16 – 19 JUNE 2020
3rd SEERC Conference Vienna 2020
Cooperation • Sustainability • Future

SEERC
South East European
Regional Council

CIGRE South East European Regional Council
Conference 2020 in Vienna, Austria

Innovation and New Technologies in the SEERC Region

Detail analyses on big number of correlated lightning events and powerline outages or damages acquired by the lightning location system SCALAR and its real time correlator service

Goran Milev[1], Vladimir Djurica[1], Klemen Jevnikar[1], Wolfgang Schulz[2], Željko Torlak[3],
Klemen Zemljak[4], Uroš Golob[5]
[1] Power research institute Milan Vidmar, Slovenia; [2] OVE Service GmbH, Austria
[3]Elektromreža Srbije, Serbia; [4] ELES, Slovenia; [5]Elektro Primorska, Slovenia
goran.milev@eimv.si

SUMMARY

The paper presents experiences on long term operation of enhanced real time powerline outage correlations with lightning events. The real time correlator service is implemented in the information system of lightning location system (LLS) SCALAR. The SCALAR system is covering the west Balkan region and it is part of the European LLS network EUCLID. EUCLID is a homogenous network and uses the same sensor technology across Europe with centralized data processing. LLS accuracy, detection efficiency, and lightning classification are the most important performance parameters and are important for the real-time correlation service. The high-quality data allows the implementation of real-time correlation in any country covered by the EUCLID network. Currently the real-time correlator service has been implemented on four power transmission networks, five power distribution networks, and one electrified 3kV DC railway network. Two decades (since 2000) of operation gave a considerable number of correlated events which have been analyzed in this paper. Additional ground truth data have been obtained from the power utilities and railways for advanced analyses. Many details about correlated lightning events such as lightning location, peak current, number of returned strokes and distances between them and powerline damages are shown in the paper. Different correlation dependencies such as temporal or permanent outages of powerlines on different voltage levels, powerline geometry, specific soil resistance and other parameters have also been considered in the analysis. The obtained data and the analysis results from the correlation process give us a better understanding and relationship between the incidence of lightning strikes and powerline outages.

KEYWORDS

EUCLID lightning location system, real time correlator, powerline outages, distribution and transmission overhead powerlines

1. INTRODUCTION

Lightning strikes that cause power line outages in Slovenia and neighboring countries are normally detected and located with the Lightning Location System (LLS) SCALAR. The SCALAR system is covering the west Balkan region and it is part of larger European LLS network called EUCLID (**EU**ropean **C**ooperation for **LI**ghtning **D**etection). EUCLID uses the same sensor technology across Europe with centralized data processing. The data provided from EUCLID is used, together with the additional information about power line outages collected from the SCADA system, in a so-called correlation process. Based on the experiences gained throughout the years of operation, especially with Slovenian power distribution companies, it became obvious that a narrow time window for correlation is the most important condition in the correlation process. All return strokes that coincides into a specified failure time window should be carefully checked for possible spatial correlation. The data collected may also be used for a statistical validation of the LLS accuracy. High quality data allows implementation of real-time correlation in any country covered by EUCLID network. Currently the real-time correlator service has been implemented in four power transmission networks, five power distribution networks, and one electrified 3 kV DC railway network. Decades of operation gave a considerable number of correlated events, which have been analyzed. Additional ground truth data have been obtained from the power utilities and railways for advance analyses.

Many details about correlated lightning events such as lightning location, lightning peak current, number of return strokes, distances between them and powerline damages are shown in the paper.

The obtained data and the analysis results from the correlation process, give us better understanding and relationship between the incidence of lightning strikes and powerline outages.

2. EUCLID LIGHTNING LOCATION SYSTEM and REAL TIME CORRELATOR

1.1 Lightning location system EUCLID

The EUCLID LLS was established in 2001 by several European countries. Since then, more countries joined the cooperation so that in 2005 EUCLID reached the current coverage (see Figure 1 in [1]). Since 2005 the network has significantly improved by updating the sensor technology, employing more advanced location algorithms and relocating sensor positions in case of poorly performing sensor sites. As of January 2020, the EUCLID network employs 172 sensors, 36 IMPACT ES/ESP (mainly analog sensor with a dead time in the range of 1–3 ms), and 136 LS700X sensors (sensor with digital signal processing of the field waveform and no dead time). More details about the EUCLID LLS can be found in [2].

