INTEGRATION OF LIGHTNING STRIKE INFORMATION INTO SCADA AND OMS TO INDICATE OR VERIFY FAULTS ON OVERHEAD LINES

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ABSTRACT

Direct and non-direct lightning strikes on overhead lines often cause tripping of protection relays and therefore power outages for customers. Grid-operation-guidelines sometimes allow manual reclosing of tripped circuit breakers when a lightning strike is identified as the reason for an outage. In some situations, damaged line equipment or the area of the problem can be localized in a smart and efficient manner by using lightning detection information. This paper addresses the support of the grid operators in a centralized operational control room with real-time correlation of data from a lightning detection system with information from SCADA, from a distribution management system (DMS) and from an outage management system (OMS). The requirements of the grid operators are met with a new application within network-control-systems. The resulting information enables the operators to reclose tripped circuit breakers or to dispatch the maintenance crew more accurately and hence to obtain quicker restoration times.

INTRODUCTION

During thunderstorms, power utilities often face overhead line faults due to lightning strikes. The subsequent outages can result in substantial economic losses. Measures to restore the power supply in the disturbed areas have to be taken immediately. Some grid operators use the confirmed information of lightning strikes on faulted lines as a criterion for an immediate reconnection attempt. If not successful, telemetered or manual switching actions by the operators or by the field-staff are necessary in order to identify the faulted area. Finally, a maintenance crew will be assigned to locate and repair a disturbed line section.

To support the operators with additional information regarding the fault location, the distribution system operators at KNG-Kärnten Netz GmbH and the Netz Oberösterreich GmbH in cooperation with SIEMENS Austria, have developed a new application in the network-control-system.

Kärnten Netz GmbH and Netz OÖ GmbH operate high-, medium- and low-voltage networks of approximately 18.400/31.400 kilometres in length with an average percentage of around 50%/31% of cables. In certain areas in Carinthia, the lightning density can be higher than 5 lightning strikes per km² per year. Upper Austrian regions (Netz OÖ) are characterized by a density of 2,5 lightning strikes per km² and year.

GRID OPERATION REQUIREMENTS

In the event of an outage, the first task of a grid operator is to decide which measures are to be taken for a quick and secure restoration of the faulted grid area. Modern network-control-systems support this task with intelligent system applications. The main goal is to localize and isolate faulted equipment in the grid. This task is an interaction between central grid operators using various systems, in particular SCADA, together with the on-site information from the field engineers.

In the case of a lightning strike on an overhead line, there are a number of possibilities to correlate lightning and grid information. Firstly, it can be done within a graphical user interface as part of a lightning location system. The main disadvantage in this solution often is the out-of-date geographical grid information and grid topology. A second alternative is the use of an independent application outside of network-control-system, as described in [1]. In this case, an additional system in the operation centre has to be installed and maintained.

A further possibility is the realisation within the network-control-system, which will be presented in this paper. The advantage of this integration is the correlation of up-to-date geographical grid information with actual status signals from other telecommunicated grid elements and documentation in OMS. Therefore, the operator will be able to obtain all information coming from the lightning location system within the network-control-system.

In summary, the requirements for such an application can be described as follows:

- integration of lightning information into SCADA, OMS and DMS
- topological and chronological on-line correlation of one or more lightning strikes with outages
- user-friendly and quick application handling
- multi-user functionality
- continuous documentation

LIGHTNING DETECTION

The Austrian Lightning Detection & Information System (ALDIS) is used to detect lightning activity in Austria [2]. The ALDIS sensors are integrated in a multinational network in Europe to improve the performance of the Austrian network. The direction finders used in Austria have a mean detection range of about 400 km. This network configuration enables a median location accuracy of better than 500 meters.

Such a lightning location system consists of three fundamental components:

- two or more sensors which determine the angle of incidence of the lightning electromagnetic field and/or the exact time of occurrence
- central lightning processor to calculate the position of the strike
- a display system for the graphical presentation of the lightning activity

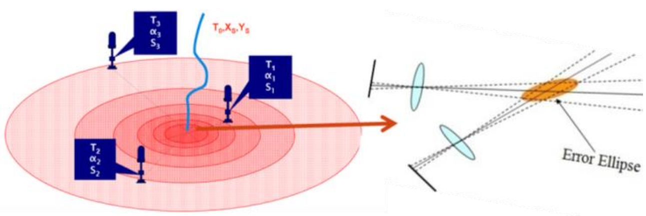

Figure 1: Lightning detection principle

The striking position can be determined by triangulation using two sensors. If three or more sensors report a discharge, an optimization which minimizes the measurement errors between the reporting sensors can be employed. A further improvement of this method combines the results regarding direction-finding and time-of-arrival. With this approach, direction finding provides azimuth information and absolute arrival time provides range information.

