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Line Arrester Application on a 110 kV High Alpine Overhead Line to reduce Lightning-Caused Outages

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SUMMARY

This contribution discusses a project, which aims to increase the reliability in an existing 110 kV overhead transmission network by taking measures addressing lightning and grounding issues. Due to the fault statistic in the past, a single overhead line was identified as a main reason for the lightning-caused outages in the area. In this work a number of possibilities for the reduction of lightning-caused outages are discussed and the measures taken in the network are described. All considerations took the special geographical situation of 2300 meter above sea level, the grounding resistance of up to 1200 Ohm and the local lightning activity of more than 6 lightning strikes per km² and year into account (4 to 5 times higher than in other Austrian regions).

An analytical process was carried out to evaluate relevant parameters and to develop a concept of practical measures. Within these evaluations, the footing resistance, the effectiveness of the shielding angle of the shielding wires and the line arrester locations were analyzed. A multiplicity of numerical calculations were performed to assess the application of surge arresters regarding the insulation coordination for the system. To improve the line performance and to decrease the line outage rate, a number of practical measures were applied to the 110 kV line. In the past, the double three phase systems of the 110 kV overhead line was constructional converted into one active single three phase system with two additional earth wires. According to the numerical results, 18 surge arresters have been installed in a line section of 9 towers, located in a high alpine part and in an area of high lightning activity. Three years of field experiences have shown that the theoretical investigations and the practical measures led to a significant decrease of lightning caused outages.

In the year 2007 a new project was started to evaluate a reconstruction of the line into the original double three phase system. New numerical calculation routines were made to apply line arresters at this important 110 kV system in an Austrian extreme mountain region. Based on this results, a new application of line arresters and the constructional change of the system is planned.

KEYWORDS

Line surge arresters, 110 kV overhead line, high alpine region, lightning outages, backflash

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1. MOTIVATION

Because of the historic development and the geographical position, the 110 kV transmission network is of great importance in Austria. Especially in the mid and southern parts of the country, long sections of the 110 kV network are situated in alpine or high alpine regions. Such areas have a high lightning activity, especially when compared to other parts of the national territory.
Furthermore, the earthing conditions tend to be bad in such areas because of the rocky soil which is accompanied by a high specific electrical resistance. Hence, it is not surprising that such lines naturally have a bad performance.
The line which will be investigated within the scope of this paper has already been under study for more than seven years now. With innovative constructive measures and the installation of line arresters in 2003 it was possible to achieve a notable improvement of the line performance. New requirements for energy transport lead to a performance update of this specific line nowadays, which is again combined with a line reconfiguration.

2. INTRODUCTION

The studied line was originally constructed as a double system, 3-phase 110 kV overhead line with one shielding wire at the tower top. The system consists of 108 steel towers with a (median) span field length of about 266 meters. It has to be noted that the line is electrically operated in parallel for 15 kilometres at one line end, which is nearly half of the total line length. For the rest of the line, each 3 phase system is operated independently (see Figure 3) [1,2].
In 2001, the network operator decided to take actions to enhance the line performance. This led to a line reconfiguration from a double system to a single system (Figure 1). Because of this rearrangement, three phase wires could be "freed", where two of them (the two upper phases) have been used as additional shielding wires and the third wire has been kept as a standby phase conductor. Additionally two phase wires (the two middle ones) have been protected by line surge arresters in the section with the highest lightning activity along the line (nine towers totally) [3].

