Application of Lightning Locating System for Improvement of Medium Voltage Power Systems Planning and Operation

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SUMMARY

The paper describes the application of lightning data based on the Lightning Locating System (LLS) for the improvement of planning and operation of the medium voltage power system. A certain number of all failures, which are caused by lightning, results in permanent damage to the equipment on the overhead distribution line. Correlating the data of lightning discharges and the information on the events in the power system one can obtain valuable information necessary to decide on the measures to improve the reliability of electricity supply. Emphasis will be given to the application of correlation between failures and outages in the medium voltage distribution network and lightning. The analysis was carried out on typical overhead medium voltage power lines with LLS data and data on failures in the power network registered in the period from 2012 to 2015. Temporal and spatial correlations were conducted in order to develop a method for determining the probability of lightning caused outages of the overhead line in the medium voltage power system. Once calculated this outage, the probability function allows the determination of the optimal line route with respect to the overall long term cost.

KEYWORDS

Lightning, lightning location system, relay protection, temporal and spatial correlation, failures, outages, medium voltage overhead lines

1 INTRODUCTION

This paper demonstrates a probability assessment method for line outages in 10(20) kV medium voltage (MV) overhead lines due to lightning strokes. A cumulative distribution function (CDF) is obtained based on the Lightning Locating System (LLS) and Supervisory Control and Data Acquisition (SCADA) system. The goal of this research is the assessment of an approximation function for line outages forecasting due to lightning in dependence of the lightning stroke to power line distance (meter) and peak lightning current amplitude (kA). This research will be conducted using the measured lightning data and distribution network operation data from 2012 to 2015.

In order to assess the accuracy of the proposed line outage approximation function, validation has been conducted using real line outage data in the distribution network obtained through SCADA, correlated with LLS data, measured from the 3rd of February 2014 to the 3rd of February 2015 (1 year).

2 DISTRIBUTION LINE OUTAGES CAUSED BY LIGHTNING

Lightning affects the reliability of transmission and distribution overhead lines. Among all overvoltage types, for distribution networks, lightning induced overvoltages present, by far, the greatest risk. As atmospheric effects on overhead distribution lines are hard to avoid, the greatest number of faults and disturbances in overhead distribution lines is caused by lightning overvoltages.

Due to lightning overvoltages, the most common occurrence is flashover on the distribution line insulator which cannot sustain the lightning overvoltage. A temporary or definite fault can occur due to flashover. Such faults are recorded and acquired using SCADA or similar monitoring and data acquisition systems.

Previous researches have shown lightning as the main cause of faults in typical distribution overhead lines. Such faults can cause temporary and permanent outages. It is considered that 5-10 % of all faults caused by lightning result in permanent damage to distribution overhead line equipment [1]. Lightning stroke creates a lightning-radiated electromagnetic field which induces overvoltages on a nearby overhead line (indirect lightning stroke). Such induced overvoltages are significantly lower than overvoltages caused by direct lightning strokes, but can still be high enough to cause flashover on medium voltage insulators, especially on 10 kV or 20 kV lines.

As 10 kV and 20 kV overhead lines are not quite high, they are partly shielded by surrounding objects (e.g. trees) from direct lightning strokes, but are exposed to induced overvoltages due to indirect lightning [2].

In the existing research, the numerical approach was analysed for the assessment of induced overvoltages as a result of lightning stroke to MV distribution overhead lines [3], [4]-[8].

In the last years, the world organisations as CIGRE or IEEE have published methods and recommendations for protection of MV overhead distribution lines from lightning overvoltages [9]-[12].

The present research on lightning impact on overhead MV distribution lines indicates that the flashover rate is lower for overhead lines of lower height, of higher insulation levels, of lower footing resistance and lower lightning current amplitudes and steepness [13].

The research on lighting protection of MV distribution overhead lines from overvoltages due to direct or indirect lightning strokes indicates that the best results in protection provides the combination of overhead line shielding wire and installation of line surge arresters along with the acceptable values of footing resistance [14], [15]. In MV networks located in areas with high lightning flash density, lightning can be the cause of more than 80% of temporary or definite faults [16].

3 INSPECTED DISTRIBUTION OVERHEAD LINES

Fourteen overhead MV distribution lines were chosen, for which fault analysis was conducted. The lightning activity map (lightning flash density) shows a high exposure of the area containing the investigated MV distribution overhead lines. Figure 1 shows lightning strokes within the observed area on the 30th of June 2014 in a 24 hours period (lightning data obtained using LINET system).

