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LONG TERM EXPERIENCE ON LIGHTNING ACQUISITION IN ITALY AND AUSTRIA AND DATA APPLICATION TO THE IMPROVEMENT OF LIGHTNING PERFORMANCE

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Abstract
Lightning location systems (LLS) are in operation in Italy and Austria since about 10 years. The two networks are running a collaboration, sharing sensors data, since the beginning. The importance of this collaboration is shown, analyzing the behavior of the two networks as standing alone or as cooperating. In particular a detailed analysis is run on a set of data, evaluating the importance of the other network sensors in the calculation of lightning and in the efficiency and accuracy of the final results. The application of LLS data to improve the lightning performance evaluation of transmission and distribution lines is analyzed. Lightning density at ground is a key factor for performance evaluation of transmission lines. More accurate and detailed maps than those standardized may be derived by LLS, indicating that standardized values (average values for an area) are not sufficiently accurate to describe the situation of a given territory. The use of LLS data to correlate faults and lightning is discussed. In particular, for MV lines, one of the problems discussed is the necessary accuracy in lightning location.
Keyword: lightning, lightning location system, lightning protection

1. GENERAL

Lightning significantly affects the insulation performance of transmission and distribution lines.
Lightning location systems (LLS) are contributing remarkably to increase the knowledge on lightning parameters, essential to improve the design and exploitation of transmission lines.
The quality of the information can be improved by transational cooperation

2. LLS SYSTEMS IN ITALY AND AUSTRIA

The lightning location systems in Austria and in Italy, described in the following paragraphs, are using lightning location sensors from Global Atmospherics Inc. (GAI) and employ IMPACT type sensors only. IMPACT sensors are using both, the time of arrival and the direction finding technique to locate a stroke. The sensors have a mean detection range of about 400 km and a bandwidth of 1-350 kHz. Both systems record the main parameters of each flash, which are time, position, peak current, polarity and number of subsequent strokes. In addition to these discharge parameters, for each stroke, quality parameters, such as the error ellipsis of the impact location and the Chi2 as a measure of the agreement of the available sensor data are recorded.

2.1 *Italian LLS*

The Italian lightning detection network (SIRF) was installed by CESI in 1994 [1] and is fully operational since 1.8.1994. CESI-SIRF is made by sixteen IMPACT sensors with a mean baseline of about 200 km. It covers all the Italian territory and the main islands with an estimated detection efficiency of 90 % and a estimated location accuracy of 1km. All the Italian sensors are set to a

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threshold of 70 mV. In order to be able to perform this study the IMPACT sensor in Gorizia is substituted by a LPATS3 sensor located in the same town. Contrary to an IMPACT sensor this type of sensor measures the electric field and records the arrival time only. The central processor of all the data is located in Milan at CESI.

2.2 *Austrian LLS*

The Austrian LLS ALDIS (Austrian Lightning Detection and Information System) was installed in 1991 and is in operation since 1.1.1992. The Austrian system is a high gain network of eight IMPACT sensors with a mean baseline between sensors of about 120 km. Due to the high density of direction finders in the Austrian lightning detection system some redundant information about the discharges in Austria is collected. A high number of flashes are located by four or even more sensors. The ALDIS network configuration allows to achieve a location accuracy of better than 1 km which has been confirmed by ground truth data collected during an experiment on an instrumented radio tower. All the Austrian sensors are set to a threshold of 50 mV.

2.3 *Merged Italian-Austrian LLS*

The merged LLS is an operational interconnection of sensors in Austria and Italy (24 sensor network as shown in Fig. 1).

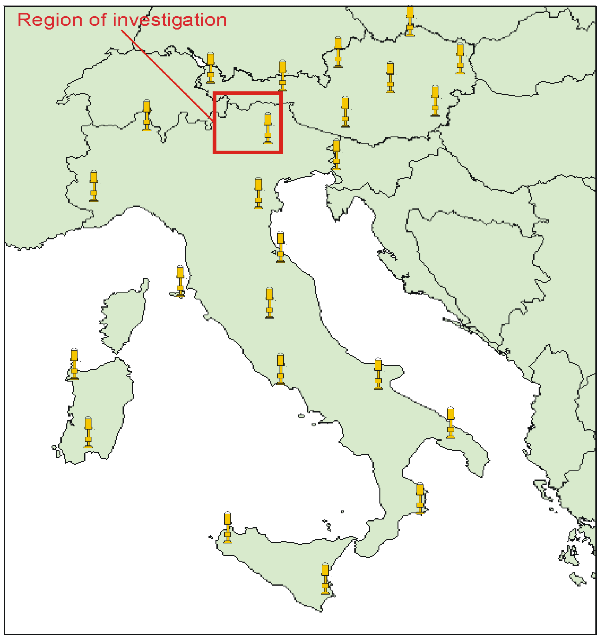


Fig. 1: Location of the direction finder in Italy and Austria

3. LLS Performances

3.1 Detection efficiency and accuracy projections

The most important performance parameters of lightning location systems are the so called detection efficiency (DE) and the location accuracy (LA). In Fig. 2 the DE and LA projections are given for the combined network.

