Application of the Lightning Location System for the selection of Lightning Protection of Overhead Medium Voltage Lines using Long Flashover Arresters

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***Abstract*--This paper will describe the implementation of the lightning strokes data based on the Lightning Location System for the selection of lightning protection of overhead medium voltage distribution lines using Long Flashover Arresters (LFA). The Lightning Location System used in this research will be described. Emphasis will be given to the application of a correlation between failures and outages in the medium voltage distribution network and lightning. The overhead medium voltage distribution lines are analyzed. The analysis and correlation of actual lightning strokes data and outages data in the medium voltage distribution lines, collected in the period from 2009 - 2012, is carried out using the described software application. Spatial analyse is carried out. These results may be used by distribution system operators as a basis for decision making on possible investments in an additional overvoltage protection.**

***Keywords*: overvoltage protection, long flashover arresters, lightning location system, overhead lines.**

I. INTRODUCTION

THE overvoltage protection has significant importance not only to prevent the damage of expensive components and equipment within the power distribution network but also to ensure the power quality.

Incomparably the most dangerous of all the types of overvoltages for power distribution systems are those of atmospheric origin. They belong to the category of external overvoltages and their values are almost independent of the power network operating voltage. Outages of overhead power lines due to lightning strokes are one of the main causes of shortages of electric supplies and economic losses of power utilities.

Lightning affect the reliability of transmission and distribution lines. Due to lightning overvoltages, the most frequent is the flashover of insulation that cannot withstand the strong electric field as a result of these overvoltages. The flashover of insulation can result in a permanent or temporary outage and failure. Such events in the power network are recorded and collected by the SCADA or similar systems for supervisory, control and data acquisition from the medium voltage power network.

Nowadays, modern means for lightning activity tracking are lightning location systems. Such systems have been developed and improved for more than twenty years. In developed countries worldwide, lightning location systems are used in networks and systems deployed in large areas such as power systems, TC networks, broadcasting transmitter networks, networks of oil and gas pipelines, security systems, military installations, meteorological services, transport infrastructure, systems of protection against forest fires and more. For example, in the United States the *National Lightning Detection Network (LDN)* is developing and covers almost the entire geographical area of the United States, and in Europe the EUCLID and LINET systems are developing [1].

Investment costs excludes the possibility that the equipment in the power system is designed to withstand arbitrarily high voltages. It is therefore necessary to select the proper overvoltage protection. Effectively implemented overvoltage protection and insulation coordination are the basic preconditions for high quality of the delivered electricity in all aspects of quality and reliability of supply through the overhead power network.

To avoid typical overvoltages that can occur on MV (medium voltage) distribution lines that are protected only by conventional surge arresters, it is recommended to install long flashover surge arresters which may mitigate some adverse parameters of overvoltage on the line. Long Flashover Arresters (LFAs) were shown [2]-[4] to be effective for lightning overvoltage protection of medium voltage overhead lines, such as those rated to 10 kV. Pole-top metal oxide arresters can protect distribution lines against induced over-voltages, but they can be destroyed in case of direct lightning stroke [5]. Long Flashover Arresters (LFAs) have been developed and used successfully for this purpose and have no possibility of being destroyed because the current flows externally along its surface [6]. Installation of long flashover surge arresters represents higher investment costs compared to conventional solutions of overvoltage protection. It is therefore necessary to conduct a statistical analysis that will help the distribution system operators can prioritize and justify the investment based on the risk of exposure of each MV

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distribution line, all in order to ensure more reliable supply of quality electricity.

For implementation of the correlation, it is necessary to perform the appropriate preparation and collection of data on outages of MV overhead distribution lines (due to the effects caused by direct or indirect lightning strokes in the vicinity of the line) as the input data set for correlation with relevant data from the appropriate lightning location system.

The results of the correlation analysis may be used by distribution system operators as a basis for decision making on possible investments in an additional overvoltage protection.

These statistical analysis will help the distribution system operators to prioritize and justify the investment (additionally protection by LFA) based on the risk of exposure of each MV distribution line.