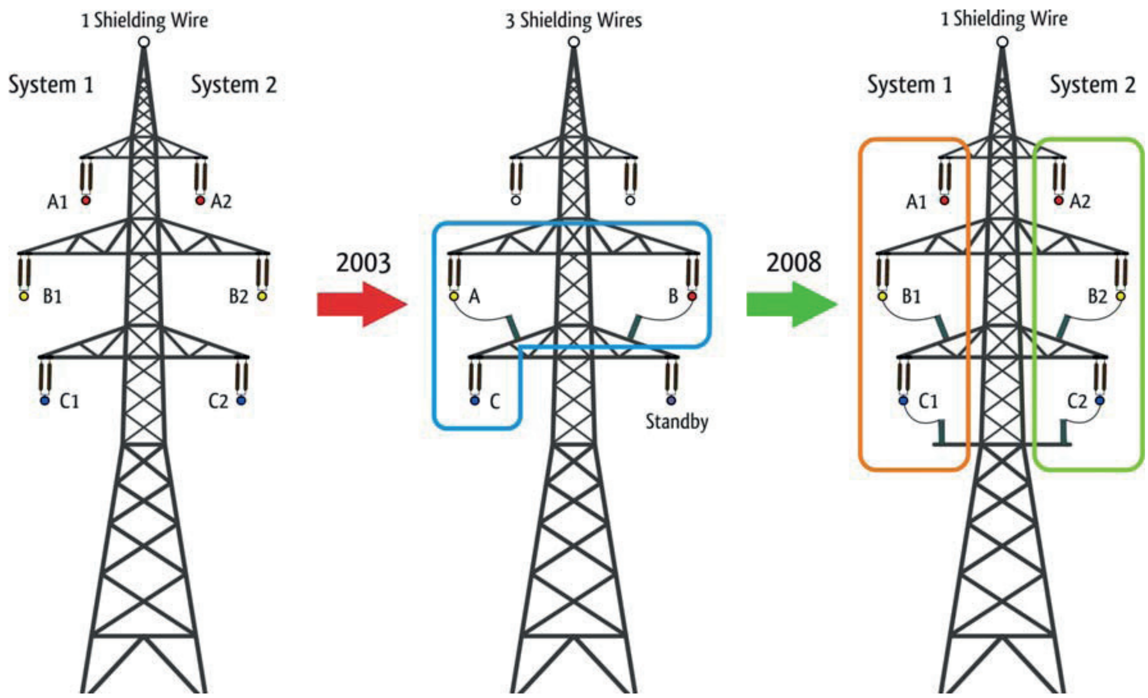

Figure 1: Original Double System without Protection (left); Present Situation: One Single System with Line Surge Arresters (middle); New Reconfiguration: Double System with Line Surge Arrester Protection in 2 Phases Each (right)

In 2007, the utility was forced to rebuild the system into the original double system on the proven condition with the good lightning performance.
Based on the line section and the towers respectively which have already been equipped with arresters, numerical simulation programs (ATP/EMTP) were used to evaluate a good solution of this specific task and to find optimized schemes for the additional placement of surge arresters.

3. MODELLING AND SIMULATION

Line Modelling

Despite the previous investigations which have been conducted, the modelling had to be started from scratch. In the past, the whole line was divided into 5 sections and these have then been modelled in ATP with different levels of detailedness. The most critical section and therefore the most important one in terms of research was Section 3 in the middle of the system (Figure 2). Studies of lightning data from ALDIS (*Austria Lightning Detection and Information System*) have confirmed the approach.