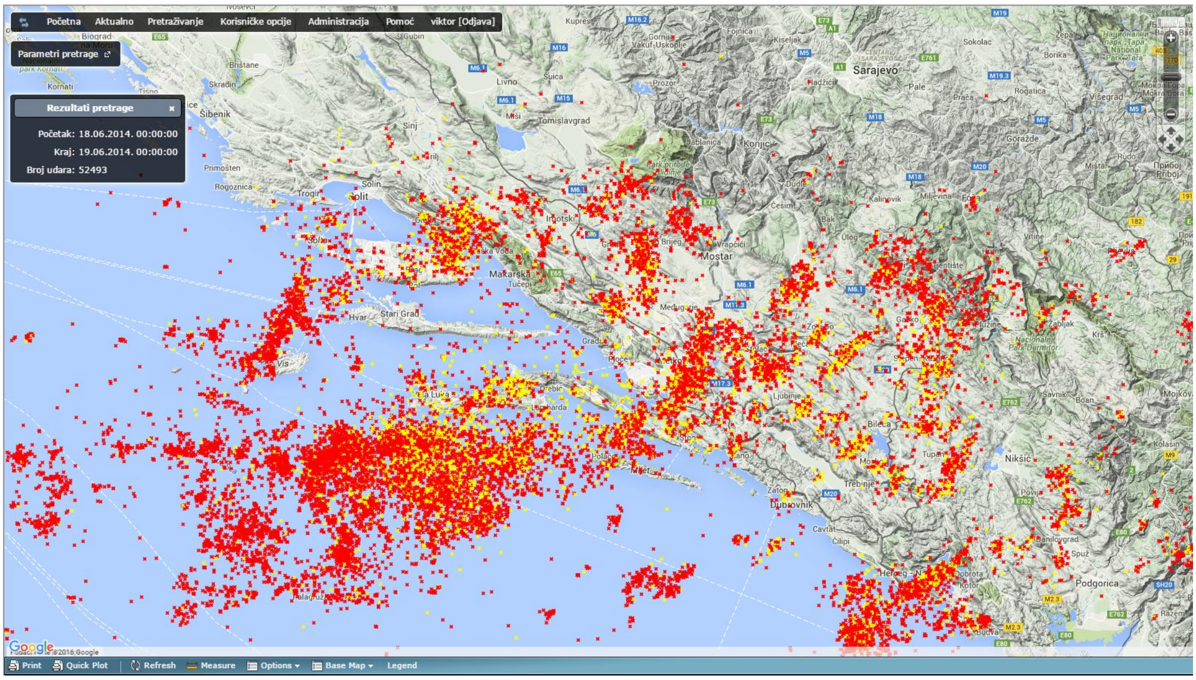

Figure 1. Lightning activity in the observed area containing analysed distribution MV overhead lines – 30th of June 2014, 24 hours period (LINET)

Lengths of inspected MV overhead lines are shown in figure 2.

