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APPLICATION OF LINE SURGE ARRESTERS TO A 110 kV OVERHEAD LINE IN AN AREA WITH HIGH LIGHTNING ACTIVITY

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Abstract: Line surge arresters (LSA) may reduce temporary line outages and problems in overhead line networks caused by atmospheric discharges such as lightning. Although the usage of LSA is already common practice in several countries, this project is the first installation in Austria at the 110 kV level.

The line, where arrestors have been deployed, is extraordinary in two ways: First, it runs through an area with a high local lightning density paired with high earthing resistances (low earth conductivity) and secondly, the line plays a major part in the utility's network. The standard line protection equipment with earth wires and arcing horns did not prevent line outages in several cases. The operational experience with LSA application and a new proposed protection scheme, which is necessary because of a line rearrangement, are described and discussed in the paper.

1. MOTIVATION

One of the main reasons for (temporary) outages of overhead lines is lightning. Although such incidents are mostly of short duration, they can lead to unscheduled line outages or to serious equipment damage at worst. Therefore outages, even those of very short duration, should be avoided in any case, when possible.

Due to the historical development of the transmission and distribution networks in Austria, the distribution network (110 kV voltage level) still plays an important role in the efficient supply of electrical energy. More than two thirds of the total high voltage overhead line network in Austria is operated at 110 kV. System performance and reliability is a key issue for an undisturbed supply of electrical energy. Thus it appears that network operators are forced to mitigate the effects of lightning because this is a frequent cause for overhead line outages. The Austrian utility Kelag Netz GmbH began to record and analyse line performance and circuit performance back in 1995. It was found that a single line in the utility's network of Kelag Netz GmbH was responsible for a number of outages several years ago [1]. On average, there are less than two line outages in the utilities network per year. However, there was a significant influence of the one line here as the outage rate has been about 5 to 10 times higher when compared to the rest of the network.

An innovative line reconfiguration combined with the application of line surge arresters (LSA) accomplished in 2003. We can show that these measures improved the line performance significantly. Recently, a line rearrangement and modifications in the utility's network made it necessary to revise the protection concept. A new protection scheme is proposed and analysed. The work described in this paper is the outcome of a long-term research project between the Austrian utility, Kelag Netz GmbH, Graz University of Technology and the supplier of the line surge arresters, Siemens AG.

2. LINE PARAMETERS

The studied line lies in a mountainous area in the south of Austria. Along its almost 30 km long route, it passes the Krezueckgruppe at around 2300 meters above sea level. Long parts of the line are situated above the timber line in areas with rocky soil.

Figure 1: The studied, high alpine overhead line

The tower footing resistances along the line can reach values up to 1100 Ω. Originally, the overhead line was constructed as a double circuit line with one shielding wire at the tower top. The line consists of 108 steel towers with span widths from 120 m to 493 m (median: 266 m).

The line corridor is also characterised by a high local lightning density, which has also been verified by the Austrian Lightning Detection and Information System *(ALDIS)*. The lightning density in the area ranges from three to more than six lightning strikes per km² per year. For this investigation, the line was divided into five sections. Lightning information gained by ALDIS revealed that the area with the highest lightning activity is not at the mountain peak but on the southern ridge (see **Figure 2**). Thus, this investigation concentrated on this critical line section (section 3). Lightning currents of 10 and 15 kA were selected for the numerical simulations. This was done on the basis of ALDIS data and shielding angle analyses based on a geometrical-electrical model combined with statistical lightning impact probability. More details and background information about the line can be found in [1, 2].

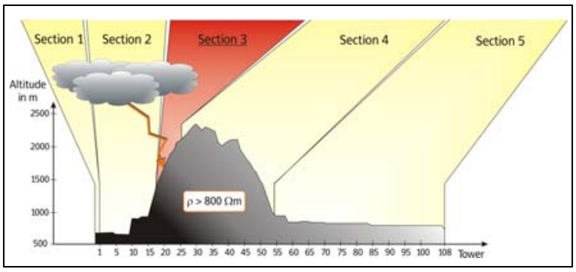

Figure 2: The investigated line is divided into five sections with the main focus on section 3

3. PROTECTION MEASURES

The line is equipped with basic protection methods: One ground wire at the tower top and arcing horns along all the insulators. It was discovered in previous studies (see also [3]) that shielding failures and back-flashovers caused by the poor local grounding situation are the dominating factors for line faults. Therefore, the main focus of attention was the avoidance of multi-phase (two or three phases) faults. A single phase fault can be tolerated by the network configuration as the utilities 110 kV network is operated compensated.