The lightning detection principle can be seen in Figure 1. The impact point is defined with an error ellipse considering the measurement errors of the detection system. Further, the date and time of each lightning strike, the current intensity and polarity as well as the number of subsequent strikes can be obtained.

The row-data from ALDIS always describes the 50% error-ellipse of each lightning location with its specific parameters (semi-major axis, semi-minor axis, inclination). They enable the modelling of a two-dimensional Gaussian distribution, abstracted with several error ellipses up to a 99% probability. This can be seen in Figure 2 [3].

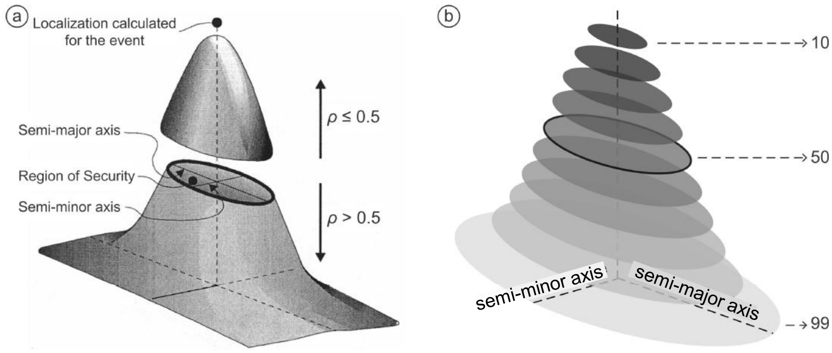

Figure 2: **a)** Two-dimensional Gaussian distribution of a 50% error ellipse **b)** Abstraction with ten error ellipses

For each arbitrarily probability ρ, which can be in a range from 0 to <1, the new scaling for the semi-axis can be calculated by applying Formula 1. The calculation of the precise length of a given semi-axis can be carried out using Formula 2. The value 1.1774 corresponds with the scaling of the 50% probability.

$$Scaling_{\rho} = \sqrt{-2\ln(1-\rho)} \qquad \textbf{Formula 1}$$

$$Semiaxis_{\rho} = \frac{Semiaxis_{\rho=0,5}}{1{,}1774} \cdot Scaling_{\rho} \qquad \textbf{Formula 2}$$

An analysis of the 50% error-ellipses of 20.000 strikes in Carinthia shows that 75% of the semi-major axis and 99% of the semi-minor axis are smaller than 1 kilometre. However, some individual strikes have a length larger than 5 kilometres. Therefore, the given impact point of a strike is not sufficient for a geographical correlation. This single point just indicates the centre of an ellipse, which represents the error probability and therefore the measurement failure of the lightning detection system. In the new SCADA application, these ellipses will be used for a correlation with the geographical information of the grid.

SOFTWARE IMPELMENTATION

The following software application features have been developed and integrated into the existing SIEMENS Spectrum Power 4 SCADA/DMS system for efficient use in a centralized control room:

- Interface to an external database to read the lightning event data including extension of the internal database to correlate and store the lightning data with the Outage Management data.
- Mapping of Gauß-Krüger location coordinates to Spectrum Power4 internal world map coordinates.
- Processing of only relevant lightning data for a defined geographical corridor.
- Visualization of lightning strike data in world maps and list of lightning events within defined time windows using:
  - date and time (ms), location, lightning strength, main and subsequent lightning strike, polarity
  - probability of lightning strike location within a geographical ellipse, defined by three parameters (semi-major axis (km), semi-minor axis (km) and inclination

The applications have been implemented within SIEMENS Spectrum Power 4, using the SCADA/DMS software framework, the Solaris operating system and an ORACLE relational database.

The following detailed requirements have been implemented within these applications:

1. Automatic cyclical query and analysis of new or updated lightning data.

   The lightning database is queried and analysed cyclically for new or updated lightning data. Based on the analysis of all lightning events, alarms are generated to indicate the start and end time of a weather front.

2. Manual query and analysis of new or updated lightning data.

   The system operator can manually trigger a query and analysis of the lightning data at any time in between automatic queries under certain circumstances, for example in case of a circuit breaker trip. The manual query is an end-to-end query that shortens any refresh cycles, both for the external and internal database.

   The geographical world maps will graphically visualize the lightning events for a selected station or line within a defined time window.

3. Generation of a lightning event list from Outage Management data.

   A list of lightning events is generated based on Outage Management such as disconnected customers and unsupplied network areas.