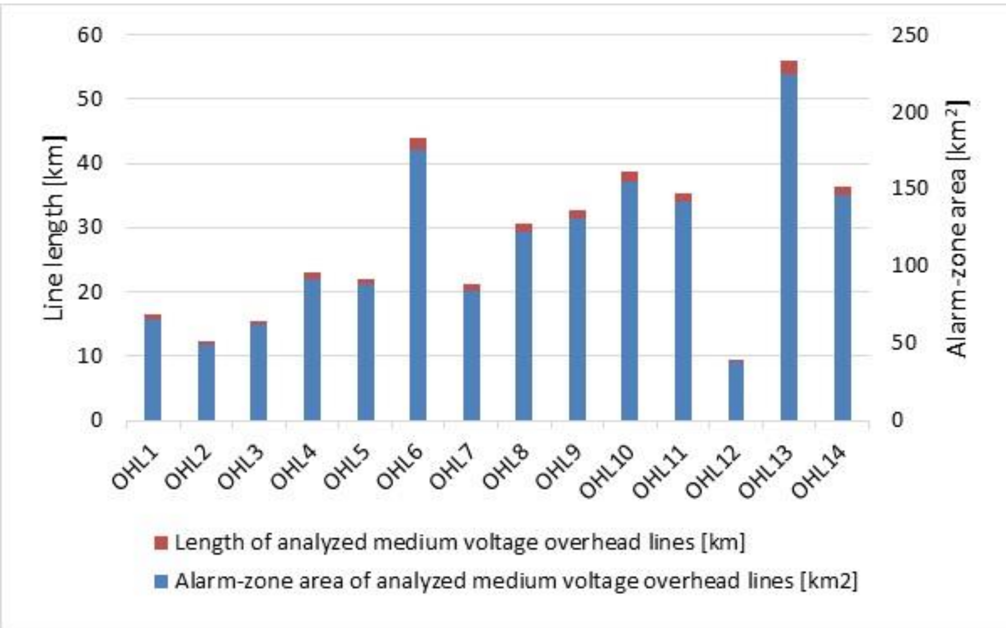

Figure 2. Length and alarm-zone area of inspected MV overhead lines (m)

4 CORRELATION METHOD BETWEEN LIGHTNING DATA AND FAULTS IN MV NETWORKS

For the implementation of the correlation procedure it was necessary to associate lightning data with events in the distribution network and geoinformation data of distribution lines.

The LINET lightning locating system, which was used in this research, was developed in Germany and nowadays consists of a sensor network of more than 550 sensors worldwide [17].

4.1 SCADA gathered data on distribution network events

The data on events in the distribution network, gathered using SCADA, among others, contain information on the exact event time and location (facility, line, etc.), along with other useful information for the correlation with the lightning data. It is necessary that the SCADA and the LLS are precisely time synchronized using GPS, ensuring precision in microseconds. For SCADA time synchronization a modular system equipped with GPS receivers is used, and the time synchronization is done through LAN. Time resolution of ±1 ms, with the timestamp format HH:MM:SS:mSS is in compliance with IEC 61850-5/ G1.2/13.7.6 in all of the control and protection equipment analyzed in this research.

The correlation results contain the following information: fault time (UTC), fault time (local time), object (line) name and identification for SCADA, SCADA source message for dispatchers, time difference between the lightning stroke (LLS data) and fault (SCADA data), shortest distance between the lightning fault and line, lightning stroke time (UTC), lightning type (CG – cloud-ground or IC – inter-cloud), lightning peak current amplitude, lightning current polarity, assessed statistical lightning locating error, lightning GPS (location) coordinates, object (line) name for LLS.

As there are exact data on protection relay pickups for investigated faults in the protection relay station computer, and replay pickup time is much closer to the lightning event time which caused the fault (and the preceding pickup), the relay pickup data is used for the correlation of line faults and lightning [18].

4.2. Geoinformation system data of inspected MV overhead lines

For the purpose of correlation of events (faults) within the distribution network with lightning, the lightning data are associated with event data gathered with the SCADA and Geoinformation system (GIS) data on the 14 inspected 10(20) kV overhead lines.

By association of data from the three above mentioned sources (LLS, SCADA and GIS) a spatial-temporal correlation between the event (fault) on an overhead line and lightning will be achieved (figure 3).

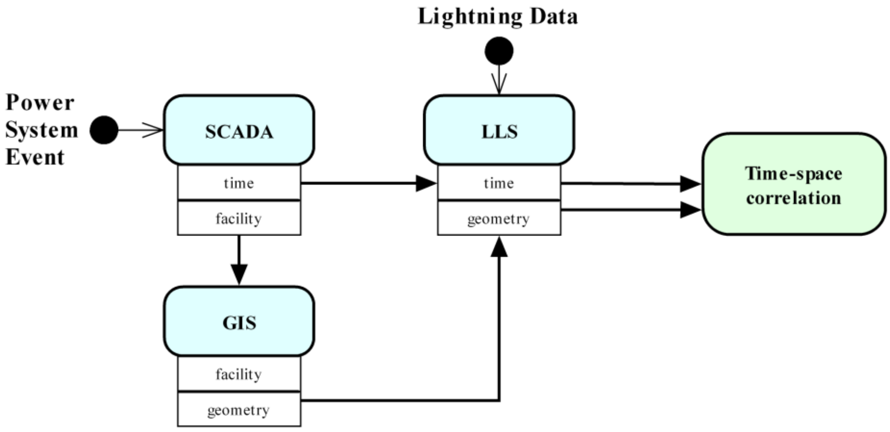

Figure 3. Data association from three sources for achievement of spatial-temporal correlation between line faults and lightning

4.3 Spatial-temporal correlation on line faults and lightning in MV network

The initial criterion for the temporal correlation between the protection relay event on inspected distribution lines and lightning stroke is a precise timestamp of line faults. Due to the need for high time precision, timestamps of relay pickups were used for the correlation procedure which were taken from the SCADA archive event list.