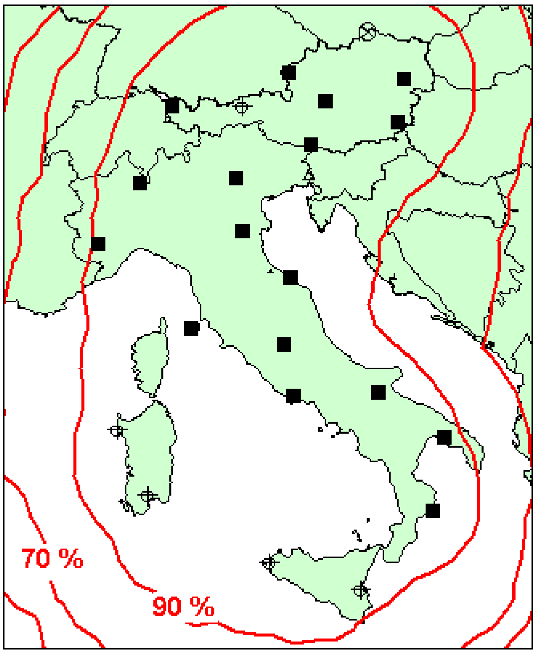


Fig. 2 a): DE projection for the combined network

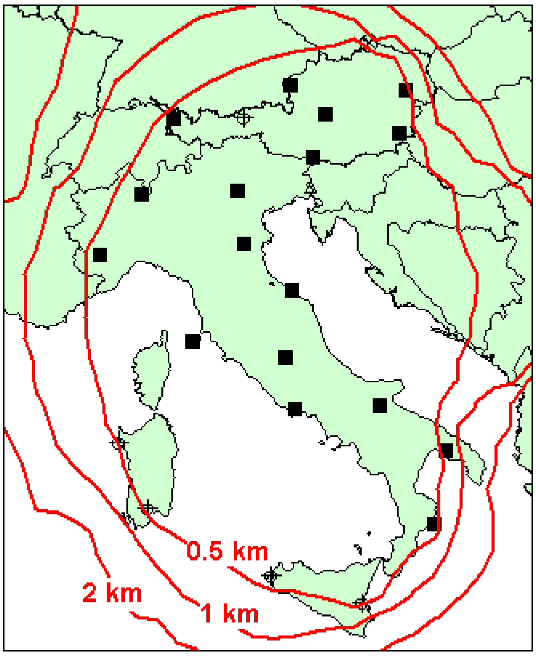


Fig.2 b): LA projection for the combined network

These projections are calculated taking into account the individual sensor types, sensor gains and a threshold of 75mV (for all sensors).
Obviously the combined network covers almost the entire region of both countries with a LA of better than 500m and a DE of more than 90% based on the projection.

3.1 *Performance Evaluation based on real data*

The performance of the networks is analyzed by evaluating data of the time period from 19.9.2000 till 7.10.2000. This time period in fall 2000 was chosen because during this time there was thunderstorm activity all over Italy and Austria. The archived raw sensor data were reprocessed for all the three networks, ALDIS, CESI-SIRF and the combined network respectively using the same parameters for the location process. Tab. 1 shows the total number of flashes/strokes detected by each network.

Tab.1: Number of flashes/strokes detected by the different networks from 19.9.2000-7.10.2000

	Flashes	**Strokes**
ALDIS	**40324**	**69880**
CESI-SIRF	**235988**	**506156**
Combined network	**261022**	**551918**

Since the biggest performance improvement of the combined network is to be expected for a region where both networks have a common border, the following analysis was done for a region between 10° and 12° longitude and 46° and 47° degree latitude (see Fig. 1).

The number of sensors reporting (NSR) and especially the average number of sensors reporting (ANSR) are often used performance parameters to describe or evaluate the detection efficiency of a LLS. Fig. 3 shows the NSR for the three different networks, the ALDIS-, the CESI-SIRF- and the combined network in the region specified above. The NSR are calculated for strokes.

