POSSIBILITIES AND REMEDIAL MEASURES TO REDUCE LIGHTNING-CAUSED OUTAGES IN A DISTRIBUTION NETWORK

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ABSTRACT

On overhead distribution lines, lightning usually causes temporary faults. If the fault is cleared by a circuit breaker, the connection may be successfully reclosed. In the past, this was acceptable, but now with the rapid growth of sensitive loads, momentary interruptions are a major concern. With the demand for improved system reliability and performance, electricity companies must focus on mitigating the effects of lightning, considered to be one of the most frequent causes of transmission line problems today.

The paper presents a project, which aims to increase reliability in an existing overhead distribution network by taking measures addressing lightning and grounding issues. Due to the fault statistic, a single overhead line was identified as a main reason for the lightning-caused outages in this area. Possibilities to reduce the lightning-caused outages are summarized and the measures taken in this distribution network are described. All considerations took the special geographical situation (2300 meter), the grounding resistance and the local lightning activities into account. Numerical calculations are performed to assess the application of surge arrestors regarding the transient voltage stress for the isolators. According to the simulation results, a strategy is laid out to implement surge arrestors in this overhead line. In this paper, the project steps and the results of the 3-years field-experience is discussed and presented.

INTRODUCTION

The 110kV high-voltage transmission system of Austria is a substantial and important component of the electrical power supply. Based on the geographical situation of Austria, a great part of the 110kV network is located in the high alpine area. The local grounding conditions are sometimes very bad in such rocky regions and have values in a range from 200 to 7000 Ohm. Additionally, the thunderstorm activity and the number of lightning strikes to the line and to the nearer surrounding are high in such areas. These geographically exposed situations and local weather conditions lead to the impairment of the power quality caused by lightning strikes.

Figure 1: 110kV overhead line in a high alpine region

Due to a number of failures in the 110 kV network the Austrian power supply company KELAG started a continuous analysis on this network in 1995. The incidental voltage dips had negative effects especially on the power supply of highly qualified industrial companies. Special attention was put in the studies on two- and three-phase faults. Due to a high outage rate of one identified distribution line several measures to reduce the outages, especially caused by lightning, were discussed.

110KV DISTRIBUTION LINE

Due to the fault statistics a single overhead line was identified as a main reason for outages in one part of the 110kV distribution network of the KELAG. In the following the orographic situation, the lightning data, the grounding conditions as well as the outage situation of this overhead line will be described.

Orographic situation

The 110 kV overhead line leads from the substation of Oberdrauburg to the substation of Außerfragant across a mountain range called Kreuzeckgruppe. This mountain range leads up to a maximum height of about 2300 m above sea level. The overhead line has a length of approx. 30km and is installed on 108 steel towers. The overhead line consists of two three-phase systems and one earth wire on

top. From tower no. 2 to tower no. 56 the system is electrically operated in parallel. This part of the overhead line with a length of approx. 15km crosses the mountain range and is located between 640 to 2320m above sea level, in a high alpine situation with rocky soil over the timber line. Before and after this section the distribution line is electrically operated single. Between tower no. 59 and 60 the earth wire is interrupted because of a crossing 220kV overhead line in this section.
The towers have a height between 30 and 55m with concrete foundations and a grounding system. The length of the spans varies between 120 and 420m. The isolators are dimensioned according to the isolation coordination for the 110kV system with spark-horns on every isolator.

Lightning detection

In the area of the 110kV distribution line the number of atmospheric discharges to the line conductors 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 average location accuracy for all detected lightning strokes in Austria can be denoted with better than 1km (ALDIS).
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 this region.

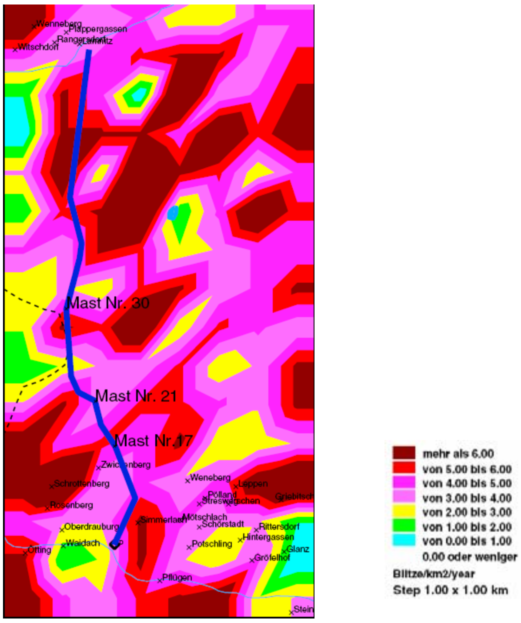

Figure 2: Lightning density in the area of the overhead line in the year 2006

Footing resistance

As mentioned before, nearly one third of the 110kV overhead line runs in a high alpine region with rocky soil and bad tower earthing conditions. The values of the footing resistances are in a range of approx. 200 to 1200Ω. The footing resistances between tower no. 34 and 39 are not documented.