II. Lightning Location System

The efficiency of lightning location systems is constantly improving so that it is possible to predict lightning in an area with increasing certainty and then determine the location and time of certain lightning strokes. In the period of development of the lightning location systems it has been shown that such systems are as effective as covering a larger geographic area.

It should be noted that, in addition to the sensors installed in B&H (Bosnia and Herzegovina), those in nearby countries (Fig. 1) are also useful for lightning detection and location over the territory of Bosnia and Herzegovina. In late 2008, Croatia joined the LINET network and six sensors are installed in Croatia (Zagreb, Rijeka, Split, Zadar, Dubrovnik, island of Korcula) [7]. Two lightning detection and location sensors are installed in Serbia (Belgrade and Nis).

Fig. 1. LINET network in Bosnia and Herzegovina and surrounding area [7]

III. Correlation between Lightning and Events in Medium Voltage Power System

For the purposes of correlation between lightning and events in medium voltage power system, it is necessary to link the data of the lightning location system to the data on the events in the power network (SCADA) and geospatial data on power facilities. The essential components of the system that will perform the procedure for the above statistical analysis are:

- lightning location system (LLS)
- systems for acquisition of data on events in the MV power system (SCADA) and
- system of geospatial data on MV power facilities (GIS) [8].

The data on an event within the power system collected by the SCADA system contain, among others, information about the exact time of the event and information about the facility in which the incident occurred.

The information about the power system is forwarded to the geographic information system (GIS) that determines the spatial geometry of the observed facility. The lightning location system has, among others, the information about the exact time and exact location of each lightning stroke. Integration of the data from these three systems gives the space-time correlation between the incidents in the power facility and lightning strokes [9].

IV. Relay Protection of Distribution Medium Voltage Lines

The reliable and quality operation of the relay protection, achieved by proper settings of the relay protection devices, improves the operation of the whole power system and therefore the requirements to be met by the protection function of the transmission line are: speed, sensitivity and selectivity.

Relay protection is used to protect the MV distribution lines. The protection relay is connected to the current and voltage instrument transformers of the protected line. The main function of the protective relay is to determine the distance of the short circuit location based on the measured impedance. The measured impedance is proportional to the distance of the short circuit location on the transmission line from the location of installation of instrument transformers.

The selection of parameters of settings of the relay protection devices is determined by the recommendations for calculation and selection by the manufacturer of protective devices and many outside influences considering the device installation location, such as soil type, geometry of the tower elements and configuration of the surrounding network, where the experience in applying relay protection devices is of great importance.

The relay protection system in the remote control and supervisory system is connected to the station computer that unites the functions of data processing and communication with the master remote control center.

The basic data on the failure time for time correlation with the lightning stroke is the data on the failure time from the relay protection device.

In case of failure caused by a lightning stroke, there is excitation of the relay protection devices at the line ends. The excitation comes from the direction of protection in the first protection zone, but it is also visible to the protective relays on adjacent lines in other protection zones (in the direction of protection and in the opposite direction). In case of a lightning stroke to one of the adjacent lines, failures in the adjacent lines are detected by the relay protection device on one side of the observed transmission line in the direction of the line protection and by the relay device on the other side of the observed line in the opposite direction of the line protection and there is an unilateral activation of the relay protection or unilateral auto-reclosing. Failures are eliminated by activation of the line relay protection devices which detected them in the first zone in the direction of the line protection. If the protection does not activate in the first protection zone, the failure is eliminated selectively towards higher protection zones until the problem is resolved. As the station computer event lists contain exact data on the time of excitation of the relay protection devices on the line on which the failure occurs, such events are suitable for correlation of activation of the relay protection devices and a lightning stroke [10].

V. Real Data Correlation and Analysis

As a case study we have selected 11 medium voltage overhead distribution lines passing through the typical terrain configuration, with peculiarities of the soil resistance. The results of the correlation analysis will be later used as an input for the statistical evaluation of the expectation of the outages of medium voltage overhead distribution lines due to lightning discharges. These results may be used by distribution system operators as a basis for decision making on possible investments in an additional overvoltage protection. In the considered case study the problem was to select two lines out of analysed 11 ones to be additionally protected in order to minimize the risk of the outage.

