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Analyses and practical measures to reduce lightning-caused outages on a 110 kV overhead line

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Abstract: This paper presents a project, which deals with various analyses and practical measures to increase the reliability of a 110 kV overhead line in an existing overhead distribution network by taking measures addressing lightning. Due to the fault statistic, a specific overhead line was identified as a main reason for lightning-caused outages. Analytical methods as well as evaluation processes for possibilities to reduce the lightning-caused outages are described and the consequential practical measures on this single line are discussed. All considerations took the special grounding issues of this high alpine situation (2300 meter) and the local lightning activities (4 to 5 times higher than in other Austrian regions) into account. Numerical calculations are performed to assess the application of line arrestors regarding the transient voltage stress for the insulation coordination. According to the simulation results, a strategy is laid out to implement surge arrestors in two phases. To obtain a better grounding- and shielding-situation, two phases of the parallel three-phase system are used as additional shield wires. Further, arrest discharge loggers were installed to record and evaluate the effectiveness of these measures.

1 INTRODUCTION

Based on the geographical situation of Austria, the 110 kV high-voltage distribution system is a substantial and important component of the electrical power supply. A major part of the 110 kV network is located in the high alpine area. The thunderstorm activity and therefore the number of lightning strikes to the line and to the nearby surrounding are high in those alpine regions. Additionally, the rocky soil is typical for this region. These geographically exposed situations of overhead lines and the local meteorological conditions lead to the impairment of the power quality caused by lightning strikes.

Due to a number of faults in the 110 kV network the incidental voltage dips had negative effects especially on the power supply of highly qualified industrial companies. To improve the power quality the Austrian power supply company KELAG started a continuous analysis on the 110 kV network in 1995, which was accompanied by the Graz University of Technology. Special attention was put on two- and three-phase faults. Due to a significant high outage rate of one 110 kV overhead line several measures (Fig.1) were discussed to reduce the outages with special respect to lightning.

Fig. 1: Line arrestor application on a KELAG 110 kV overhead line in this extreme alpine region

2 HIGH ALPINE 110 KV LINE

A comparison of the outages of the 110 kV distribution network of the KELAG had shown that one single overhead line had a significantly high rate of outages. In the following, the main parameters like orographic situation, lightning data, grounding conditions as well as the outage situation of this overhead line will be described.

The 110 kV overhead line run from the substation of Oberdrauburg to the substation of Außerfragant across a mountain range called Kreuzeckgruppe (Fig. 2). The line has a length of approx. 30km installed on 108 steel towers with two three-phase systems and one earth wire on top. Along the route, the overhead line leads to a height of about 2300 m above sea level. From tower no. 2 to tower no. 56 the system is electrically operated in parallel (double system). Before and after this section the distribution line is electrically operated in a single system.

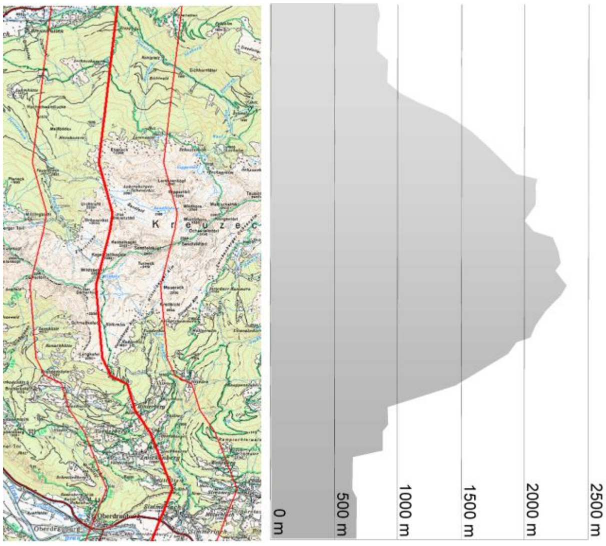

Fig. 2: Line route and sea level of the 110 kV overhead line across the Kreuzeckgruppe in Carinthia

The towers height is between 30 and 55m with concrete foundations and a grounding system each. The length of the spans varies between 120 and 420m. The insulators are dimensioned according to the isolation coordination for the 110 kV system with spark-horns on every insulator.

In the area of this 110 kV distribution line the number of atmospheric discharges to the line and/or into the surrounding environment is higher than the average value of Austria, which is confirmed by the data of ALDIS (Austrian Lightning Detection & Information System). The lightning density in the region of the overhead line is in a range from 3 up to more then 6 lightning strikes per km² and year. Of course these values can vary from year to year, but they are always higher than the average values of other regions.

As mentioned before, nearly one third of the 110 kV overhead line runs in a high alpine area with rocky soil and bad tower earthing conditions. The values of the footing resistances are in a range of 200 to 1200Ω.

The number of line outages in the 110 kV distribution network of the KELAG is in average lower than 2 outages per year in total. This specific 110 kV overhead line was identified with 49 outages in a time span of 5 years. The outage rate was approx. 5 to 10 times higher than the average value of the complete 110 kV system.