3.1. Preliminary steps

After a detailed investigation of the specific line characteristics, a number of measures were taken. More than 20 different protection schemes and configurations were evaluated with the help of numerical transient programs based on EMTP and ATP. The preliminary steps are partly overlapping with points researched in our previous studies. However, for a qualitative analysis, we studied the following issues:

- Evaluation of the line sections to find the most critical (Section 3)
- Variation of line setups (single system, double system, system rearrangements)
- Variance of arrester location (regional and phase variation)
- Quantity of applied arresters
- Influence of tower footing resistance (potential reduction through construction works)
- Application of alternative methods (e.g. counterpoise wires)

What we found was that the application of surge arresters on the two middle phases in connection with a system reconfiguration was the optimum in terms of feasibility, protection effectivity and efficiency.

System rearrangement

The system rearrangement conducted in 2003 (**Figure 3**) was a very unusual and extraordinary measure to improve the protection effectiveness. The original double system was converted into a single system. With this measure it was possible to use two phase wires as additional ground wires. These two wires have been connected to each steel tower (the insulators were shunt out). The third phase wire, which was unused due to the reconfiguration, was kept as reserve phase wire. With this measure, the protection angle was increased and the three phase wires of the -now- single system experienced an improved protection against direct lightning strikes.

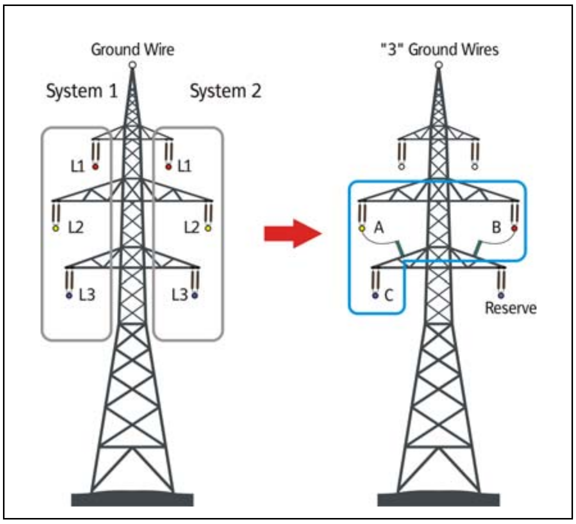

Figure 3: Protection scheme and application of line surge arresters

Application of surge arresters

For some decades, the application of surge arrestors onto overhead lines is common practice in several countries. In Japan, for example, the deployment of LSA started already in the 1980s, and in Brazil there is also good knowledge of LSA application [4, 5]. In connection with this respect several different application philosophies have been studied. There is no silver bullet of a general application strategy - the final decision about the deployment has to be studied for each particular case.

The line location holds additional aggravating circumstances – It is not possible to access the line during the winter season at all. Therefore, it had to be secured so that with the implemented protection scheme an unhindered line operation is possible at all times, even in case of the failure of an arrester or one of it components. Eventually, modern gapless metal-oxide surge arresters were implemented. In total, 18 surge arresters were deployed on 9 towers (2 LSA per tower). The connection between LSA and phase wire was made with a flexible line that was protected with an disconnection device. This device separates the phase wire from the arrester in case of component failure.

Furthermore, surge arresters were applied in each phase at the end of the overhead line in both substations.

Figure 4: Application of a line surge arrestor on a dead-end tower (arrester located at bottom cross-arm)

The final application scheme was found via optimizing analysis of technical, operational and economical issues in view of avoidance of multi-phase faults.

Improvement of grounding conditions

In the course of the construction work on the line reconfiguration, the installed ground wire was exchanged against a newer one with integrated fibre-optic conductors in 2002. The electrical connection between the ground wire and the towers were improved in several locations. This was achieved through the implementation of shunt wires between the earth wire and the tower tops.

The reduction of tower footing resistance was evaluated with simulations but it was found that the effort was out of all proportion to the benefit. It is very unlikely that a dramatic enhancement can be achieved in such a rocky area with low earth conductivity.

3.2. Line Surge Arresters (LSA)

In 2007 it was necessary to reconfigure the line. In connection with modifications in the utility's network there was a changeover of the line from the innovative protection scheme to the original double system. Therefore, it has now become necessary to rework the protection scheme.