For implementation of the empirical part of the research, there were performed a proper preparation and collection of data on outages of medium voltage overhead distribution lines (as a result of atmospheric overvoltages caused by direct or induced overvoltages caused by the so-called indirect lightning strokes in the vicinity of the line) as input data set for correlation with relevant data from the appropriate lightning location system.

For a discussion of correlation and analysis of the actual data on the 10 (20) kV medium voltage distribution lines, data were taken from the relay protection of the 110/35/10(20) kV transformers which supply the analyzed overhead lines.

An important function of the lightning location system is creation of lightning density maps for the areas of distribution facilities. These data are useful to engineers when selecting ways to protect lines (line surge arresters) and facilities from lightning (lightning protection system of transformers). LINET records each lightning as a separate data set. For this reason, certain areas on the map have a very high lightning density. In the construction of new facilities and selection of line routes we can accept the risk of outage of the future line due to lightning activity.

The lightning density for the line route is determined by the following formula:

$$N_g = \frac{n}{A \cdot t} \quad \left[lightning\ strokes / km^2 / year \right] \tag{1}$$

where n is the number of lightning strokes to the route, A is the route area and t is the detection period.

The observed lines are in the area of increased lightning activity where isokeraunic values reach values up to 45 thunderstorm days per year. Fig. 2 shows the density of cloud-to-ground discharges for the area of the analyzed MV overhead lines in the period 2009-2012.

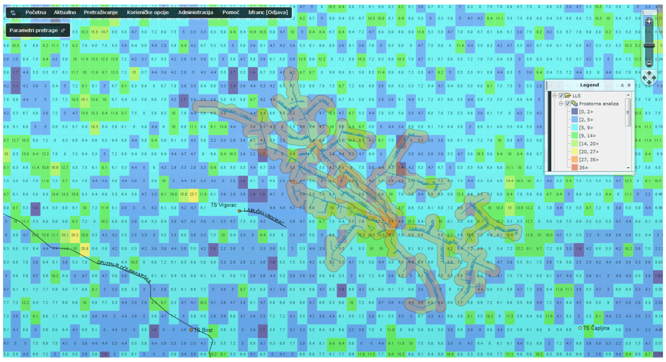

Fig. 2. Cloud-to-ground lightning density in the period 2009-2012 for the area of the analyzed MV overhead lines

The length of the analyzed MV lines are shown in Fig. 3, while the areas of alarm zones for 500 meters radius from the line route are shown in Fig. 4.

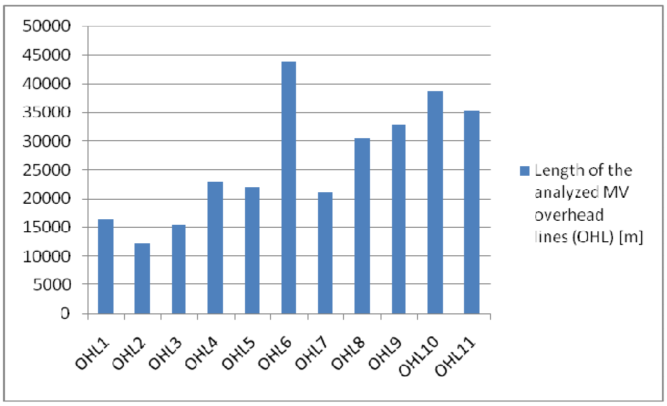

Fig. 3. Length of the analyzed MV lines

Fig. 5 shows the number of lightning strokes by quarterly periods and Fig. 6 shows the total number of lightning strokes to the alarm zone of MV lines that are the subject of correlation, all in the interval of the performed correlation for the period from January 1, 2009 to December 31, 2012 (48 months).