The LINET lightning locating system uses GPS for time measurement and synchronization. The protection relays of inspected overhead lines are synchronized with SCADA which also uses GPS for

time synchronization. The declared precision of GPS is adequate, which makes the SCADA data on line faults suitable for the correlation with LLS data on lightning strokes.
As the necessary criteria for fault to lightning correlation, the time difference of no more than 1 second between the detection of fault and the lightning stroke is determined.
The postulate for spatial correlation is GIS data on inspected overhead lines. Due to lower insulation levels on inspected 10(20) kV overhead lines (operational voltage 10 kV, insulation level 20 kV) a radius of 2000 meters around the inspected overhead line was taken to define the area around the lines in which lightning strokes were observed. Based on analysis of LLS statistical and systematically locating error in the area, a radius of 2000 meters was determinated to be adequate to encompass all direct and indirect lightning strikes which could cause lightning induced overvoltages on the line.
The correlation procedure was conducted with some limitations and the results contain the statistical and systematic error of the LLS (precision limitation of the lightning locating method).
The spatial-temporal correlation of lightning data and line faults on the 14 overhead distribution lines was conducted based on the data from the 12th of April, 2012 to the 2nd of February, 2014.
The correlation procedure is composed of several steps. In the first step all line faults were analysed and those with known cause, which is not lightning, were sorted out. In the second step lightning strokes were analysed and those which did not occur in proximity (2000 m) of inspected overhead lines were sorted out. The observed area around the inspected overhead lines are shown in figure 2.
Based on such filtered data on events and faults and the lightning data, a temporal-spatial correlation was conducted in a way described as follows.
Fault e_i is considered to be a result of a lightning induced overvoltage u_i if the following conditions are met:

1) the lightning stroke u_i occurred within 2000 meters of the overhead line where the line fault e_i occurred,
2) the line fault e_i occurred no more than 1 second after the lightning stroke within the line area (2000 m radius).

5 PROBABILITY ASSESSMENT OF AN OVERHEAD LINE OUTAGES CAUSED BY LIGHTNING STROKE STOP

The procedure for predicting outages of a typical 10 (20) kV overhead line caused by lightning stroke is described as follows. The outage of the overhead line is the function of the distance of lightning stroke, from the axis of the analyzed overhead line and lightning currents [19].
The purpose of the model is to predict the outage number of distribution overhead line caused by lightning stroke.
The mathematical function of outage approximation of distribution line estimates the long-term maintenance costs and outage costs caused by lightning strokes.
The development of the function that enables the assessment of probability of overhead line outages, in the observed part of the distribution system caused by lightning stroke, based on the available data, was conducted using the program Matlab. Parameter values of distances were discretized for every 100 m in the range from 0 up to 2000 m.
On the basis of the obtained data on lightning strokes from the LLS, temporally and spatially correlated with the data of the outage of the observed distribution lines caused by lightning strokes from the SCADA system, the overall probability of the overhead distribution lines outage depending on the distance of lightning stroke from the all observed distribution lines, is shown in Figure 4.
Adding the amplitude of lightning current as the input factors, the probability of the overhead distribution line outage is depended on the distance of lightning stroke to the distribution line and amplitude of lightning currents. The probability of the overhead distribution line outage for all observed distribution lines is shown in Figure 5.
The values of current amplitude of lightning strokes were discretized every 10 kA in the range of 0 up to 100 kA.

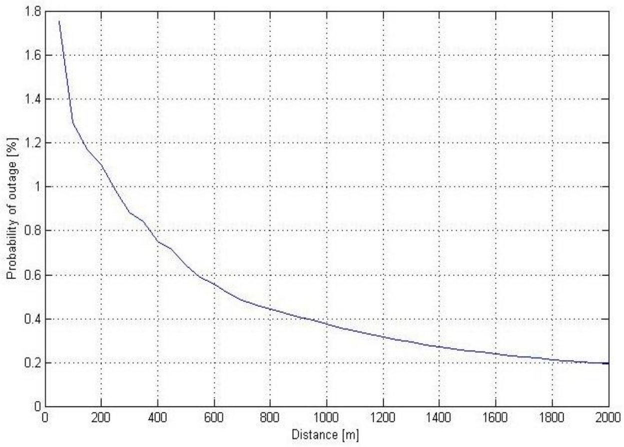

Figure 4. The overall probability of the overhead distribution lines outage depending on the distance of lightning strokes from the all observed distribution lines

Figure 5 shows a 3D graph that represents the probability distribution function of outage in the case the point of lightning stroke is less than the value of r and the lightning current is less than the value of *i*. If the lightning stroke distance from the distribution line is less, the probability of distribution line outage is higher and if the value of the amplitude of lightning current is greater, the probability of the distribution line outage is higher. The dependence of amplitude of lightning current is less pronounced compared to the dependence on the distance.