Beside the location and an exact time of each individual stroke the EUCLID LLS also provides an estimate of the lightning peak current and the 50 % confidence ellipse (often called error ellipse). The median (50%) confidence ellipse circumscribes a region centered on the computed (optimum) location, within which there is a 50% probability that the stroke occurred ([3]).

The performance in terms of detection efficiency and location accuracy of the EUCLID LLS has been validated with data from tower measurements in Austria ([2], [3]), Germany ([4]), Switzerland ([5]) and with data from video and field recordings ([2], [6]). While the detection efficiency for Cloud-to-Ground (CG) flashes/strokes was quite stable (> 96/84% [2]) the location accuracy improved during the last years. Nowadays the median location accuracy is in the range of about 100 m (see Figure 1).

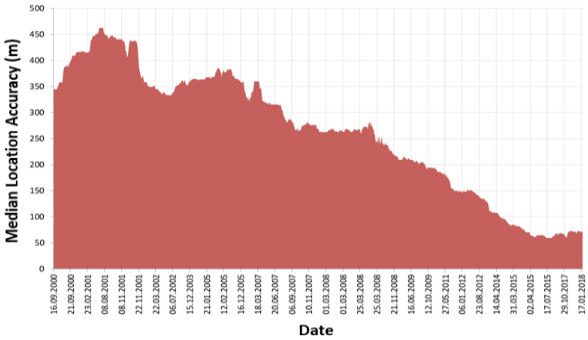

Figure 1: Median location error over time calculated as moving median over the last 100 return strokes measured at the GBT.

Because of the varying return stroke speed and different propagation paths of the individual strokes the estimated peak current scatters around the ideal value (see [2] – Figure 8). The mean absolute error of the peak current estimate in percent is 19 %.

1.2 Real time powerline outage correlator due to lightning

The CorrelatorService was developed by the SCALAR team. It provides real-time correlation between overhead power line outages and atmospheric discharges. The CorrelatorService uses geographical and topological power grid data and data about atmospheric discharges. Using this data, the CorrelatorService compares power line outage timestamps with timestamps from atmospheric discharges and at the same time calculates the geographical proximity between atmospheric discharges and power lines. The CorrelatorService declares that two events are correlated, only when time and spatial criteria are fulfilled.

It was primary developed for transmission or distribution power grid operators, who are automatically informed about information of the most probable location of power line failures that may have led to power line outages. Based on correlated event information, the operator can dispatch the service team to the vicinity of a failure, thus considerably reducing the line outage time.

The CorrelatorService operates in real time and uses static and dynamic data collected from three sources. First one is a database with static data describing the network: topological and geographical data, settings of protection relays, RTU (remote terminal unit) and delay data. Second source is from the SCADA system, which supplies the correlation process with data on switching maneuvers of circuit-breakers statuses. Third source is the system SCALAR which provides dynamic data on atmospheric discharges, including confidence ellipses.

For a successful correlation of the line outage with an atmospheric discharge those events must coincide regarding to the time and the spatial criteria. The CorrelatorService first performs a temporal location comparison and if it succeeds, then performs an additional multi-level spatial comparison, which consists of multiple spatial checks using different corridor widths along the power line. All incoming data are processed in a state processor, which ensures that each incoming piece of information is processed in a satisfactory manner. This is to ensure that the end

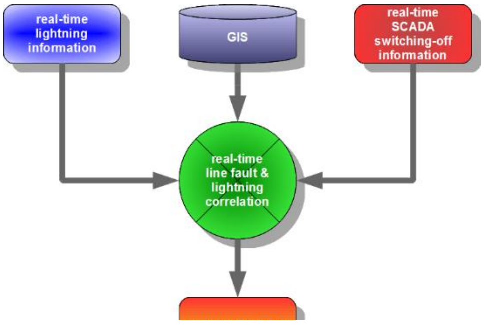

Figure 2: Information needed in correlation process.

user gets a sufficiently complete information about the event, i.e. whether the event was temporary or permanent.

1.3 Time criterion

The correlation process is divided in a time and a spatial correlation. Time correlation compares time stamps of two events: atmospheric discharges timestamp and circuit-breaker operation timestamp.