To ensure user-friendly application handling, the following extensions in the visualization of lightning data were implemented:

- New lightning events are displayed with a yellow, blinking circle at the proper geographic location in the world map. The brightness of the lightning symbols fades with the elapse of time.
- A new function calculates the distance of the lightning event to the overhead line.
- Mouse-over detailing with display of an information window showing the lightning event details when moving the mouse over the lightning symbol in the world map. This window can be visualised permanently.
- The tracing function visually supports the connectivity analysis of network components, such as lines.

Some helpful extensions have been added to the Outage Management software:

- Lightning data and outage data are being correlated. Relevant lightning data is added to the internal Outage Management data and stored on demand.
- Realization of a Lightning List which summarizes the lightning events stored to the Outage Management database. This list is the main interface between user, databank and the visualisation in the world maps.

SCADA APPLICATION

The data transfer between ALDIS and SCADA and the overlapping visualisation of grid and lightning data can be seen in Figure 3. In a first step, the data from ALDIS are stored in an Oracle database. If a request occurs, this data are delivered from ALDIS to SCADA.

The lightning event list, which is the core element of the new SCADA application, can be initiated from different sources. This can be any event in a protocol, an OMS record, a certain geographical area or any grid element. Depending on this source data, the lightning list will be automatically prefilled, e.g. with time slots and/or the geographical coordinates.

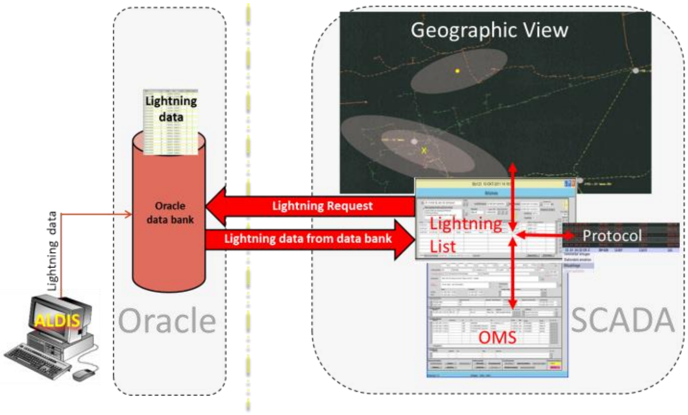

Figure 3: SCADA-application and data transfer

As a result, the lightning event list identifies all lightning strikes within the predefined specifications. In the case of a trigger due to a single event (e.g. protection relay tripping), experience demonstrates that the time stamp is very close to the GPS-time of the responsible lightning strike. The time deviation depends on the technology used for the protection devices, their time registration and the telecommunication technology being employed and can be up to several hundred milliseconds.

A subsequent adjustment of this time deviation would be very complex and is not necessary for the correlation process. In the case of an outage – taking into account the average lightning density in Carinthia which varies from 1,9-4,8 strikes per km^2 per year with an average outage rate of 2,6 outages per feeder per year – the time deviation of a few hundred milliseconds between lightning strike and protection tripping indicates a very high correlation rate.

Each identified strike is listed with its individual error-probability due to the measurement accuracy and is specified with the parameters for the error-ellipse. The correlating lightning strike(s) will be visualized individually in the geographical SCADA-view with two pre-set probabilities. A dark-grey ellipse indicates the area with a 50% impact-probability, a light-grey with a 99% impact-probability.

The combination between the chronological and geographical correlation guarantees a very high hit-rate. The application is designed to support multi-user requirements with simultaneous requests from different operators. Furthermore, an integrated documentation with export functions to other systems (e.g. email systems) is implemented.

EVALUATION

The development of this new application commenced in December 2012 and was implemented in summer 2013. Figure 4 shows one example of a SCADA-visualisation of an outage in a medium-voltage grid due to a lightning strike. The identified fault location, which was drawn-in afterwards, lies within the 99% light-grey error ellipse. The number of the tower – in this case tower number 91, is also illustrated. For a better topological representation, the operator used the new mouse-over function to highlight the adjoining transformer station.

The detailed information of the lightning strike is shown in a window in the lower-left-hand corner of Figure 4. It can be seen that the strike has an amplitude of -4 kA with a semi-major axis of 300 meter and a semi-minor axis of 100 meter of the 50% error ellipse. The time delay between the strike and the first outage signal is 14 milliseconds.

The fault reactance from the distance protection relay, which is automatically indicated in SCADA, determines the fault to be approximately 700 meters from the real fault location. This deviation can be explained because of the increasing number of decentralized generation units in this part of the grid.