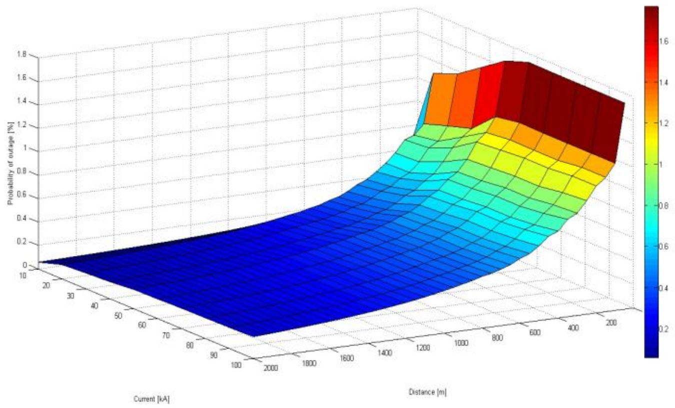

Figure 5. The probability of the overhead distribution line outage caused by lightning stroke depended on the distance of lightning stroke to the distribution line (m) and amplitude of lightning current (kA)

6 APPROXIMATION OF PROBABILITY FUNCTION OF TYPICAL OVERHEAD MEDIUM VOLTAGE LINES OUTAGES CAUSED BY LIGHTNING

This section describes how to get getting of the approximated probability function for prediction of distribution line outages in the case of future lightning stroke, depending on the distance of lightning stroke from the distribution line and the amplitude of lightning current. The mathematical method of the least squares was used in the Program Matlab [20]-[22].

An expression is obtained that represents 3D feature-function approximations depending on the parameters:

- Probability of outage (%),
- Distance r (m),
- The current amplitude of lightning (kA).

According to the empirical analysis of lightning events and the expected mathematical contributions of individual input parameters, the initial form of the approximation function is determined by the following formula:

$$\hat{f}(r,i)=\sum_{\substack{p+q\leq n\\ p\geq 0\\ q\geq 0\\ n\geq 0}} c_{p,q}\cdot\left(\frac{1}{r}\right)^{p}\cdot i^{q} \qquad (6.1)$$

Where:
r - Distance between the lightning stroke and the nearest point of the distribution line (m);
i – Current amplitude of lightning (kA).
$c_{p,q}$ - Coefficients of the approximation function,
q, r – potency of i and r members in polynomial approximation.

The shape of function approximation (6.1) is selected since the increase of the distance of lightning stroke from the distribution line decreases the probability of distribution line outage and the increase of lightning current increases the probability of distribution overhead line outage. The probability of distribution line outage is increasing also with increasing steepness of lightning current but this information is not available from LLS.

The starting point for the mathematical expression is the data set collected from the LLS LINET, i.e. SCADA as follows:

- Current amplitude of lightning i_k; $k = 1,...,N_i$
- Distance between the lightning stroke and distribution line r_k; $k = 1,...,N_r$
- Information of the distribution line outage in the form of Boolean variables with the value of the variable 1 if the outage occurred or 0 if it has not occurred.

Based on the data above, the distribution function of the outages was calculated in the following form:

$$p(i_i, r_j) = P(i \leq i_i, r \leq r_j) \qquad (6.2)$$

Where:
i_i - a series of uniformly spaced values in the interval $[i_{min}, i_{max}]$,
r_j - a series of uniformly spaced values in the interval $[r_{min}, r_{max}]$.