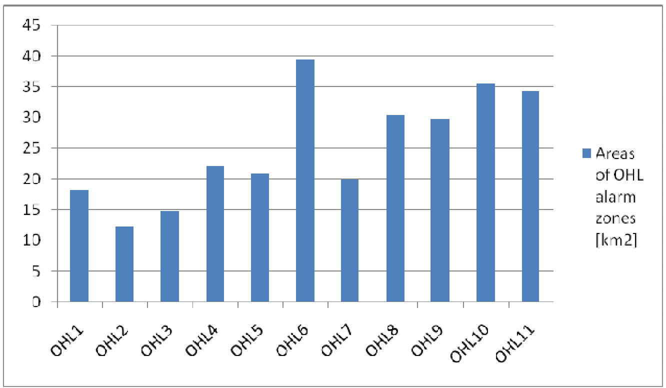

Fig. 4. Areas of alarm zones for 500 meters radius from the line route

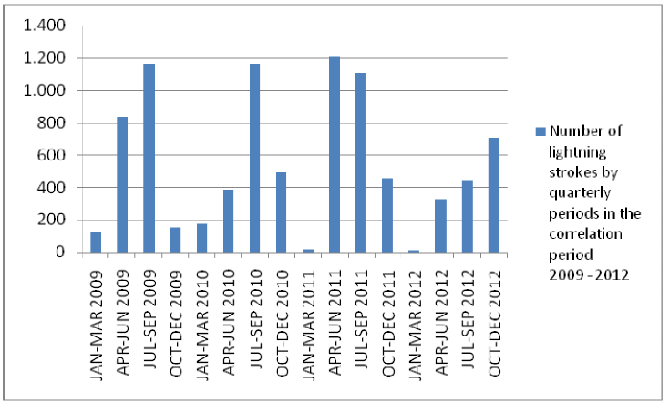

Fig. 5. Number of lightning strokes by quarterly periods

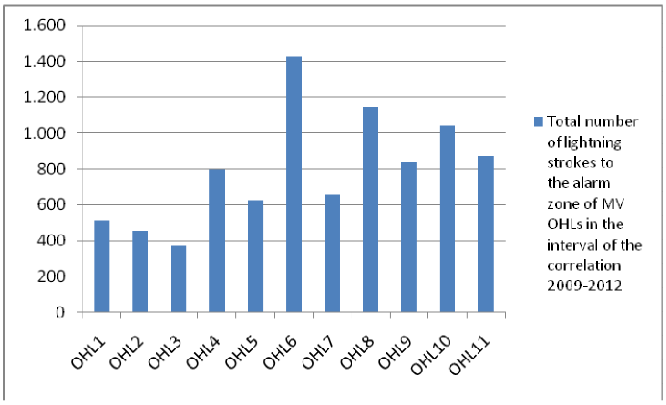

Fig. 6. Total number of lightning strokes to the alarm zone of MV lines

Fig. 7 shows the number of lightning discharges by lines, for each observed line by type ('CG' - cloud-to-ground, " CC " - cloud-cloud) and by lightning polarity (“neg”- negative, “pos” - positive) in the interval of correlation from January 1, 2009 to December 31, 2012.

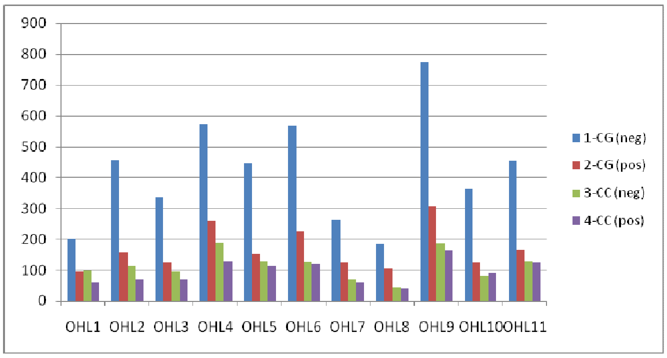

Fig. 7. The number of lightning strokes by overhead line, by type of stroke and by lightning polarity

The data of failures on lines from the station computer and dispatching reports were analyzed [11]. The data contain information about auto-reclosing failures and failures which are assumed to be caused by lightning strokes for the period from January 1, 2009 to December 31, 2012 (48 months). Fig. 8 shows the total number of outages in the period 2009-2012, and Fig. 9 shows the total number of outages by individual observed MV line in each analyzed year (2009-2012).