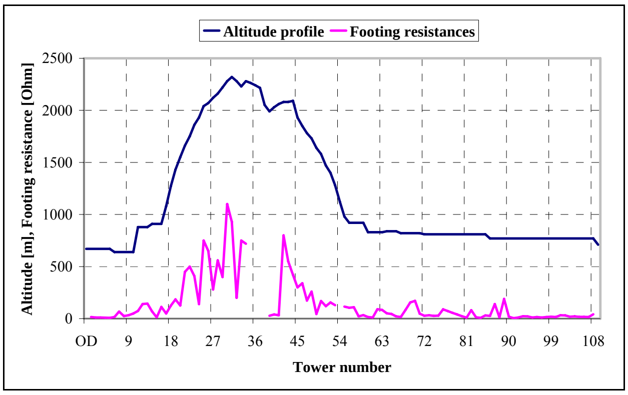

Figure 3: Altitude profile and footing resistances along the overhead line

Outages 1995 - 2000

As shown in figure 4, the number of line outages in the 110kV distribution network of the KELAG is in average lower than 2 outages per year. One single 110kV overhead line has 49 outages in a time span of 5 years and therefore approx. 5 to 10 times higher than the average value of the outages in the system.

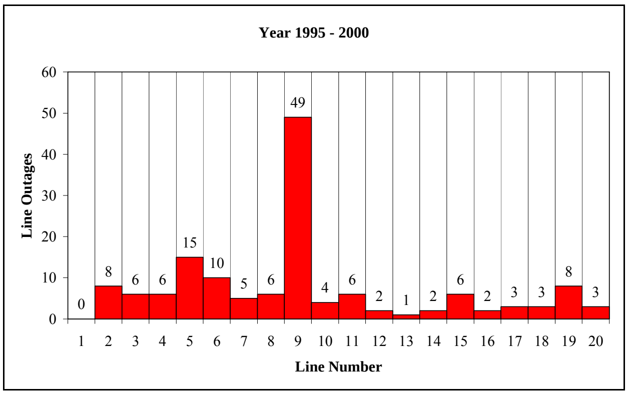

Figure 4: Line outages in the 110kV distribution network 1995 – 2000

ANALYTICAL EVALUATION

An analytical process was carried out to evaluate relevant parameters to develop a concept of practical measures.

Footing resistance evaluation

This specific high alpine distribution line has partially high footing resistances. In the year 2001 the footing resistances at 5 towers were measured with and without the earth wire connected on the tower top. Values between 100 and 1200Ω were measured.

Shielding angle analyses

Within the analytical analyses the effectiveness of the shielding area of the earth wire was considered in the defined line section. The 110kV overhead line crosses a mountain range 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 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 (table 1).

Table 1: Lightning sphere radii, Lightning currents for selected towers

	Lightning sphere radii	lightning currents
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

Evaluation of the line arrestor location

For the evaluation of the location of the surge arrestors along the overhead line numerical calculations were made with the program ATP. For the computation of the transient behaviour the equivalent circuit of the line was assembled of individual elements.
Basically two sub ranges can be defined. 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 high alpine region the grounding of each tower has to be modelled individually. This is considered with resistors at each tower between the tower bottom and the reference earth of ATP.
Every part of the steel tower is modelled by surge impedances and the individual height.
The line spans are modelled with LCC elements of ATP with the parameter line length and the surge impedances for the overhead earth wire and the overhead conductor.
For the protection of the overhead conductor against overvoltages, a modern metal-oxide surge arrester was implemented in the numerical model. The metal-oxide arrestors are modelled by a voltage dependent resistor with a non-linear characteristic for the metal-oxide.
A multiplicity of computations was done to evaluate the performance of this line section. The applications of surge arrestors were varied due to the number of protected phases as well as the number of protected towers.

PRACTICAL MEASURES AT THE 110KV LINE

To improve the line performance and to decrease the line outage rate the following practical measures were applied to the 110kV line.

System rearrangement

The double three phase systems of the 110kV overhead line was constructional converted 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 area of the three earth wires.

Surge arrestor application

Due to the results of the transient calculations for the application of the surge arrestors along the overhead line, a number of 18 surge arrestors were installed along the overhead line and 6 arrestors in the substations Oberdrauburg and Außerfragant. All three phases of the substations were equipped with surge arrestors. In the selected line section (9 towers) only two of the three phases were equipped with surge arrestors.

Figure 5: Line arrestor application on the 110kV steel tower

Improvement of the grounding situation

To improve the grounding situation, the earth wire has been changed by an earth wire with an integrated light conductor. Because of a very high contact resistance between the earth wire and the tower an additional shunt wire between the earth wire on top and the tower was installed.
The missing earth wire between tower no. 59 and 60 (crossing 220kV system) was added.

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.