Atmospheric discharges are provided by the SCALAR LLS. They are time-stamped by GPS and their accuracy is well below a millisecond.

The accuracy of time stamps provided by the SCADA systems may be in the range from some tens of milliseconds up to a few seconds. The main reason is that Remote Terminal Units (RTU), which are the source of circuit-breaker event information, are either not sufficiently synchronized to a stable time reference or are not synchronized at all. It is true that the situation in control systems and the related RTU is constantly improving and that the number of GPS-synchronized RTUs is increasing, but typically the time difference between atmospheric discharges and circuit-breaker time stamps, are in the worst case about 10 seconds.

Based on experiences typical time differences for GPS-synchronized RTUs in Slovenia are between 50 and 500 ms. Those differences are mostly related to the protection relay settings. The line or feeder protection time is usually set to some “on set time”. This is the time when protection relay requests the failure to be presented in the network, before it trips the circuit breaker.

Over the last 15 years of correlator operation in the Slovenian transmission and distribution networks, we have learned that events with time difference more than 500 ms are not related to each other it is strong excluding criterion.

1.4 Spatial criteria

From the very beginning of our correlation project, we gave the greatest weight to the spatial correlation criteria. When dealing with spatial correlation, the relations between two spatial objects must be defined. First object is the confidence ellipse and the second is corridor polygon that surrounds the distribution or transmission power line.

The algorithm calculates possible intersection points between the power line or feeder sections and the confidence ellipse. If there is an intersection, the algorithm stops. In case that there is no intersection between the confidence ellipse and the power line, the spatial correlation between the confidence ellipse and the power line corridor is continued. This requires that (based on the power line or feeder section) the corridor around the power line is calculated. Determination of the corridor width is the key parameter. If it is too narrow, only a few correlations are obtained, and the correlator is inefficient. On the other hand, too wide corridors will result in inaccurate correlations. In the year 2000, when our project started this value was set to 500 m which represented the LLS accuracy at this time. During correlator operation,

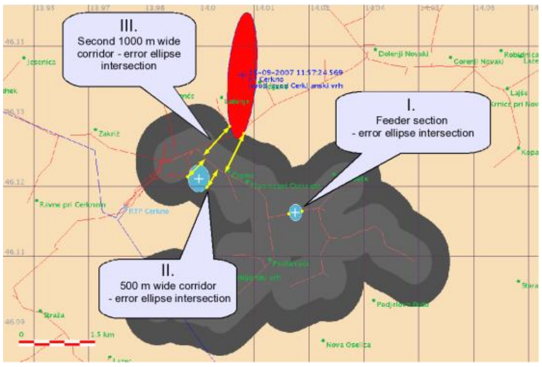

Figure 3: Geographical object that are subject of spatial correlation.

we have noticed, that some manual correlations have been done by our customers in area outside of 500 m corridor. This means that the 500 m corridor was too narrow to cover all correlations.

Following our customers experiences, we decided to introduce multi-layer corridor processing. The width of each next corridor was increased by factor 2. The first corridor is now still 500 m wide, the second 1000 m and the third is 2000 m wide.

3. RESULT OF CORRELATED EVENTS ANALYSIS

In our analysis the lightning location is represented as a single point and the power line by a polyline. The so-called reference point is defined as the nearest single point between the power line and the lightning location. The lightning location accuracy of LLS in early 2000 was estimated to be about 500 m, in the years around 2010 to be 250 m, in 2015 to be 150m and today somewhere around 100m.

Data in Table 1 shows results of all correlated events for 5 distribution networks (correlated since 2003), 4 transmission networks (correlated since 2000) and one electrified railway network (correlated since 2014). Column “Nb. correlated outages” shows the number of correlated outages for each voltage level. Column “Median distance” gives the median distance between reference points and the correlated lightning locations. “Median Stroke peak current” shows calculated result of all correlated lightnings peak currents.

Table 1: Analyses of real time correlator results.