It can be seen that for the region of investigation there is an increase of the overall NSR and therefore an increase of performance. The ALDIS network alone has the lowest performance in the region of investigation (46% of the located strokes are reported by two sensors only) followed by the CESI-SIRF network alone. Of course the combined network is the best network in terms of DE. This is also reflected by the ANSR shown in Tab 2.

The location accuracy estimate of the individual stroke is represented by a statistical parameter called semi major axis of the 50 % error ellipse. The error ellipse describes a region centered around the calculated stroke location. There is a 50 % probability that the stroke occurred within the area of the 50 % error ellipse. Therefore a distribution of the semi major axis of the individual strokes should show a significant increase of performance for the combined network. Fig. 4 shows this distribution.

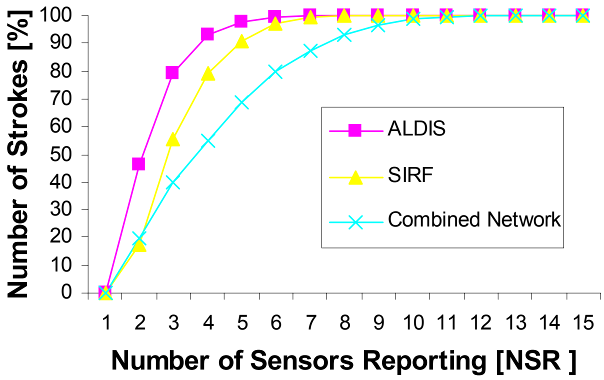


Fig. 3: Number of sensors reporting for the three different networks in the geographical region 46°-47°/10°-12°.

Tab. 2: ANSR for the individual networks

	ANSR
ALDIS	**2.8**
CESI-SIRF	**3.6**
Combined network	**3.8**

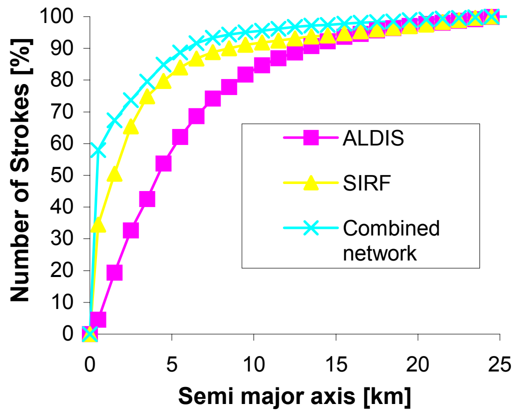


Fig. 4: Distribution of the semi major axis for the different networks

A clear improvement of performance from the individual networks to the combined network is obvious. It is worth to note that the calculated error ellipse for a stroke is a function of the number of sensors contributing to the calculation and the assured standard deviation for the time and angle measurements provided by the sensors. The error ellipse as a statistical value might be different from the actual accuracy of an individual stroke.

4. IMPROVMENT OF LIGHTNING KNOWLEDGE FROM LIGHTNING LOCATION SYSTEMS

Systematic lightning observation is leading to significant improvement on the knowledge of lightning parameters of interest for design.

The lightning density at ground Ng (number of lightning per square km per year) is one of the fundamental parameter for lightning protection.
In the past Ng was based either on the observation of thunderstorm days or CIGRE counters.
Lightning observation may substantially improve the knowledge, mainly because LLS permits to have local information [2], [3].
As an example Fig. 5 reports the observed Ng in Sicily in the year 2000. Sicily is historically an area of very low lightning activity: the Italian standards attribute Ng =1.5 for most of the territory (the minimum value over Italian Territory). The LLS recordings, on the contrary, show an area with high-density value near Etna volcano and the mountains next to it. This area is surely an area which should have a higher density than the value shown by historical data, because Etna is a high mountain (roughly 3000 m) and with the attached group of mountains forms a major discontinuity on the Sicily ground profile.

