application. We investigate the total number of faults caused by lightning during past seven years prior to arrester installation. After complete installation over the line, as Figure 10, it is expected that the failure rate of the line with arrester go down from 5.47 to 2.66 [frequency / 100 km*year]. As in Figure 11, more interest thing is great reduction of the double circuit fault. It changes from 2.2 to 0.0 [frequency / 100 km*year].

2.6 Monitoring of arrester discharging current

It is not easy to discriminate which line arrester with series gap is exposed to lightning overvoltage and is related to faults, recorded by protective relay or SCADA. It made us devise a monitor equipped with current sensors and wireless communication. The current sensor can pick up a discharge current of arrester from 0.5 kA up to 30 kA. Detected current stored temporarily inside a monitor
mounted on the tower and then transmit to the database located in office via wireless communication network. It can also be configured to send a text message to pre-registered cellular phones at the same time. On centralized management server, it is possible to recognize which arrester discharge current and status of current sensors, communication module and power supply. If discharged current detected at the monitor coincide with measuring at lightning detector and no trip signal from protective relays, it would indicate that lightning stroke intruded into the line but arrester discharged it and suppress successfully the overvoltage.

![Figure 12 Discharging current of arrester due to 180 kA stroke the top of the tower](image)

Figure 12 Discharging current of arrester due to 180 kA stroke the top of the tower

EMTP calculation in Figure 12 shows that upper phase arrester discharge surge current of 9.87 kA peak due to stroke of 180 kA to tower top. The discharge current is extinguished within about 40 micro seconds. Figure 13 shows the software based on geometric information system. The dot signs in the Figure. 13 indicate lightning which are from Korean Lightning Detection Network with eight sensor sites over south Korea. Figure 14 shows the waveforms of line arrester current measured at the tower. On the monitor at the point detect the discharging, it transmitted data via CDMA wireless network. The received data coincided with zone what distance relay indicated at the substation.

![Figure 13 Lighting around test the line](image)

Figure 13 Lighting around test the line

3. REFERENCES


4. CONCLUSIONS

As another solution against simultaneous double circuit trip of 154 kV transmission line by lightning, an unbalanced insulation method with gap type line arrester was considered, and its performance was evaluated. The predictive study with the field operation demonstrate that the lightning performance of the 154 kV transmission line with arresters is expected to be enhanced by about 50%, and the double circuit failure rates is expected to be decreased to zero.