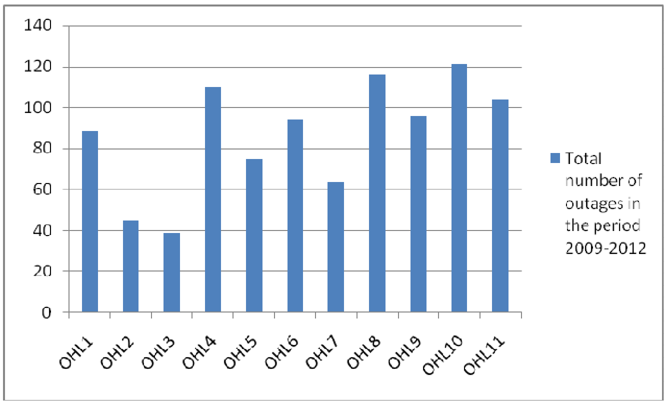

Fig. 8. Total number of outages in the period 2009-2012

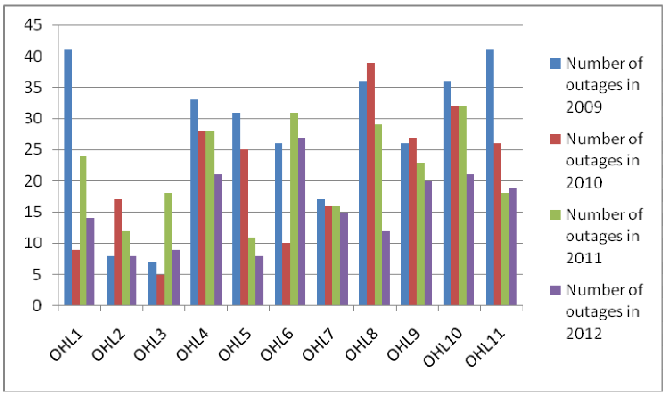

Fig. 9. Total number of outages by line in each analyzed year

From the available data we can get the number of lightning strokes to the alarm zone by a standard line length (100 km) as shown in Fig. 10.

With the available data, we can also get the number of outages by a standard line length (100 km) as shown in Fig. 11.

Fig. 12 shows a comparison between the number of outages per 100 km length of the line by year average for the correlation period 2009 - 2012 and the number of lightning strokes to the alarm zone per 100 km length of the line by year average for the correlation period 2009 - 2012.

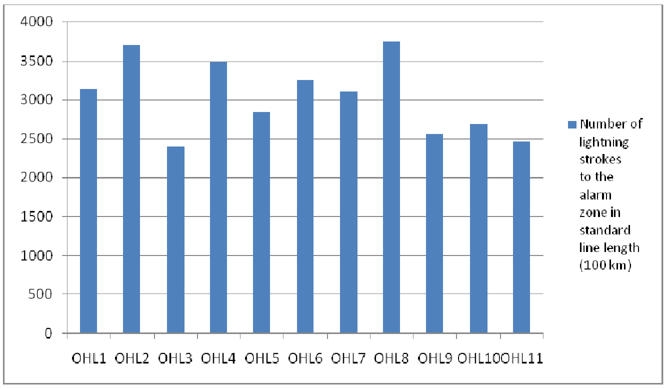

Fig. 10. Number of lightning strokes to the alarm zone in standard line length (100 km)

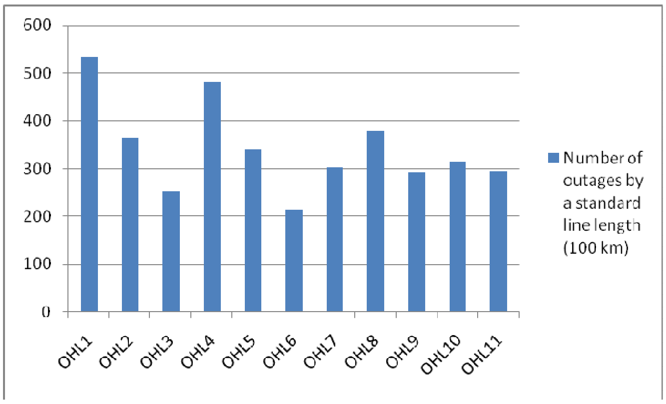

Fig. 11. Number of outages by a standard line length (100 km) in the period 2009-2012