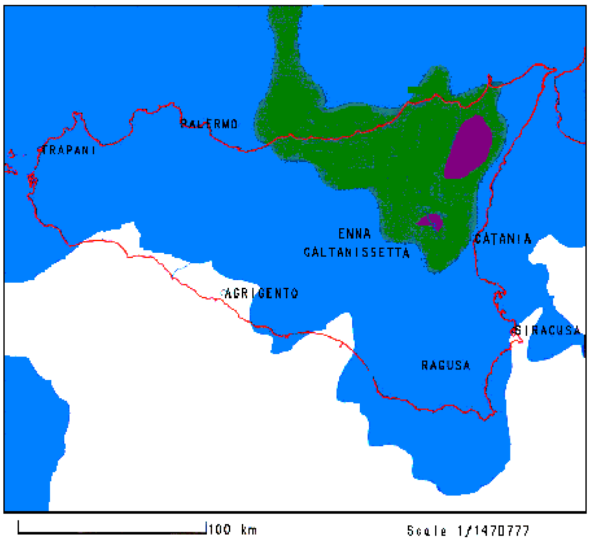
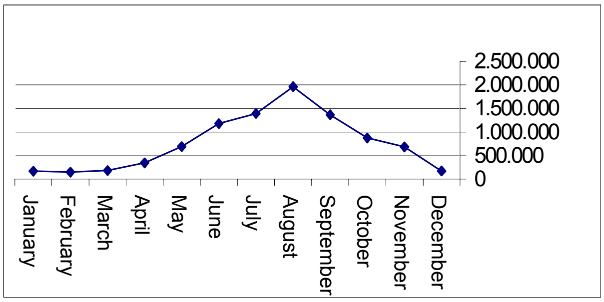
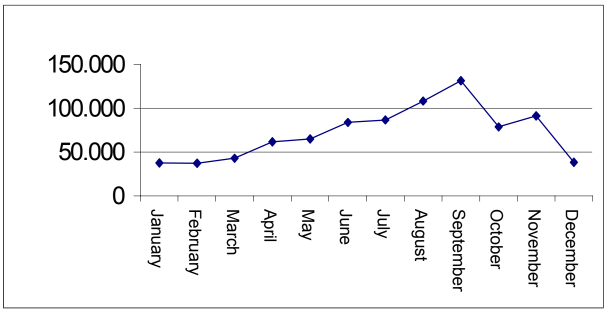


Fig. 5: Ng in Sicily; 2000 data set. The area NorthEast in dark gray is equal to 4 flashes / y km² and corresponds to Etna cone and surroundings.

Years of observation will lead on one side to a more reliable map of the territory than the present reference one and on the other side will permit a comparison of the lightning severity of the single years/seasons, and thus of the risks related to lightning. The observation with interconnecting networks like the Austrian-Italian one will lead to a common base of information with a uniform measure on Ng also on the border regions, that will help in the performance analysis and in the risk evaluations for these border areas, in which traditional data show lacks of information and discrepancies between different countries.
Continuous observation permits to evaluate the lightning activity with season and to obtain reliable information on the number of positive and negative lightning, as shown in Fig. 6.



a) Negative flashes; data set 1995-2001



b) Positive flashes; data set 1995-2001

Fig. 6: Number of flashes as a function of the month in Italy

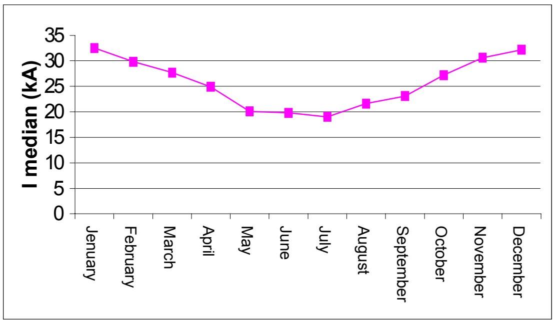
The value of the lightning current is the other important parameter. Information on the lightning currents is derived from the measured electromagnetic field emitted by the return stroke and received by the sensors. The median and standard deviation of the log normal current distribution observed in Italy, using the complete data set on whole Italy for each year, are reported in Table 3 for example.

Table 3: Lightning currents evaluated in Italy

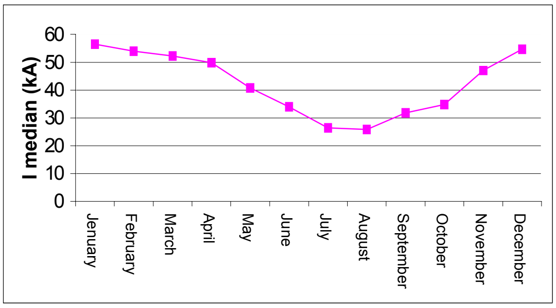
Year	I Median negative kA	stnd	Median positive kA	stnd
1995	21,9	0,3	36,5	0,3
1996	23,2	0,3	37,6	0,3
1997	22,9	0,3	36,6	0,3
1998	21,6	0,3	37	0,3
1999	22,8	0,3	32,5	0,4
2000	20,2	0,3	35,4	0,4
1995-2000	22,7	0,3	35,8	0,3

Lightning current presents a seasonal variation also as shown in Fig. 7.