The aim is to choose a suitable approximation of the probability function of the distribution line outage caused by lightning.
From the literature it is known that an overvoltage which is generated is proportional to the amplitude i and steepness of lightning current and inversely proportional to the distance of lightning stroke to distribution line r. For this reason, as a potential candidate for the approximation function is selected in the following form:

$$\hat{p}_k(i,r)=\sum_{p+q\leq n} c_{p,q}\frac{1}{r_k^{p}} i_k^{q}, \quad p\geq 0, q\geq 0. \qquad (6.3)$$

In order to calculate the coefficients of the approximation function $c_{p,q}$, a quadratic objective function is defined in the next form:

$$MSE = J = \frac{1}{2\cdot n_i\cdot n_d}\sum_{k=1}^{n_i\cdot n_r}\left(\hat{p}_k(i,r)-p(i,r)\right)^2 =$$

$$\frac{1}{2\cdot n_i\cdot n_d}\sum_{k=1}^{n_i\cdot n_r}\left(\sum_{p+q\leq n} c_{p,q}\frac{1}{r_q^{p}} i_k^{q}-p(i,r)\right)^2 \qquad (6.4)$$

Where:
n_i - the number of discrete values of lightning currents used to calculate the approximation function,

n_r - the number of discrete values of distances of lightning strokes used to calculate the approximation function of distribution line outages.

This function is commonly called the Mean Squared Error function (MSE).

The optimal coefficients of models $c^*_{p,q}$ are those with which function J achieves a minimum.

The minimum value of objective function J is achieved at a point where its derivations by coefficients $c_{p,q}$ are equal to 0:

$$\frac{\partial J}{\partial c_{p,q}} = 0, \quad \forall p \geq 0, \quad \forall q \geq 0, \quad p+q \leq n. \qquad (6.5)$$

The calculation of the first derivation of the function J by the coefficient $c_{p,q}$ gets the next set of equations that must be satisfied:

$$\frac{\partial J}{\partial c_{0,0}} = \sum_{k=1}^{n_i \cdot n_d} \left(\sum_{p+q \leq n} c_{p,q} \frac{1}{r_q^p} i_k^q - p(i,r) \right) \cdot \frac{1}{r_k^0} i_k^0 = 0, \qquad (6.6)$$

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$$\frac{\partial J}{\partial c_{n,0}} = \sum_{k=1}^{n_i \cdot n_d} \left(\sum_{p+q \leq n} c_{p,q} \frac{1}{r_q^p} i_k^q - p(i,r) \right) \cdot \frac{1}{r_k^n} i_k^0 = 0, \qquad (6.7)$$

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$$\frac{\partial J}{\partial c_{p_0,q_0}} = \sum_{k=1}^{n_i \cdot n_d} \left(\sum_{p+q \leq n} c_{p,q} \frac{1}{r_q^p} i_k^q - p(i,r) \right) \cdot \frac{1}{r_k^{p_0}} i_k^{q_0} = 0, \qquad (6.8)$$

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$$\frac{\partial J}{\partial c_{0,n}} = \sum_{k=1}^{n_i \cdot n_d} \left(\sum_{p+q \leq n} c_{p,q} \frac{1}{r_q^p} i_k^q - p(i,r) \right) \cdot \frac{1}{r_k^0} i_k^n = 0. \qquad (6.9)$$

The previous expression is written in matrix form as follows:

$$\begin{pmatrix} \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^0} i_k^0 & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^p} i_k^q & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^n} i_k^n \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^{p_0}} i_k^{q_0} & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^{p+p_0}} i_k^{q+q_0} & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^{n+p_0}} i_k^{n+q_0} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^n} i_k^n & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^{p+n}} i_k^{q+n} & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^{2n}} i_k^{2n} \end{pmatrix} \cdot \begin{pmatrix} c_{0,0} \\ \vdots \\ c_{0,n} \\ \vdots \\ c_{p,q} \\ \vdots \\ c_{n,0} \end{pmatrix} =$$

$$\begin{pmatrix} \sum_{k+1}^{n_i \cdot n_r} p(i_k, r_k) \\ \vdots \\ \sum_{k+1}^{n_i \cdot n_r} p(i_k, r_k) \frac{1}{r_k^p} i_k^q \\ \vdots \\ \sum_{k+1}^{n_i \cdot n_r} p(i_k, r_k) \frac{1}{r_k^n} i_k^n \end{pmatrix} \qquad (6.10)$$

Whence follows:

$$\begin{pmatrix} c_{0,0} \\ \vdots \\ c_{0,n} \\ \vdots \\ c_{p,q} \\ \vdots \\ c_{n,0} \end{pmatrix} = \begin{pmatrix} \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^0} i_k^0 & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^p} i_k^q & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^n} i_k^n \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^{p_0}} i_k^{q_0} & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^{p+p_0}} i_k^{q+q_0} & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^{n+p_0}} i_k^{n+q_0} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^n} i_k^n & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^{p+n}} i_k^{q+n} & \cdots & \sum_{k=1}^{n_i \cdot n_r} \frac{1}{r_k^{2n}} i_k^{2n} \end{pmatrix}^{-1} \cdot \begin{pmatrix} \sum_{k+1}^{n_i \cdot n_r} p(i_k, r_k) \\ \vdots \\ \sum_{k+1}^{n_i \cdot n_r} p(i_k, r_k) \frac{1}{r_k^p} i_k^q \\ \vdots \\ \sum_{k+1}^{n_i \cdot n_r} p(i_k, r_k) \frac{1}{r_k^n} i_k^n \end{pmatrix} \qquad (6.11)$$