3 EVALUATION

A significant number of line outages could be assigned to lightning strikes directly to the line or in the ground nearby. Due to the exposed situation of this specific line and the high lightning activity, a concept of practical measures was developed to increase the line performance during lightning activity.

3.1. Shielding angle analyses

Within the analytical analyses the effectiveness of the shielding angle of the earth wire was considered in a representative line section. The 110 kV overhead line crosses a mountain ridge where the line is located on a hillside situation. The maximum lightning currents, which can probably hit the phase wires directly, were determined with the geometrical-electrical model. With this detailed determination of the currents, the hillside situation was accounted as well as the lightning flash density in this region. For the most exposed towers, the maximum currents for a direct strike to the phase wires were determined (Tab. 1).

Tab. 1: Lightning sphere radii and lightning currents for representative towers

	Lightning sphere radii [m]	lightning currents [kA]
tower no. 21	66,25	18,71
tower no. 22	95,00	32,13
tower no. 23	82,50	27,43
tower no. 24	132,50	52,92
tower no. 25	137,50	55,95

3.2. Calculation model

The implementation of the line arrestors is based on numerical calculations with a transient program (ATP). For the calculations basically two sub models were taken. One for the complex overhead line with the tower, the line section, the grounding situation and the protection device (surge arrestors) and one for the transient source, which represents the lightning discharge.

In this alpine region, the grounding values varies from tower to tower. Therefore, each tower has to be modelled individually. This is considered with impedances at each tower between the tower bottom and the reference earth.

Every part of the steel tower is modelled by surge impedances and the individual height.

For the computation of the transient behaviour, the equivalent circuit of the line was assembled using adapted line modules. The line spans are modelled with LCC elements with the parameter line length and the surge impedances for the overhead line conductors and the overhead earth wire.

For the protection of the conductors against overvoltages a modern metal-oxide surge arrester was implemented. The metal-oxide arrestors are modelled by a voltage dependent resistor with a non-linear characteristic according the data sheet.

The lightning discharge is realised by a transient current source with the wave shape 1,2/50µs (high voltage testing) and an amplitude of 15kA (50% median value of lightning amplitudes).

3.3. Calculation procedure

A large number of computations routines were done to evaluate the performance of the overhead line under various setups. The application of surge arrestors was varied due to the number of protected phases as well as the number of protected towers. Originally, the line is setup as a double three phase system. Additionally, a system rearrangement was taken into account were the double three phase system was converted into one active three phase system with three wires in reserve. Over all 20 different variations were computed.

For the numerical calculations, a specific line section was selected were the application of the line arrestors were varied and computed. In the area of this specific line section the lightning strike density is the highest within the line route, the orographic situation is rough and the footing resistances have values above average. The line outside this specific section was modelled by a continuous homogeneous line. The two substations far away were modelled by surge impedance models, the transformers were modelled by their impulse impedances.

3.4. Double three phase system

Eleven variations were calculated with the double three phase system. Within the calculations the number of surge arrestors along the special line section was varied.

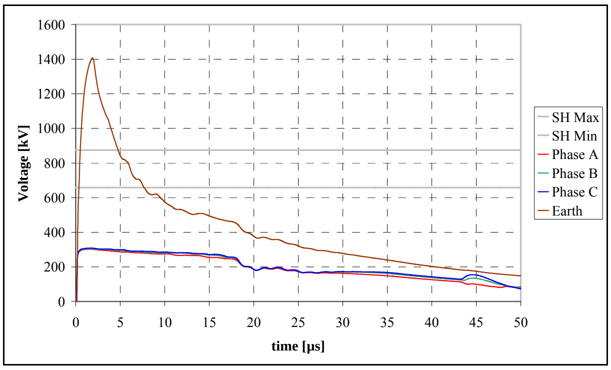

Fig. 3: Calculated voltage stress at phase A, B, C and earth on one tower with surge arrestors on every single phase

Thereby, all phases on the towers were equipped with arrestors as well as only selected phases. Also the number of equipped towers was varied. The variations were calculated with and without sparking horns at the insulators.

The transient voltage stress without any protection device reaches 2500kV. The usual protection with sparking horns on the insulators reduces the voltage stress to approx. 700kV peak. On towers with protected phases (line arrestors) the voltage stress is limited to approx. 300kV (Fig. 3). On towers without surge arrestors the phase voltages at the sparking horns can exceed the Basic Insulation Level (BIL). The transient voltage outside the protected line section increases according to the distance.

3.5. Single three phase system

As a result of the system rearrangement the two phase wires on top were converted into additional shielding wires (insulated by 110 kV insulators). Nine variations were calculated with this single three phase system. Within these calculations the number of surge arrestors was varied. All three phases on the towers were equipped with arrestors as well as only two phases. Also the number of equipped towers was varied.

On towers with protected phases (line arrestors) the voltage stress is limited to approx. 300kV (Fig. 4). On towers without surge arrestors the phase voltages at the sparking horns can exceed the BIL. The transient voltage outside the protected line section increases according to the distance.

