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EFFICIENCY OF LIGHTNING PROTECTION OF POWER LINES - COMPARISON OF ESTIMATED AND OBSERVED FAILURES

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Abstract:
Lightning is one of the main causes for power line outages. We have correlated HV line outages of either unknown reason or when lightning was already assumed to be the reason, with the archived lightning data from ALDIS for about 25 power lines (400 kV and 220 kV). For about 25% of the outages we found good correlation with a located lightning discharge in a corridor of up to +/- 5000 m. Some of the remaining outages are assumed to be either caused by other severe weather related events (strong wind, moisture on insulators, etc) or by lightning flashes that have not been detected by the lightning location system.

Based on the data archive of the lightning location system ALDIS we have determined values of the actual ground flash densities for the individual lines and we applied the IEEE-FLASH software - which is based on the Electro-Geometric-Model (EGM) - to estimate the number of outages per 100 km and year for each line. For some lines the comparison of the estimated outage rate and the actual observed outage rate are very much different.

Introduction

In Austria the power utility VERBUND operates the majority of the 400-kV and 220-kV high voltage transmission network of a total length of about 3600 km. It is a densely meshed network and most high voltage lines are double system lines.

In a detailed study we have analyzed the lightning exposure of the high voltage network in terms of (1) average ground flash density (GFD) in the vicinity of the lines and (2) correlation of line outages with data from the Austrian lightning location system ALDIS.

1. Lightning Exposure of High Voltage Lines

Based on the archived data from the Austrian Lightning Detection System (ALDIS) for the years 1995 to 1999 we have determined the ground flash density of 43 high voltage line segments of lengths ranging from 30 km to 170 km (some examples see Table 1).

Table 1: Examples of GFD

HV line	Length in km	Flashes/km2 per year
vg_473d	33,7	2,4
vg_471d	72,0	2,6
vg_451d	86,0	1,2
vg_443	37,5	1,4

2. Correlation of outages with ALDIS data

The Austrian lightning location system is in operation since 1992 [1], whereas outage records from the power utility with a sufficient accuracy of time information up to a second are available only since 1996. For this reason for the following analysis we have only used data from 1996 until July 1999.

We have searched in the ALDIS database for time correlated events of power line outages of “unknown” reason or when lightning was assumed to be the reason and located lightning flashes in a time window of +/- 5 seconds and a spatial distance of up to 5 km from the line.

The numbers of correlated events and the time difference between outage records and lightning events are summarized in Table 2.

Table 2:

Year	**Time Difference in [s]**							
	-4	**-3**	**-2**	**-1**	**0**	**1**	**2**	**Sum**
1996				1	20			21
1997			2	3	14	2		21
1998		1	3	4	27	4	1	40
1999	1	1	1	2	10	3		18
	1	**2**	**6**	**10**	**71**	**9**	**1**	**100**

Table 2 shows that most of the correlated events (90 %) are within ± 1 second.

3. Comparison of estimated outage rate and observed outage rate

IEEE provides an engineering method to determine the backflash- and shielding failure rate of HV-lines. The calculation is based on the following input parameters:

- Distribution of lightning peak currents
- Ground flash density (GFD) along the line
- Tower geometry (position of phase/ground wires
- Tower footing resistance

We have calculated the estimated outage rate of the different HV-lines based on their corresponding ground flash density (see Table 1) using the IEEE FLASH 1.7 program [2].

3.1 Distribution of lightning peak currents

In a previous analysis of the ALDIS-data we have determined a mean value of about 14 kA for the peak current distribution in Austria [3] which is quite different from the lightning peak current distribution specified by CIGRE or in some other standards for lightning protection with a mean value of 31 kA (see Fig.1).

3.2 Ground Flash Density (GFD)

GFD of the individual HV lines is calculated by dividing the number of located flashes in a corridor of ± 1000 m along the line by the according area of the corridor and time periode. This method provides an accurate number for the GFD, even when the GFD varies significantly along a line of a length of several ten's of kilometers.

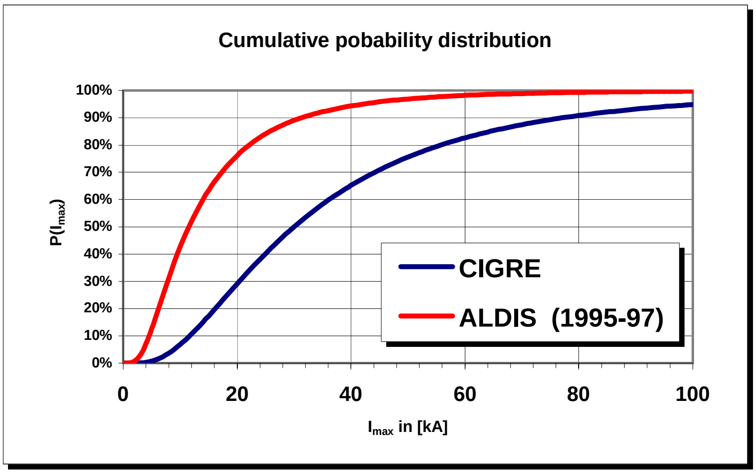

Fig.1: Comparison of CIGRE peak current distribution and the ALDIS data

3.3 Tower geometry

A typical geometry of a 400 kV tower used in Austria is given in Fig.2. A single ground wire is located on top of the tower. Height and horizontal position of the six phase conductors relative to the ground wire determine the shielding effectiveness of the ground wire based on the electro-geometric model.

