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Lightning Performance of High Voltage Power Lines

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Abstract:
Lightning is one of the major sources for power line outages. We have correlated 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 very good correlation with a 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 LLS.

In the past there have been claims of increased lightning activity in the vicinity of high voltage power lines. Detailed analysis of the lightning data near power lines does not support this claim. Power lines in flat area exhibit no effect to the local ground flash density near the power line.

We have also determined values for the actual ground flash densities for the individual lines and we used the software IEEE-FLASH to estimate the number of outages per 100 km and year assuming two distinct peak current distributions (CIGRE distribution with 31 kA and LLS based distribution with 12 kA mean). Comparison of the estimated values and the actual observed number of outages shows poor correlation. This leaves some open questions, whether the FLASH program is not applicable for the type of power lines used in Austria or the number of reported outages caused by lightning is not well defined.

1. Introduction

VERBUND operates in Austria the 400-kV and 220-kV high voltage transmission network of a total length of about 3600 km. It is a highly meshed network and most high voltage lines are double system lines.
In this study we have analyzed the lightning exposure of the high voltage network in terms of (1) average flash density in the vicinity of the lines and (2) correlation of line outages with data from the Austrian lightning location system ALDIS.

2. Lightning Exposure of High Voltage Lines

Based on historical data from the lightning location system for the years 1995 to 1999 we have determined the ground flash density of 43 high voltage line segments of lengths ranging from 1 km to 170 km.
In Austria there were always some arguments by local people that they have observed a significant increase in lightning activity after a new high voltage line has been installed.
For an initial test of these arguments we have determined the ground flash density of all the lines for corridors along the line of a distance of 1, 2, 3, 4 and 5 km respectively.
In case of any effect of the HV-line on the local ground flash density we would expected to see some increase in the flash density close to the line (D = 1 km) compared to the corridor of 5 km.
Any changes in flash density as a function of corridor width may also be a result of the topography near the line. In Austria we observe a significant increase of flash density as a function of height in the mountainous area [1].

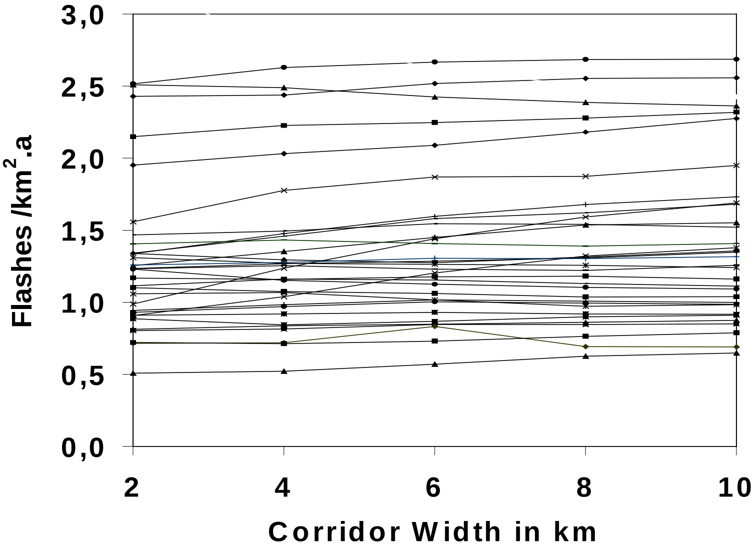

Fig. 1: Average Flash Density (1995 – 1999) as a function of corridor width for 33 lines of length greater than 20 km.

Fig. 1 shows the average flash density for 33 different HV-lines of a length greater than 20 km. The average flash density is in a range from 0,5 flashes/km^2**.**a to 2,7 flashes/km^2.a.
Obviously there is no decrease of flash density as a function of corridor width and therefore there is no support for the above mentioned claims of an increase of flash density due a nearby HV-power lines.
As an additional result of this analysis we observe a lightning risk variation of the individual HV-lines of a ratio of about 1:5 even in a small area like Austria.

3. Correlation of outages with lightning location data

The Austrian lightning location system is in operation since 1992 [2]. In 1994 a major upgrade of the system to IMPACT sensors took place. On the other hand outage records from the power utility with time information accurate up to a second is available only since 1996. For this reason we use data from 1996 until July 1999 for the following analysis.
In a first step 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 1.

Table 1:

Year	**Time Difference in [s]**									**Total**
	-4	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	
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
*) until July 1999	**1**	**2**	**6**	**10**	**71**	**9**	**1**			**100**

Fig. 2 is a graphical display of Table 1 and it shows that most of the events (90 %) are within ± 1 second.