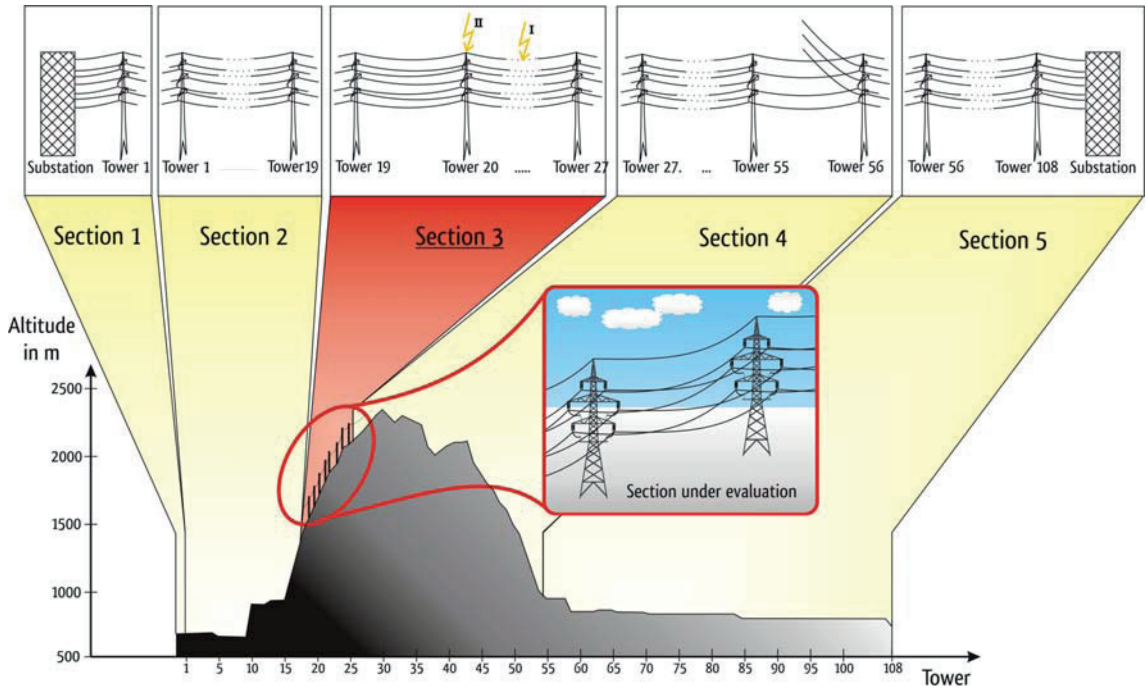

Figure 2: Line Sections and Altitude of the evaluated Line

Frequency dependent line models (LCC) have been used for the modelling of the whole line. Tower footing has been simulated for every tower where applicable. The power frequency voltage has not been taken into account. Section 3, consisting of 9 towers and also the two adjacent sections (Section 2 and 4) have been modelled detailed with single towers (transient tower model [4]) and the actual tower footing resistance. A direct discharge to one tower (Tower 25) with an injected lightning current of 15 kA is assumed for all of the simulations.

Mitigation of Lightning-Caused Outages

Before the first line reconfiguration in 2003, the double system was protected with one shielding wire at the top of the line and with arcing horns at the insulator strings as usual. With the re-fitting of 9 towers with surge arresters in Section 3 (Figure 3) and the acquisition of two additional shielding wires the overall line performance was increased dramatically.

Based on 3 years of operational experience, a new technical solution for the double system has also to guarantee the proven line performance. Therefore the additional application of line surge arresters and the numerical evaluation of the insulation coordination status was a central measure. Nevertheless, two additional topics have been simulated, namely the improvement of the earthing conditions (in particular the tower footing resistance) and the installation of a counterpoise wire in this section.

The improvement of the footing resistances is in fact quite impractical and inefficient in this special case because of the very high values of up to nearly 800 Ohms in Section 3 and even more in the adjacent sections. For example, a reduction of more than 80 percent of the actual resistances was studied. Such a theoretical reduction still implies a high risk for back flashovers and it should not be disregarded that it is not likely that such a reduction could be achieved in practice.

Counterpoise wires can be helpful for the equalisation of the earthing conditions along the line. For this specific situation the installation was not possible as the towers could not handle the additional load. Severe weather conditions like ice load or wind speed in this high alpine region have to be taken into account.

Figure 3: Tower with 2 Line Surge Arresters (Present Situation)

4. Solutions for Line Arrester Application

The application of line arresters at every phase and every tower of such an important overhead line within critical sections might be common practice sometimes but it is also the most cost intensive option [5,6]. The costs in this specific case can be divided into costs for research and evaluation work, unit costs for the arresters itself and costs for construction work and strengthening of the tower, if necessary. Additionally, the situation of the high voltage grid and the lightning activity was taken into account. Therefore separate costs for the grid monitoring and network analysis in the utility and costs for the lightning detection system influence the economic situation.
In this work a practicable and cost optimized solution has been worked out with the help of numerical simulations. Based on this process, a reduction of the number of line arresters is reasonable, still with respect to the insulation coordination and the utility specific operation demands.

Standard Protection

A double system overhead line is protected with one shielding wire at the top of the line and with arcing horns at the insulator strings usually. Theoretically without any protection devices, the peak values of the transient voltages can reach levels up to 2,2 and 2,5 MV, which exceeds the electrical withstand voltage of the insulation by far. With the standard integration of arcing horns at each insulator string (typical application in Austria), the voltage peaks can be reduced to values in the range of 550 to 850 kV.

One Protected Phase Wire per System

The protection of one single phase per system is a very economic one, but still two phases are not protected. In this case the voltage in the protected phase is limited to the residual voltage of the surge arrester. The voltage stress of the other two unprotected phases depends on the system arrangement including the surge arrester position. The insulation coordination studies have shown, that for an optimal protection the lower phase is preferred when using one arrester only (Table 1).