The modifications actually changed the protection scheme from two protected phases (single system) to just one protected phase per system (double system) – The phases placed on the tower middle cross arms were protected only. Consequently, it was possible for multi-phase faults to occur on the line again. A multiplicity of new protection schemes were analysed. Different variations were evaluated, even the equalisation and reduction of tower footing resistance through the installation of counterpoise wires were studied. However, such methods were dropped basically for mechanical and efficiency reasons, see also [6]. It was found that for this special application case the most effective protection, especially in view of the special line section, was the installation of two additional line surge arrester below the bottom cross arm at the 9 towers (**Figure 5**). This method was furthermore chosen because it was within the ones that could be realized also from the mechanical point of view.

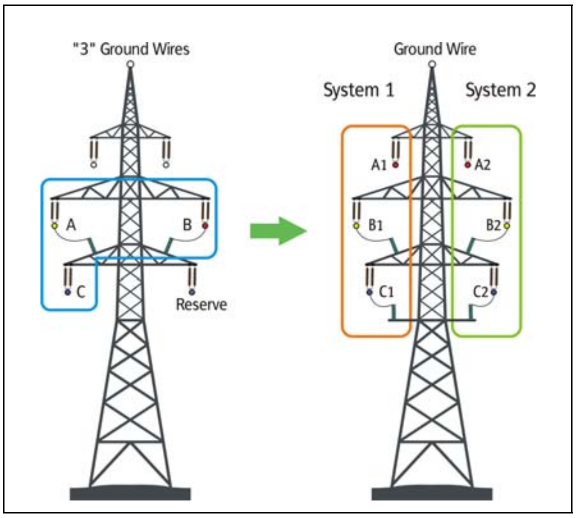

Figure 5: Proposed upgrade of LSA protection scheme after the line reconfiguration (back fitting to the original double system)

4. EVALUATION AND OUTLOOK

The innovative solution with line reconfiguration, application of line surge arresters and improvement of grounding conditions significantly reduced the line outages caused by lightning. Between 2004 and 2006 there were only 8 lightning caused outages; this equals a specific line outage rate of 2,7 outages per year on average (see **Table 1**). In this period, 799 lightning strikes, resulting in 1463 flashes, were detected by ALDIS within the line corridor. The average lightning current amplitude was in the region of about -15kA which backs up the previous investigations.

Table 1: Average outage rate per year

Period	Protection Method	Mean outages per year
1995-2003	Double system w/o protection	6,4
2004-2006	LSA on single system	2,7
2007-2008	LSA on double system	4,5

The field experience showed that with the theoretical investigations and practical measures the lightning caused outages could be more than halved from 6,4 outages to 2,7 mean line outages during the observation period. Furthermore, it has been demonstrated that the effect of system rearrangement in combination with LSA application (2,7 outages) is larger than the protection of two single phases with LSA only (4,5 outages).

4.1. Proposed solution and outlook

The now proposed solution is pictured in **Figure 5**. In view of the avoidance of multi-phase faults at least two phases of each system need to be protected. However, the placement of the arresters, as already mentioned before, needs to be evaluated individually. Since the line has to withstand harsh environmental conditions (wind and especially ice loads), other protection measures could not be applied. They might work in theory and also at other selected realisations [7], but at this special application the abovementioned preconditions put such special solutions out of question

Future investigations will show if the new concept will prove as practicable and effective than the previous system was. Currently we are studying if a selected equipment of additional towers with LSA can contribute to an improved protection. Further data is also needed for a more comprehensive outage statistic.

5. CONCLUSION

The application of line surge arresters is an effective method to reduce overhead line outages and to improve the reliability of the network. This is clearly shown through statistics which compare line outages before and after the installation of line surge arresters. Studies of LSA application in other countries also support this conclusion.

Despite the effectiveness of the line reconfiguration in terms of protection, this method can not be applied in general. Now with network modifications it is not possible to use this concept here anymore. A possible alternative could be the installation of more ground wires to the tower, but this is a question of mechanical strength and furthermore a question of benefit-cost relationship as well. Such measures only lower the possibility of direct hits and effects but they are ineffective against back-flashovers. Also the deployment of counterpoise wires needs to be examined in detail. Although this method is used on several lines worldwide, the application is not possible in every case.

As an optimised strategy for the application of line surge arresters depends on a multitude of factors, numerical simulations can provide a substantial contribution in the decision making. For the arrester deployment in 2003 and also for the new proposed scheme, more than 20 different protection variants have been studied. Finally, the field experiences show that the application of LSA can decrease the lightning caused line outages significantly in the protected network part.

6. ACKNOWLEDGMENTS

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