Voltage level	Nb. correlated outages	Median distance	Median stroke peak current
3 kV DC	3454	401 m	14,2 kA
10 kV, 20 kV, 35 kV	15654	300 m	12,0 kA
110 kV	1572	500 m	19,0 kA
220 kV	640	470 m	20,0 kA
400 kV	52	416 m	23,0 kA

This analysis contains also lightning data from the time period when lightning location accuracy was in the range of 500 m. We therefore think that the median distances from table 1 are reasonable because they are inside LLS accuracy. The real time correlator cannot provide the information whether lightning stroke the powerline directly or not but gives the exact information that the cause of an outage is due to a specific lightning strike. It is obvious in table 1 that the median stroke peak current increases with increasing voltage level. Having in mind that shielding failures for transmission lines with overhead ground wires are caused by low peak current strokes the increase of the median peak current indicates that the main cause of power line failures are back flashovers.

2.1 Result of correlations in power distribution networks

In distribution networks we managed to gather operational statistics for permanent outages (unplanned events) only. Temporary outages (failure duration less than 3 minutes) are excluded from this study, because it is hard to determine the real cause of the outage and get reliable data. Table 2 shows the percentages of outages due to thunderstorm versus other causes. The thunderstorm category includes all failures related to storm events (uncorrelated lightning strikes, wind, rain, tree fall, avalanche, etc.). This classification is not based on a real time correlation only, but also on operator observations. Outages due to lightning strike comprise all events correlated by real-time correlator or with a physical proof of damage. From data in Table 2 we can conclude that in a distribution network about 50 % of all unplanned events are related to thunderstorms. About 50 % of those events are caused by direct or indirect effects of lightning strikes.

Table 2: Operational statistic of distribution network.

Cause of failure	Permanent failure
Thunderstorm	35 %
Lightning strike	13 %
other	52 %

In the following three typical examples of damages on overhead medium voltage powerlines, for which there is a high probability that the cause of a damage is a direct or very close lightning stroke, are given.

Figure 4 shows an overhead cable where the damage occurs on the cable insulation. The real time correlator automatically correlated the event with lightning data from the LLS (Figure 5). The correlator determined that the cause of the outage/damage as a lightning flash with 3 return strokes, with peak currents: -26.9 kA; -23,8 kA; -37,1 kA. The distance between the reference point and the closest located lightning is 180 m which was the first stroke with 26,9 kA.

Figure 4: Damaged cable insulation.

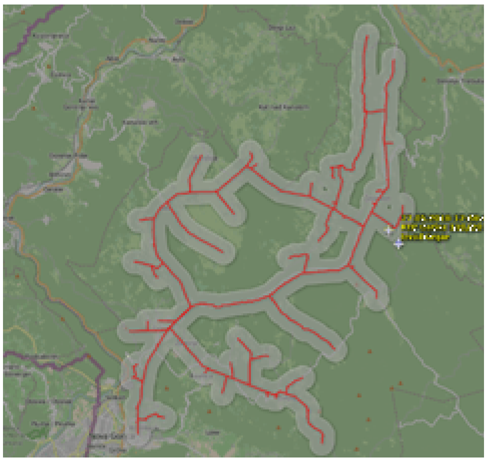

Figure 5: Real-time correlation.

In Figure 6 an overhead powerline with a damage on the insulator is shown. We can assume that lightning stroke struck the powerline somewhere between pylons and an overvoltage wave damaged the ceramic insulator. The real time correlator automatically correlated the event with lightning data from LLS (Figure 7). The correlator determined that the cause of the outage/damage is lightning one of 11 return strokes, with peak currents: -37,9 kA; 17,1 kA; -12,9 kA; -26,8 kA; -14,1 kA; -8,4 kA; -4,1 kA; -18,4 kA; -36,8 kA; -10 kA; -26,3 kA. The smallest distance between the reference point and the closest located lightning is 50 m. Again the first stroke with -37,9 kA was the closest stroke.

Figure 6: Damaged insulator.

Figure 7: Real-time correlation.

In Figure 8 an overhead cable with a damage on the overhead Al/Fe powerline is shown. We can assume that a lightning stroke struck the powerline somewhere between pylons and the powerline was cut due to thermal damages. The real time correlator automatically corelated events with lightning data from LLS (Figure 9). The correlator determined that the cause of the outage/damage as lightning flash with 5 return strokes, with peak currents: -36,8 kA; -9,5 kA; -10,5 kA; -23,5 kA; -36,8 kA. The distance between the reference point and the closest located lightning event is 80 m. Also in this case the first stroke with -36,8kA was correleted.

Figure 8: Damaged powerline.