Table 1: Peak Values of the Transient Voltage Stress with only One Phase Wire protected

Voltages in kV of Phase:	Protected Phase A	B	C
A	325	900	957
B	1179	326	973
C	1344	1083	326

Two Protected Phases Wires per System

The protection of two phases can be seen as some sort of compromise between economics, protection and line performance. In this work several aspects have been studied to find out a efficient protection. The peak values of protected and unprotected phases are listed in Table 2.

Furthermore, it has to be taken into account, that one unprotected phase sometimes can be tolerated, if a single phase failure does not influence the system performance which is given by the operational structure of the utility.

Table 2: Peak Values of the Transient Voltage Stress with Two Phase Wires protected

Voltages in kV in Phase:	Protected Phase A, B	A, C	B, C
A	309	309	676
B	315	715	310
C	899	316	313

From the mechanical point of view it would be desirable to protect the top phases and the middle phases because the according surge arresters can be mounted on the subjacent tower crossarms. Electrically, the protection of the two lower phases in each system could be found as an optimal solution for minimising the transient voltage stress.

Three Protected Phase Wires per System

Some utilities run the strategy to apply arresters on each phase per system. The protection method can be stated as the most efficient one, but can also be seen as the most cost intensive method regarding the number of arresters and the mechanical tower dimensioning.

With respect to the evaluation in this specific transmission line, the maximum transient voltage stress per system could be calculated in the range of about 310 kV for all phases. To protect the lower phase with an surge arrester, an additional platform is necessary to be mounted at the tower.

Global Situation

A global overview of the peak values of the transient voltage stress is given in Figure 4. In this diagram the effectiveness of the surge arrester application can be seen, comparing different protection schemes.

Regarding to the line situation without arrester protection, the installed surge arresters in Section 3 solve the biggest issues concerning line outages. With two installed arresters on each system, the global situation of the whole line could be improved (see Figure 4). Nevertheless, the protection basically remains limited to the line section with the arresters installed. It has to be taken into account, that the adjacent sections of the line can be stressed by transient overvoltages (flashovers can occur).

Typical transient voltage time trends can be seen in Figure 5. In this figure, a protection scheme with 2 protected phases on each system is demonstrated. It is assumed that Tower 25 experiences a direct lightning strike with a 1,2/50 µs wave shape and a current of 15 kA as it is shown in the left picture. Furthermore it is assumed that the lower two phases of each system (Phase wires B (green) and wires

C (blue) in Figure 5) are protected. This would correspond to the arrester application as it is shown in Figure 1 in the very right picture.

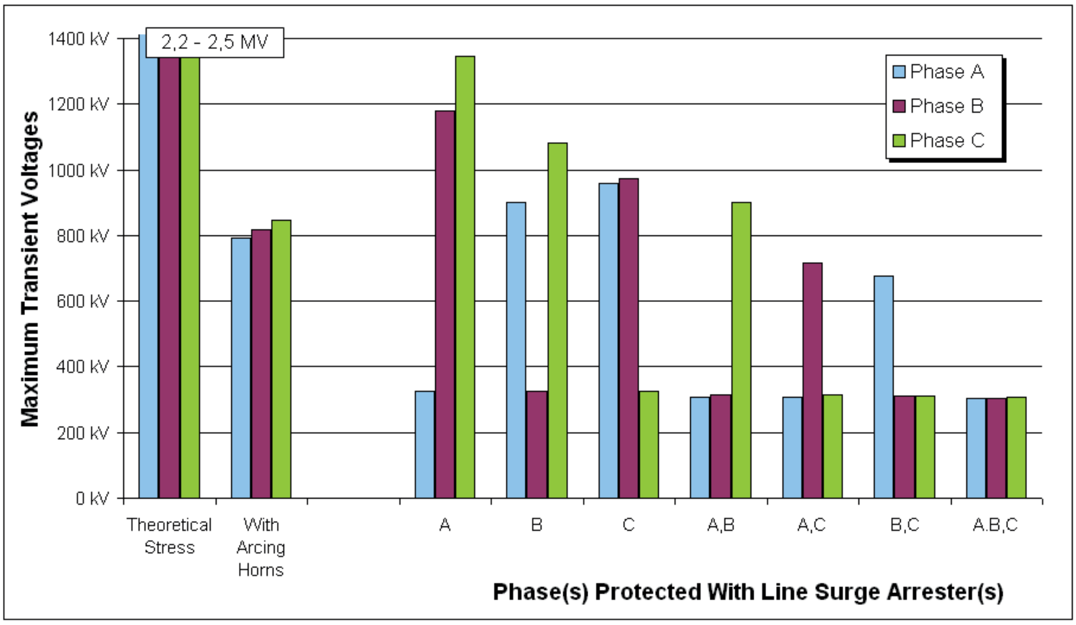

Figure 4: Peak Values of the Transient Voltage Stress in Section 3 for a 110 kV Transmission Line