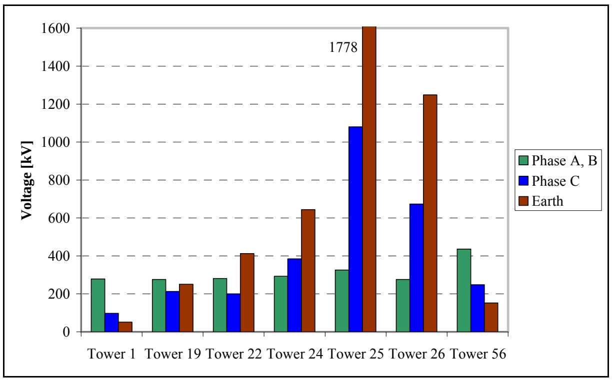

Fig. 4: Transient stress (peak values) at phase A, B, C and earth on selected towers with surge arrestors on phase A and B

3.6. System with additional earth wires

Based on the single three phase system, a variation of connections between the additional shielding wires and the tower-top were simulated.

The results of these calculations are similar to the single three phase system with an additional reduction of the transient voltage stress in total.

On towers with line arrestors the voltage stress is limited to approx. 300kV (Fig. 5). The transient stress of the unprotected phase is reduced significantly from 1080 kV to 800 kV peak value.

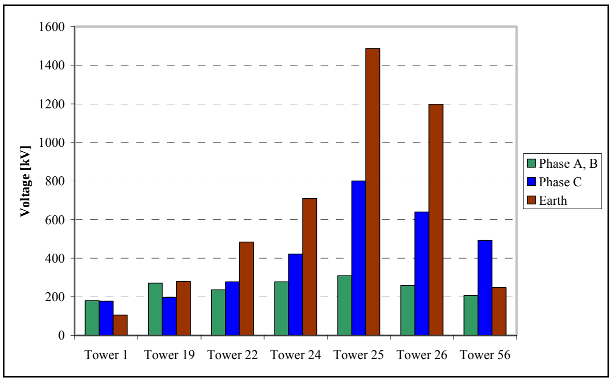

Fig. 5: Transient stress (peak values) at phase A, B, C and earth on selected towers with surge arrestors on phase A and B with additionally connected earth wires on towers with high footing resistances

4 PRACTICAL MEASURES

Based on the evaluation of the 110 kV overhead line, the shielding analyses and the numerical calculations the following practical measures were applied.

4.1. System rearrangement

The double three phase systems of the 110 kV overhead line was constructional converted (Fig.6) in one active three phase system with three wires in reserve. The two phase wires on top of the towers were connected to each steel tower. As a result of these connections, the two wires on top became two additional earth wires. This measure implemented a larger protection angle of the three earth wires.

Fig. 6: Constructional connection of the two additional earth wires with the tower

4.2. Surge arrestor application

Due to the results of the transient calculations 18 surge arrestors were installed along the overhead line and 6 arrestors in the substations Oberdrauburg and Außerfragant.

In the selected line section of 9 towers only two of the three phases were equipped with surge arrestors. At the substation all three phases were equipped with surge arrestors. A disconnection device was installed between the phase line and the surge arrestor at each arrestor (Fig.7).

Fig. 7: Line arrestor and disconnection device between the phase conductor and the arrestor

4.3. Improvement of the grounding situation

The improvement of the grounding situation in the observed line section was based on extensive measurements on site (Fig. 8). One of the first measures was to change the earth wire by a new wire with integrated optic fibre. To avoid a high contact resistance between the earth wire and the tower top additional shunt wires were installed between the earth wire and the tower top.

Fig. 8: On site measurements to evaluate the tower grounding situation in the observed line section

4.4. Arrestor discharge records

For registration and recording of the discharge behaviour of the installed surge arrestors, a Rogowski inductor and an Arrestor Discharge Logger (ADL) were installed at every arrestor (Fig.9).

Fig. 9: Arrestor Discharge Logger (SIEMENS) at the line arrestor on the pole arm

5 SUMMARY

Due to a registered high outage rate of one single 110 kV overhead line in a rough alpine region, a systematic evaluation was set up in a project, to increase the performance and the reliability of the energy supply.

A number of important analyses were done to determine this specific situation. The orographic situation, the unusual high tower footing resistances with a wide range, the shielding angle analyses, the lightning activity and numerical calculations for the insulation coordination were taken into account.

Following scientific analyses and practical measures have been carried out:

- Selection of the most critical line section based on the lightning activity.
- Numerical calculations to simulate different line setups and arrestor locations.
- Theoretical and numerical investigations to apply the practical measures.
- System rearrangement of a double three phase system to a single three phase system.
- Additional shielding wires with shunt connections to the tower top to increase the protection of the phase conductors.
- Numerical determination of the number of line arrestors at each tower.
- Application of 18 surge arrestors in a section of only 9 towers in the most stressed line section.
- Field experience with arrestor discharge loggers (ADL) and data evaluation.
- Significant decrease of lightning caused outages in the observed network part.
- Significant increase of the line performance and a better reliability for the consumer.

6 ACKNOWLEDGMENT

This project for the application of line arrestors for this specific line situation was based on a scientific cooperation between the Carinthian utility KELAG Netz GmbH, the Institute of High Voltage Engineering and Systemmanagement at Graz University of Technology and SIEMENS AG PTD H Berlin in Germany.

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