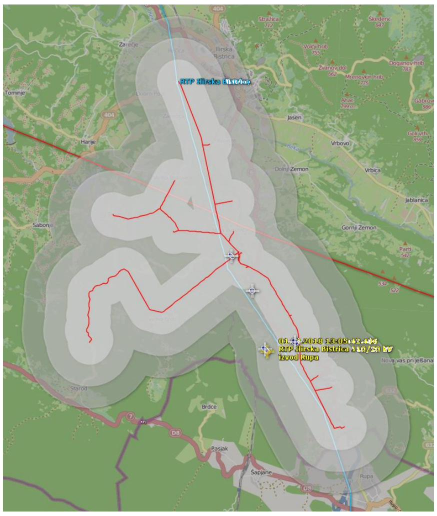

Figure 9: Real-time correlation.

Based on the shown examples, we can claim that damages in all three cases occurred due to direct hits (Figure 4 and Figure 8) or strokes very close to the powerline.

2.2 Result of correlations in power transmission networks

We managed to gather operational statistics from one transmission company for all unplanned events (temporal and permanent). Median failure duration of temporary outages is less than 3 minutes. Median failure duration for permanent outages is more than 3 minutes. Table 3 shows the percentages of outages due to thunderstorm versus other causes. Thunderstorm category contains all failures related to storm events (uncorrelated lightning strikes, wind, rain, tree fall, avalanche, etc.). This classification is not based real time correlation only, but also on operator observation. The category lightning strike contains all events correlated by real-time correlator or with physical proof of damage.

Table 3: Operational statistic of transmission networks.

Cause of failure	Temporary failure	Permanent failure
Thunderstorm	25 %	14 %
Lightning strike	19 %	10 %
other	56 %	76 %

From data in Table 3 we can conclude that in transmission networks around 44 % (25%+19%) of all unplanned events are related to thunderstorms including correlated events.

The different ratio between distribution and transmission networks (smaller percentage of thunderstorms and slightly higher percentage of lightning strikes) is also related to the fact that the corridors of the transmission networks are better maintained, e.g. in the corridors are no objects or trees. The construction of HV pylons and other HV equipment is much more robust, better and more frequently (annual review of all high voltage equipment) maintained. There is no possibility of a tree fall, influence of minor floods or similar incidents that can occur on MV powerlines.

In the following two examples of damage on overhead powerlines, where a high probability exists that damage is caused by a direct or very close lightning stroke, are given. In Figure 10 a damage on ceramic insulation is shown. The lightning stroke somewhere between pylons and an overvoltage wave damaged the ceramic insulator. Contamination of the insulator surface or some other reason may contribute to the powerline failure before the overvoltage protection reacted. The real time correlator automatically correlated the event with lightning data from LLS (Figure 11). The correlator determined that the cause of the outage/damage is a lightning stroke with peak current of -30 kA. The distance between reference point and the located lightning event is 85 m.

Figure 10: Damaged insulator.

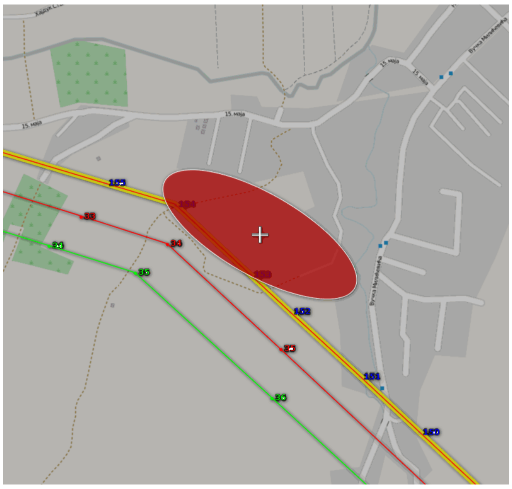

Figure 11: Real-time correlation.

Figure 12 shows damage on a ceramic insulation. The lightning stroke somewhere between pylons and overvoltage wave damaged the ceramic insulator. The real time correlator automatically correlated the event with lightning data from LLS (Figure 13). The correlator determined that the cause of the outage/damage is a lightning stroke with 7 return strokes with peak currents -36,8 kA; -12,1 kA; -13,3 kA; -7,7kA; -5,5 kA; -19,8kA; -9,8 kA. Distance between reference point and closest located lightning is 0 m - practically located on powerline Also in this case the first stroke with peak current of -36,8 kA is correlated.