The right picture in Figure 5 shows the transient voltages of one system on Tower 15. This tower is outside of Section 3 and is therefore not equipped with surge arresters. Because of the fact, that this tower is approximately 2500 meters away from the point of impact, the transient voltages are already lower than the voltages at Tower 25 but there are still oscillations.

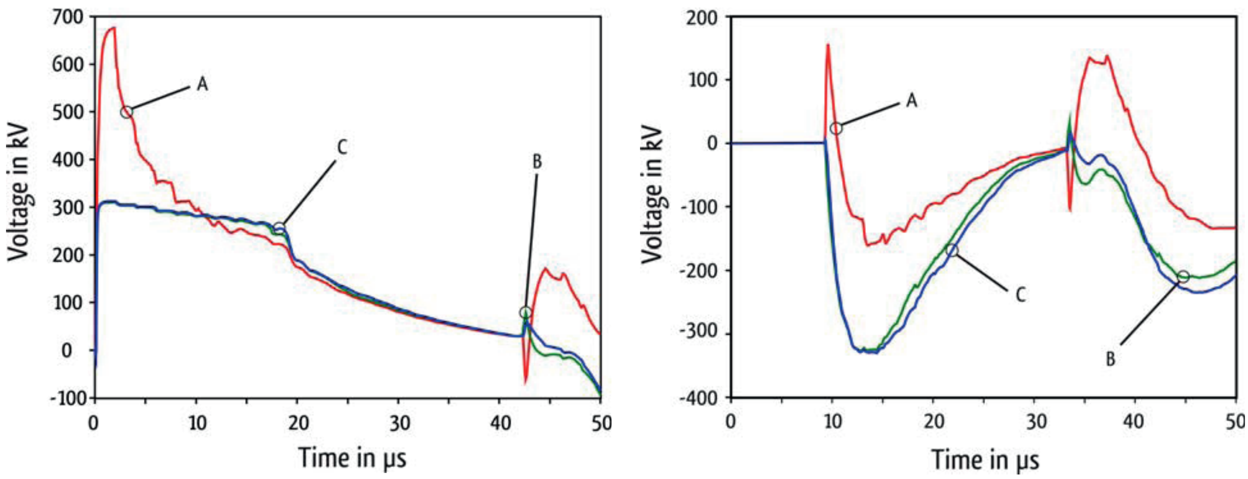

Figure 5: Transient Voltage Time Trends with Two Line Surge Arresters (placed at middle and bottom phases); Tower 25 (Left Graph) and Tower 15 (Section 2, Unprotected; Right Graph); Red – Top Phase (A), Green – Middle Phase (B), Blue – Bottom Phase (C)

5. CONCLUSION

The usage of line surge arresters for such an application has not been done before in Austria. Due to a registered high outage rate, one specific section of 8 spans within a high alpine transmission line was identified. A systematic evaluation of the local situation of the insulation coordination was done by using numerical calculation tools. Within a cooperation between an utility and Graz University of Technology, research projects covering this topic are running since 2001. It was also a novelty that a double system overhead line was reconfigured to a single system in 2003 to enhance line performance and also to increase the overall transmission network performance. In 2008, matters of energy transport necessitated the double system again. This further reconfiguration should be conducted with the maintenance of the upgraded line performance. As a result of the good operational experience, the usage of additional line arresters has been researched.

Line surge arresters are well suited for the mitigation of transient overvoltages and the related line outages. Especially in regions with poor earthing conditions and high lightning activity, line arresters can contribute very effectively to the line performance. Several years of operational experience of that special line are showing that. In this special case it is planned to equip a small but critical section of a double system overhead line with line surge arresters in Summer 2008.

6. ACKNOWLEDGEMENT

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