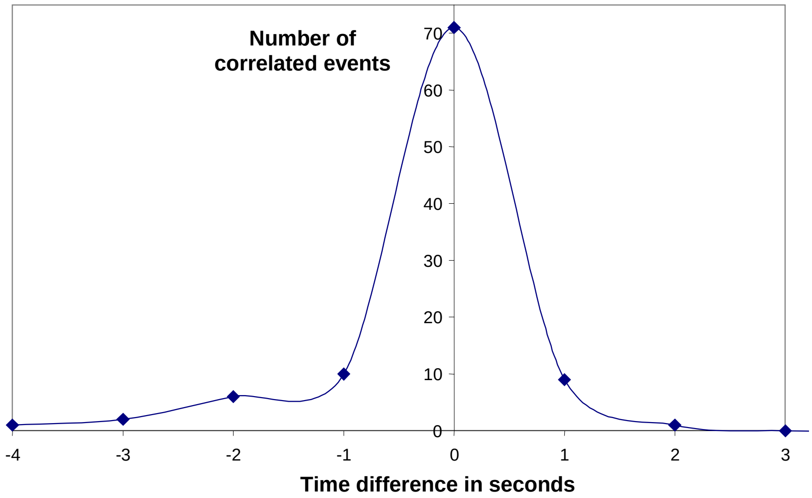

Fig. 2: Time difference between outage records and lightning events in a ± 5 km corridor

In a next step we have analyzed the stroke peak currents provided by the location system for the correlated events. In Fig. 3 a histogram for the peak current in steps of 10 kA is shown. Median of peak current is about 11 kA with a tendency to separate in two groups. One group are events of peak currents < 70 kA and the second group are events of peak currents > 80 kA.

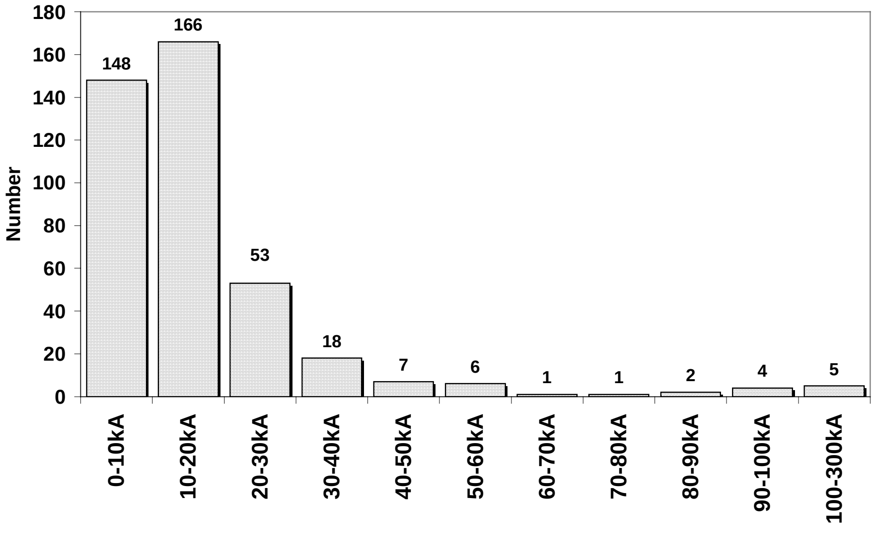

Fig. 3: Histogram of lightning peak currents of the time correlated events

We can speculate that the group of smaller peak currents are mainly related to shielding failures and the events with peak currents > 80 kA are related to back-flash failures.

To test this assumption we have analyzed the median peak current as a function of failure type. Fig. 4 shows that single-phase and double-phase failures are caused by strokes of a median of about 14 kA whereas double-phase-ground failures and 3-phase failures have median peak currents of 38 kA and 102 kA, respectively.

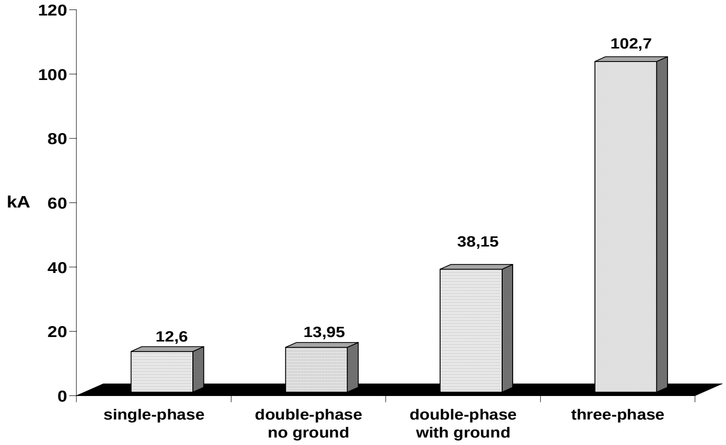

Fig. 4: Median of peak current for the different failure types
(NOTE: Only data from 1995 and 1996 are used for this analysis)

4. Comparison of estimated outage rate and observed outage rate

IEEE has developed a 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
- Tower geometry
- Tower surge impedance
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We have calculated the estimated outage rate of the different HV-lines based on their corresponding ground flash density (see Fig. 1) using the IEEE Flash 1.7 program [3]. In previous data analysis of the ALDIS-data we have determined a mean value of about 14 kA for the peak current distribution in Austria [4]. For comparison we have done the calculation with a log-normal distribution of a mean of 31 kA (CIGRE) and 14 kA (ALDIS),respectively.
Table 2 is a summary of the results and shows quite a difference between the observed and estimated outage rates (see also Fig. 5). In general a lower median for the peak current distribution results in a lower estimated outage rate.