In general the data show that the median values are always smaller than those assumed in the past [4]. This is a common result of different national networks. This could be partially explained considering that previous data were derived from measurements on high towers, with a different expectable current distribution from lightning on flat ground.



7a) Current intensity: median, negative polarity. 1995-1999 data set on whole Italy



7b) Current intensity: median, positive polarity. 1995-1999 data set on whole Italy

Fig. 7: Median value of flash current intensity varying with month

5. APPLICATION OF ADDITIONAL KNOWLEDGE TO IMPROVEMENTS IN SYSTEM DESIGN AND EXPLOITATION

Many faults, especially on MV lines, are related to lightning.

As an example, an extensive analysis was carried out in Italy to verify how many line faults are related to lightning [5]. To this purpose real time recording of events were correlated to LLS recordings. The investigation was carried out in two Italian regions (Umbria and Lombardia).

A summary of the investigation is presented in Table 4.

Table 4:Correlation between MV faults and lightning, correlation between fault and T-storm periods; percentage of faults correlated to lightning on faults related to storms.

FAULTS		UMBRIA	LOMBARDIA
Correlated to Lightning / tot.	%	22	21
Correlated to T-.Storm / tot	%	50	41

In spite of the different results obtained in the different regions, due mainly to different line configuration and protections, not to be discussed here, it is evident from this study that 40-50% of the line faults occur during thunderstorm and that a remarkable part of the events were caused by lightning. This kind of study may be useful to underline particular problems in some lines or areas and to the improvement of the insulation coordination in those critical parts of the network. Local lightning information, on the other hand, will be very important for the design of new lines and for the improvement of the design and thus of the lightning performance of old HV lines. A precise lightning information is essential for both this purposes. For this reason an interconnected network can provide better results, due to its better precision both on the point of impact and on the efficiency in lightning detection.

Lightning data may thus be very useful to analyze the service quality, the level of which has to be guaranteed by the Utility. High penalties are in fact foreseen in case of unsatisfactory service quality.
Annual variations of Ng may contribute to explain difference in service quality in different years, especially in case of extreme Ng increase, beyond expected values and design values.

The definition of extreme conditions is also of interest: that is conditions very rare, reasonably not to be taken into account in design. It could be reasonable not to take into account the faults in these extreme conditions in the evaluation of the service quality.
Extreme situations can be also clearly detected. As an example of extreme events Fig. 8 shows the number of lightning occurred recently in Italy during a single thunderstorm.
The lightning density at ground was higher than that expected in a whole year (Ng).

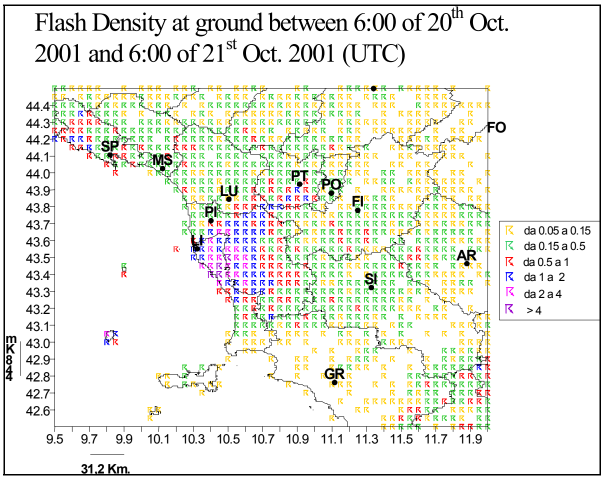


Fig. 8: Local lightning density at ground during a single thunderstorm in Tuscany; an area classified with Ng = 1.5 f/ykm² shows a density at ground of Ng>4 f/ykm² in one day of intense Thunderstorm.

This single Thunderstorm was obviously an exceptional event and line faults due to this event may be considered unpredictable and these faults should not be counted in the quality service evaluation.

For the evaluation of these extreme situations in the border mountain areas of the Alps, the most high lightning density region, the interconnection of LLS networks is very useful due to the higher efficiency and detection accuracy achieved.

Local lightning information as those in the previous paragraph will be very important for the design of new lines and for the improvement of the design and thus of the lightning performance of old HV lines.
As an example local and accurate information on Ng will help to explain unsatisfactory performance of sections of existing lines and thus will give indications for local interventions.

6. CONCLUSIONS

- Integration of LLS systems permits to improve the accuracy of lightning data
- LLS systems are tremendously increasing the information on lightning data
- The additional knowledge on lightning will contribute to improve the design and exploitation of transmission and distribution systems.

7. REFERENCES

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