Figure 12: Damaged insulator.

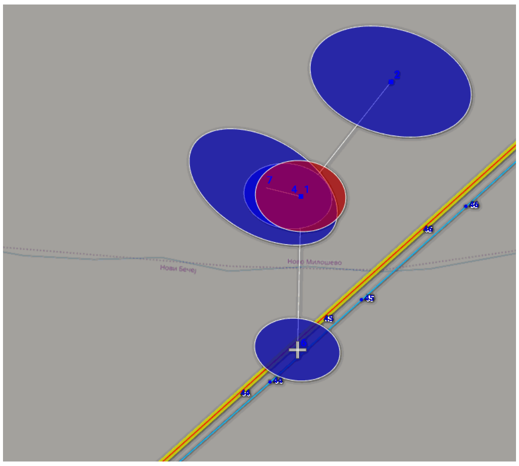

Figure 13: Real-time correlation.

CONCLUSION

In this article, we briefly described the validation of LLS data and the functionality of a real-time automatic correlator service. During the years of real time correlator operation, we have collected a large number of events, that can illustrate the usage of lightning data provided by LLS in power utilities. From the correlator results it is clear that the distance between lightning strikes to the nearest point of the powerline is within the LLS location accuracy. We cannot determine precisely if the cause of failure is by a direct or indirect lightning impact on the powerline, but we can claim it is highly probable that lightning strike caused the failure. Median peak current of all lightning strikes in the area covered by SCALAR system is somewhere around 11 kA. The median peak current of correlated lightning strokes increases with increasing voltage level (see table 1). This could indicate that the main cause of outages due to lightning are back flashovers and not shielding failures... We presented some examples from different voltage levels, where we can conclude that failures were caused by direct lightning strikes. In all the above cases, the peak currents of the lightning strikes, that caused the network outage, turned out to be high. Regardless of the condition of the equipment and the grounding of the pylons, we should rate such events as events due to a higher force. The article briefly describes the statistic of operational data from various electric power companies. We found that about 50% of outages occur during a storm. About 50 % of them are likely caused by an atmospheric discharge. We can conclude that lightning has an extremely large impact on the reliability of power networks. Therefore, the real time correlator tool is useful and gives us also additional insight to the lightning impacts on powerlines lines. This tool can be very useful for detailed event analysis which can improve the protection of the powerline network.

BIBLIOGRAPHY

[1] D. R. Poelman, W. Schulz, G. Diendorfer, and M. Bernardi, “The European lightning location system EUCLID – Part 2: Observations,” *Nat. Hazards Earth Syst. Sci.*, vol. 16, no. 2, pp. 607–616, Mar. 2016, doi: 10.5194/nhess-16-607-2016.

[2] W. Schulz, G. Diendorfer, S. Pedeboy, and D. R. Poelman, “The European lightning location system EUCLID – Part 1: Performance analysis and validation,” *Nat. Hazards Earth Syst. Sci.*, vol. 16, no. 2, pp. 595–605, Mar. 2016, doi: 10.5194/nhess-16-595-2016.

[3] G. Diendorfer, H. Pichler, and W. Schulz, “EUCLID Located Strokes to the Gaisberg Tower – Accuracy of Location and its assigned Confidence Ellipse,” in *23rd International Lightning Detection Conference & 5th International Lightning Meteorology Conference (ILDC/ILMC)*, 2014.

[4] F. Heidler and W. Schulz, “Lightning current measurements compared to data from the lightning location system BLIDS,” in *International Colloquium on Lightning and Power Systems (CIGRE)*, 2016.

[5] M. Azadifar *et al.*, “Evaluation of the performance characteristics of the European Lightning Detection Network EUCLID in the Alps region for upward negative flashes using direct measurements at the instrumented Säntis Tower,” *J. Geophys. Res. Atmos.*, vol. 121, no. 2, pp. 595–606, Jan. 2016, doi: 10.1002/2015JD024259.

[6] W. Schulz *et al.*, “Performance Validation of the European Lightning Location System EUCLID,” in *CIGRE International Colloquium on Lightning and Power systems (ICLPS)*, 2014.