Instead of the probability function of outages (6.1), it is often necessary to have information on the probability of outage if the lightning stroke point is in the interval [r_1,r_2] and current amplitude of lightning is in the interval [i_1,i_2]. The corresponding probability function can be calculated from the calculated associated probability function *p(i,r)*:

$$p\left(x \middle| r_1 \le r \le r_2, i_1 \le i \le i_2\right), \qquad (6.12)$$

Which describes the probability of outage if the lightning stroke point is at a distance $r_1 \le r \le r_2$ and lightning current is $i_1 \le i \le i_2$

The probability function can be calculated as follows [23]:

$$\begin{gathered} p\left(x \middle| r_1 \le r \le r_2, i_1 \le i \le i_2\right) = \\ F(r_2, i_2) - F(r_1, i_2) - F(r_2, i_1) + F(r_1, i_1). \end{gathered} \qquad (6.13)$$

More degrees of freedom, i.e. the more degrees of a polynomial were introduced to achieve a more accurate approximation. The higher degree of polynomial includes all the members of the lower degree. For example, the approximation function will be expressed in the second degree of polynomial.
Figure 6 shows the approximation function expressed by the second degree of polynomial and outage probability (obtained by measuring and correlation) of distribution overhead line depending on the distance of lightning stroke point from axis of line (m) and current amplitude of lightning (kA).
Figure 7 shows the error of approximation of outage probability for the approximation function expressed by the second degree of polynomial function depending on the distance of lightning stroke point from axis of line (m) and current amplitude of lightning (kA).
The approximation of the probability function of distribution line outage expressed as the second degree of polynomial function is:

$$\begin{gathered} \hat{f} = -\frac{5,3053 \cdot 10^3}{r^2} + \frac{0,5029}{r} \cdot i + \frac{146,9158}{r} - \\ 5,6183 \cdot 10^{-5} \cdot i^2 + 0,008 \cdot i - 0,105 \end{gathered} \qquad (6.14)$$

Where:
r - the distance of lightning stroke point from axis of distribution line (m),
i - current amplitude of lightning (kA).

To better quantify the error of the probability function, it is appropriate to use the criterion function RMSE (Root Mean Squared Error) which is the square root of the sum of squares of errors divided by

the number of data, ie. it represents the average error per data element, expressed in units of the original variables.
RMSE, for the second degree of polynomial function is 0.0833.

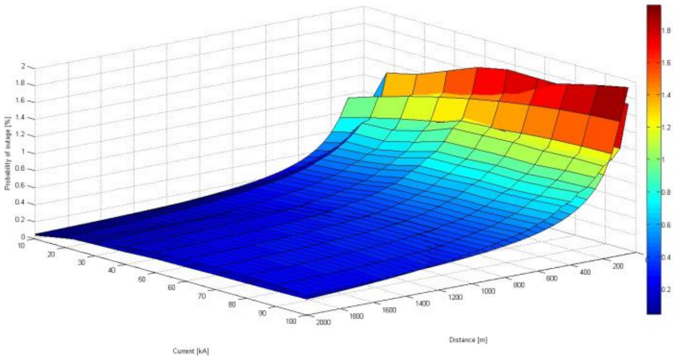

Figure 6. The approximation function expressed by the second degree of polynomial and outage probability (obtained by measuring and correlation) of distribution MV overhead line depending on the distance of lightning stroke point from axis of line (m) and current amplitude of lightning (kA)

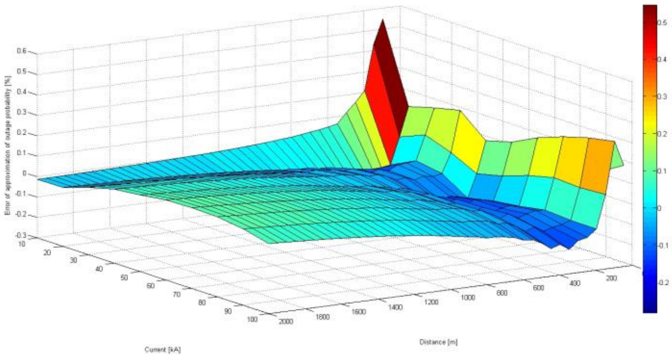

Figure 7. The error of approximation of outage probability for the approximation function expressed by the second degree of polynomial function depending on the distance of lightning stroke point from axis of line (m) and current amplitude of lightning (kA)

It is obvious, from Table 6.1 that the increase of the degree of polynomial increase the accuracy of the approximation function as is evident from reduction of RMSE.