Overall for several lines the lightning caused outage rate is much higher than estimated by the IEEE FLASH program. In reality this disagreement may be even higher because some more outages are certainly caused by lightning without any correlated location system data.

Whether the 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.

5. Conclusion

Analyzing the lightning exposure of the high voltage network in Austria revealed several interesting results:

(1) HV-power lines do not cause any increase of local ground flash density in the vicinity of the line.
(2) A time window of ± 1 second seems appropriate to determine correlated line outages and lightning location data.
(3) 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.

Table 2:

HV-line	Length [km]	Correlated Outages	IEEE-FLASH estimated outages per 100 km .year I_mean=31kA	IEEE-FLASH estimated outages per 100 km .year I_mean=14kA
vg_266p3	170	**1,8**	**1,0**	**0,9**
vg_435d1	131	**0,5**	**0,5**	**0,3**
vg_221d	125	**2,0**	**1,1**	**0,9**
vg_433d1	117	**0,9**	**0,9**	**0,5**
vg_207d	115	**0,2**	**0,6**	**0,5**
vg_431d1	113	**1,4**	**1,0**	**0,5**
vg_231d1	107	**2,5**	**0,8**	**0,4**
vg_275d	104	**2,8**	**0,9**	**0,6**
vg_225d1	95	**1,9**	**2,9**	**1,8**
vg_421d	92	**1,0**	**0,8**	**0,4**
vg_451d	86	**0,8**	**1,7**	**0,8**
vg_471d	72	**6,2**	**3,3**	**1,59**
vg_223d	71	**1,3**	**1,2**	**1,0**
vg_246p1_b	64	**0,7**	**0,5**	**0,3**
vg_226d1	61	**0,7**	**1,3**	**1,0**
vg_237d	60	**0,7**	**0,2**	**0,2**
vg_232d1	53	**0,4**	**0,2**	**0,2**
vg_269d	49	**0,5**	**1,2**	**0,8**
vg_298	43	**0,5**	**0,8**	**0,4**
vg_227d1	39	**0,6**	**1,3**	**0,7**
vg_219d	10	**2,3**	**0,7**	**0,6**

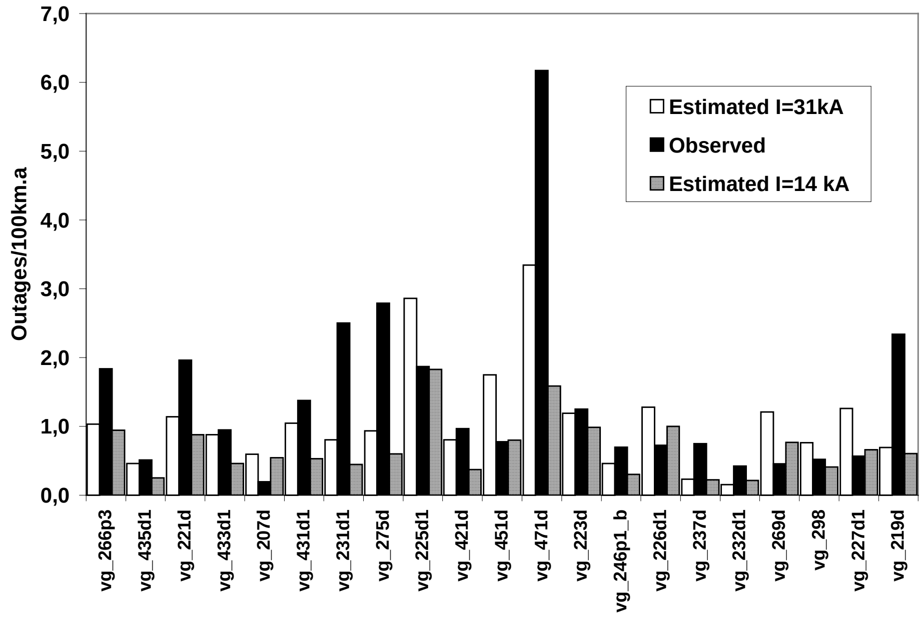

Fig. 5: Comparison of estimated and observed outage rate of HV-power lines

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