THREE YEARS FIELD EXPERIENCE

Based on the evaluation work and practical measures at the 110kV line, the field experience of the years 2004 to 2006 were analyzed. Based on the scientific cooperation between the KELAG and the Technical University Graz a correlation between the registered outages and registered ADL records was made, supported by ALDIS with their lightning activity data.

Lightning activity 2004 - 2006

Within the field experience ALDIS made an observation of the lightning activity in the area close to the overhead line in this three years period. The observation corridor of 3km width was as long as the line section (30km), 1,5km width each side of the line.
ALDIS detected in this three years observation period from 2004 to 2006 a total number of 799 lightning strikes with a total number of 1463 flashes. The average value of the amplitude of the detected strikes was approx. 15kA. As shown in figure 6 most of the lightning strikes are with negative polarity. In the year 2004 90% and in the year 2005 95% of all lightning strikes had a negative polarity, which corresponds to the well known polarity distribution. In the year 2006 an uncommon high number (31%) of positive discharges were registered in this line corridor.

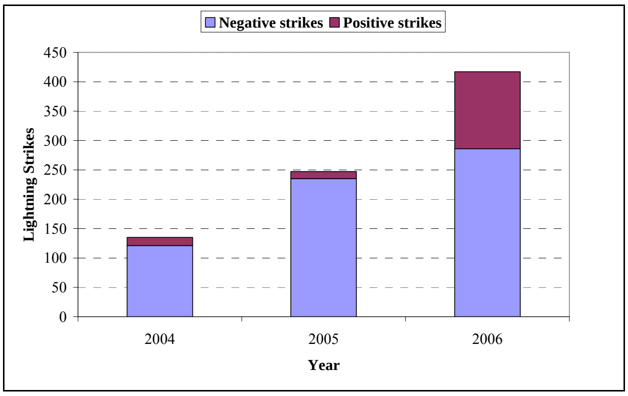

Figure 6: Number of lightning strikes in the line corridor in the three years observation period (2004 – 2006)

Outages 2004 - 2006

Based on the internal event recording system of the utility the number of 2- and 3-phase faults and phase-to-ground faults for the observed line was available, as seen in figure 7.

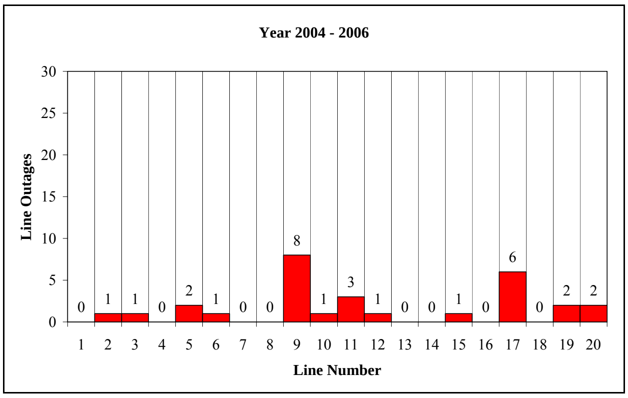

Figure 7: Line outages in the 110kV distribution network 2004 – 2006

A total number of 8 2- and 3-phase faults were registered, none of them within the rearranged section of the line. Further, a total number of 8 temporary phase-to-ground faults could be correlated with lightning activity in the line corridor. Therefore, the lightning activity has lead to earth faults and not to 2- and 3-phase faults. Outside the rearranged line section the number of failures is comparable with the failure rate between 1995 – 2000.

SUMMARY

Due to a registered high outage rate of a double system 110kV line of a distribution network, a scientific evaluation project was set up to increase the performance of the energy supply. A number of important tasks like the orographic situation of the line, the tower footing resistances, the shielding angle analyses, the lightning activity and numerical calculations for the insulation coordination were taken into account.
As an output of this evaluation the line was converted to a single system with the original earth wire on top and two additional earth wires instead of the two upper phase wires. All three earth wires were additionally connected to the steel tower by a shunt connection. With these measures the grounding conditions of the line in this high alpine region have been improved significantly.
Due to numerical calculations 18 surge arrestors were installed in a line section of 9 towers located in a high alpine part and in an area of high lightning activity.
The three years field experiences has shown that the theoretical investigations and the practical measures have led to significant decrease of lightning caused outages on the observed 110kV network part.

REFERENCES

[1] M. Muhr, S. Pack, M. Kompacher, 2003, "Möglichkeiten und Maßnahmen zur Reduzierung der Fehlerhäufigkeit einer 110kV Hochgebirgsleitung", *Scientific Report*, VA03332

[2] J.A.T. Gillespie, 2001, "A case study on the lightning performance of a North Queensland transmission line", *CIGRE Symposium Cairns*, 100-03

[3] G. Diendorfer, W. Schulz, 2003, "Ground flash density and lightning exposure of power transmission lines", *IEEE Bologna Power Tech Conference*, BPT03-84

[4] E.B. Shim, et al., 2006, "Lightning outage rate calculation of arrestor installed 154kV transmission line considering statistical lightning current data and geographical features", *CIGRE Paris Session*, C4-105