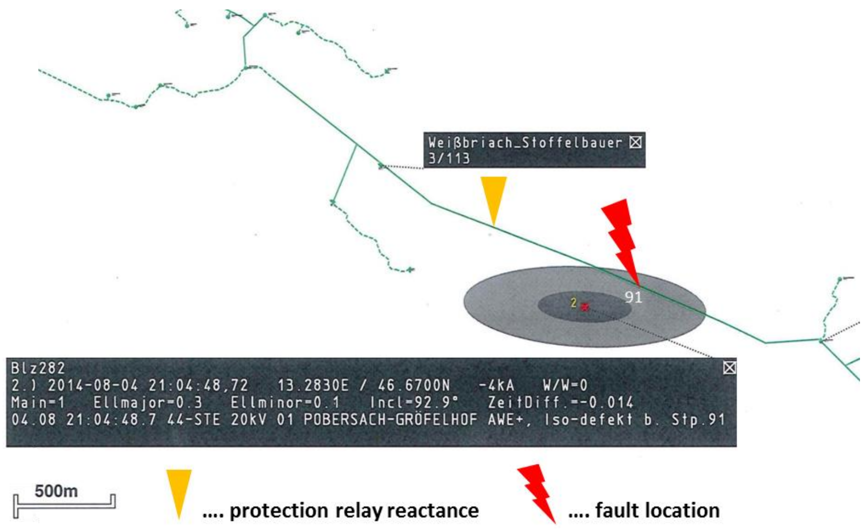

Figure 4: Lightning strike indication in SCADA

A detailed analysis of 33 outages due to lightning strikes was carried out to evaluate the accuracy and therefore the benefit of the SCADA application. All strikes except one were negative; the average current magnitude was 21,6 kA with an absolute range from 4 kA up to 139 kA. The time difference between the lightning strike and the tripping of the protection device was in average 121 ms, varying from 3 ms to 389 ms.

Figure 5 shows the correlation of the impact point of the strike with the real fault location. The damages were in these cases mainly on insulators, on the conductor, on surge arrestors or on high voltage fuses. The first bar, with 34% of the analysed events, indicates the outages where the fault location was found to be within the 99% error ellipses.

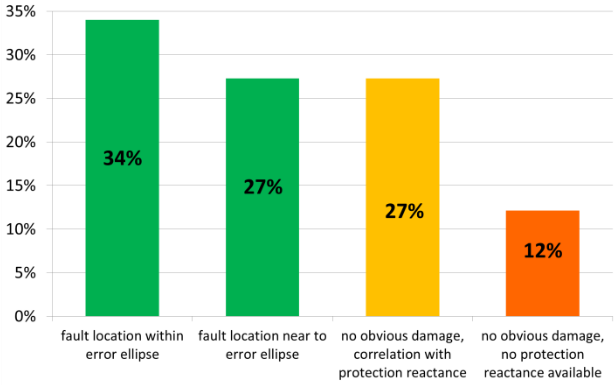

Figure 5: Impact point and fault location

In 27% of all events, the fault location was outside of the error ellipse but still close to it. In these cases, the damages were mainly surge arrestors or high voltage fuses at the next transformer station with an average distance of 328 meters from the error ellipse. These damages can be explained by the fact that the impact of a lightning strike generates travelling waves on the overhead line with a high peak voltage.

In another 27% of the events, no obvious damage was found during line inspection. However, the reactance of the distance protection relays correlates with the error ellipse. In these cases, it can be assumed that the indication of the lightning strike was correct but the electric arc did no damage to any grid equipment.

For the last 12%, no damaged equipment was found. Furthermore, there was no available information about a fault reactance from protection relays. For these cases, no further conclusions about any correlation can be drawn.

FURTHER DEVELOPMENTS

Not all grid operators use a geographical layer as their working platform in SCADA. Therefore, one future development is the extension of the lightning-correlation in a schematic overview.

A further step in this application is a fully-automated correlation of the lightning data with the grid geography and topology with SCADA status signals (e.g. from remotely signalled short-circuit indicators) and with the fault reactance of tripped distance protection relays. The results of this correlation should be visualised and will further automate and expedite the fault localisation.

CONCLUSION

The presented SCADA application enables a quick and reliable correlation between lightning strike locations and power line outages. The basis for these results is on the one hand, a chronological congruence between the protection tripping time and the GPS time of the lightning event and on the other hand, a geographical interference of the lighting probability area with the faulted line. In addition, together with existing fault indicators or other expert systems, this application further decreases the outage times during thunderstorms. This fact has been confirmed with operational experiences of two grid operators over two summer periods.

Besides the functional requirements, the focus in this project was especially on the user-friendliness of the application. Due to an increasing number of software applications in central operation centres, the acceptance of a new tool mainly depends on its easy and self-explanatory handling. The experiences gained from this project demonstrate that the effort and the expense for the basic functionalities is at least in the same magnitude as the effort for an integrated and user-friendly application.

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