3.4 Tower footing resistance

Tower footing resistance is measured by the power utility regularly for each tower of a HV line. Although all the towers have a grounding system of equal geometry the resulting resistance values are different depending on the local ground conductivity at the tower site. From the individual measurements we have determined the distribution of tower footing resistances.

In Table 3 the results for line 471 are shown.

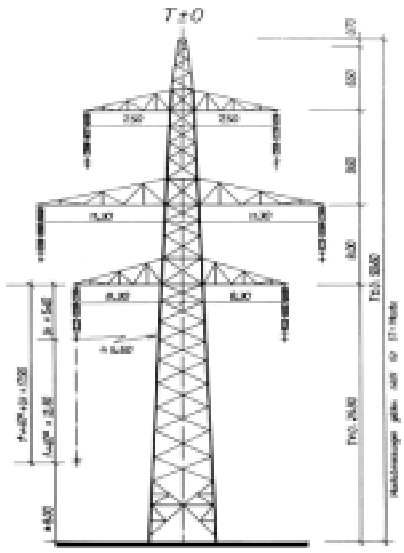

Fig.2: Tower geometry line 471

Table 3: Distribution of tower footing resistance

LINE 471		**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
Number of Towers	244	39,27	21,82	10,31	6,18	4	2,9	2,1	1,6	0,93
Mean [Ohm]	12,1									
Maximum [Ohm]	66,7									
Minimum [Ohm]	0,6									
Standard deviation [Ohm]	16,4									

4. Estimated outage rate versus actual outage rate

We have performed the calculation with the IEEE FLASH program using a log-normal distribution for the lightning peak currents of a mean of 31 kA (CIGRE) and 14 kA (ALDIS), respectively and compared the results with the observed actual outage rate (see Fig.3). The 14 kA median for the peak current distribution results in a lower estimated outage rate - usually both, the rate of shielding failures and the rate of back flashover is smaller.

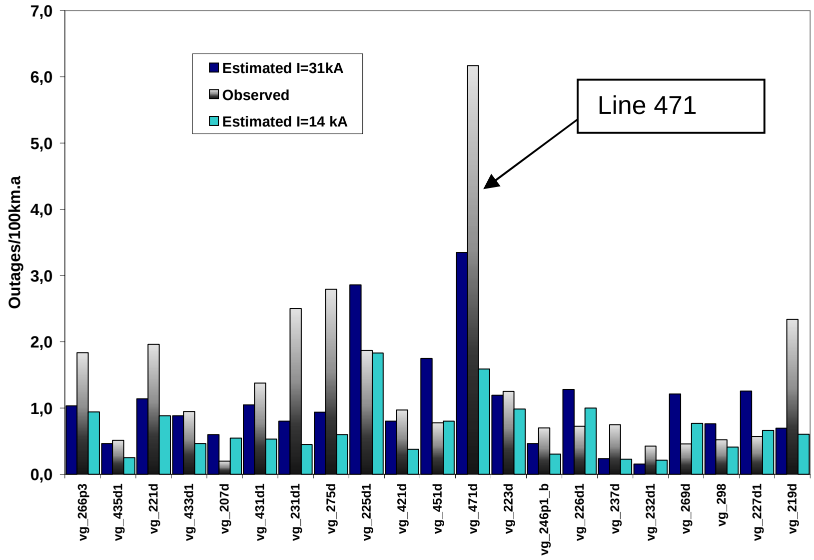

Fig.3: Comparison of estimated outage rate for $I_{50\%}$=31 kA and $I_{50\%}$=14 kA, respectively and the actual observed outage rate for different HV lines

Overall for several HV lines the observed lightning caused outage rate is significantly higher than estimated by the IEEE FLASH program. In reality this disagreement may be even higher because some more outages may be caused by flashes that have not been detected by the location system.

Whether the obvious disagreement of observation and estimation is a result of a too short observation period, erroneously correlated lightning events or a problem of the IEEE FLASH program is unclear at the moment.

4. Conclusion

Analyzing the lightning exposure of the high voltage network in Austria revealed several interesting results:
(1) A time window of ± 1 second seems appropriate to determine correlated line outages and lightning location data.
(2) Estimated and observed outage rates are in poor agreement. Further investigations are needed to separate the effects of different input parameters that may result in such a disagreement.

References

[1] Diendorfer G., Schulz W., Rakov V.: Lightning characteristics based on data from the Austrian lightning location system. IEEE Transactions on EC, Vol. 40, No. 4, 1998.

[2] Hileman, R.A.: Insulation coordination for Power Systems, Marcel Dekker, New York, 1999.

[3] Schulz W., Diendorfer G., Pedeboy St.: Effect of Lightning Location Network Setup on evaluated Lightning Characteristics. ILDC, 1998, Tucson.