Table 6.1 – Approximation error for the different degree of polynomial

Degree of polynomial	2.	3.	4.	5.
RMSE	0.0833	0.0344	0.0241	0.0192

7 CHECKING THE ACCURACY OF THE PROBABILITY FUNCTION OF LINES OUTAGES CAUSED BY LIGHTNING

In order to check the quality of the obtained probability function, it is necessary to check the function on data that are not used during the teaching. For this purpose, the data for the period from the 3rd of February 2014 (00:00 UTC time) to the 3rd of February 2015 (24:00 UTC time) were used.
Figure 8 shows the approximation function of distribution overhead line outage depending on the distance of lightning stroke point from axis of line (m) and current amplitude of lightning (kA) based on the data collected in the test period and approximation function expressed by the fifth degree of polynomial.
RMSE for the probability function of outage (obtained by measuring and correlating data from LLS and SCADA systems in the period from 3rd February 2014 to 3rd February 2015) and the approximation function expressed by the fifth degree of polynomial is 0.698.

The test results show that the approximation function well describes what happened on the analysed overhead lines. The RMSE factor confirms that the approximation function is well coordinated and properly describes the outages of analysed distribution overhead lines.
The results in figure 8 show that the developed function is applicable for the prediction of distribution overheard line outages caused by lightning strokes. The relatively high amount of RMSE is related to the area of function in very short distance to distribution line, where the approximation function is rapidly growing (Figure 8).

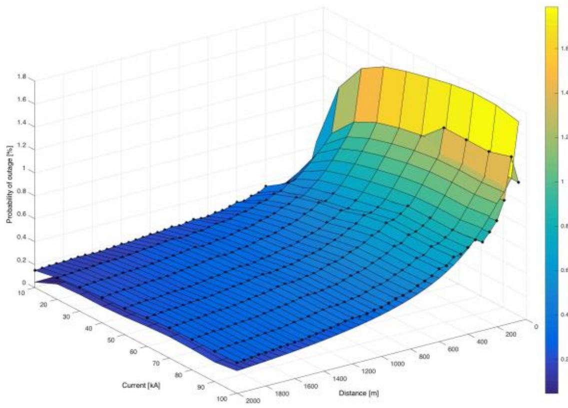

Figure 8. The approximation function expressed by the fifth degree of polynomial and outage probability (obtained by measuring and correlation based on the data collected in the period from the 3rd of February 2014 to the 3rd of February 2015) of distribution overhead line depending on the distance of lightning stroke point from axis of line (m) and current amplitude of lightning (kA) (Outage probability 3D curve is marked by points)

8 CONCLUSION

It is known that lightning strokes are one of the major causes of overhead distribution lines outages, which has a significant impact on the power quality. It is possible to improve the power quality using correlation of lightning stroke data and information about line outages in the distribution power system. Information on stroke location can be used to detect the location of a fault in the distribution line. Knowing the cause of the line outage and its location can shorten the time required for its removal, which results in increasing the reliability of power supply.
The goal of this research was the assessment of an approximation function of line outages caused by lightning in dependence of the lightning stroke to power line distance (meter) and peak lightning current amplitude (kA). This research was conducted using the measured lightning data and distribution network operation data from 2012 to 2015. The validation was conducted using real line outage data in the distribution network obtained through SCADA, correlated with LLS data.
The probability function of distribution line outages caused by lightning, obtained on the basis of statistically determined probability function, includes all impacts on 10 (20) kV line outage because it made the observation causes (lightning strokes) and consequences (failures and outages) regardless of the known and (possible) unknown influences.
The function of the probability of distribution line outages, along with the aforementioned data from the LLS, can greatly serve the distribution system operators as a basis for making decisions about the prioritization of investment in additional overvoltage protection with respect to the expected number of line outage and the cost of these line outages and failures will cause.

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