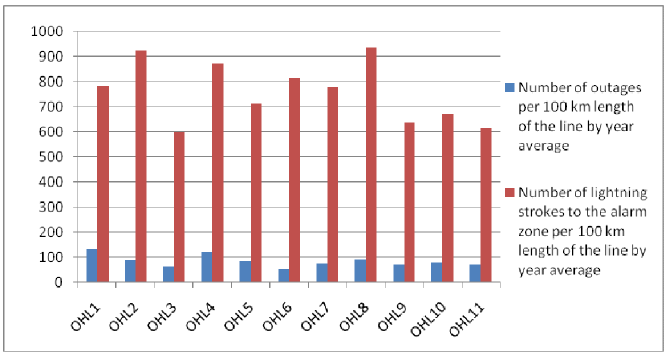

Fig. 12. Comparison between number of outages and number of lightning strokes to the alarm zone

The value of the MV line exposure risk represents the quotient of the number of outages per 100 km length of the line and the number of lightning strokes to the alarm zone per 100 km length of the line in a certain period.

Fig. 13 shows the risks of exposure of the analyzed MV lines per year average for the correlation period 2009 - 2012.

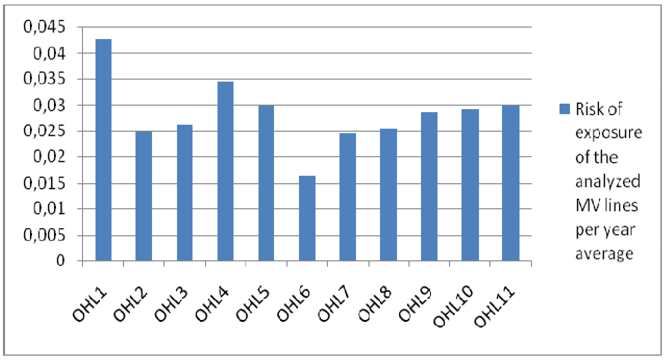

Fig. 13. Risk of exposure of the analyzed MV lines

VI. Lightning Protection of Overhead Medium Voltage Lines using Long Flashover Arresters

In order to make a fair comparison of the risk of exposure of the analysed MV distribution lines we have normalized them to the same line length of 100 km. Such the normalised values of the risks can be directly used as indicators for selecting the lines to be additionally protected. In the considered case study, based on the results shown in Fig. 13, it is apparent that the overhead lines OHL1 and OHL4 to should be additionally protected by LFA.

A. Long Flashover Arresters (LFA)

Widely separated pole-top metal oxide arresters can protect a distribution line against induced overvoltages. The main problem of using pole-top metal-oxide arresters is that they can be destroyed at direct lightning stroke to an overhead line [5]. In some countries, for lightning overvoltage and conductor-burn protection of 10 kV overhead lines, Long Flashover Arresters (LFAs) have been used for more than three years [3], [12]. The operating principle is based on extension of the impulse flashover channel on the arrester surface through the creeping discharge effect. Owing to a long flashover length, the power arc gets extinguished. The main advantage of LFA is that current passes outside the apparatus, flowing along arrester surface. Therefore, the arrester cannot be destroyed by excessive current, even at direct lightning stroke. LFA's construction is rather simple and reliable.

There are several types of LFA under development. LFA of Loop type (LFA-L) is intended for protection of overhead lines against induced overvoltages. Principle of operation and its design are detailed in [5]. LFA-Ls are recommended to be installed one arrester per pole with phase interlacing [13]. LFA of Module type (LFA-M) can protect overhead lines against induced overvoltages and direct lightning strokes as well. In latter case it should be installed in parallel to each insulator at a pole [12].

B. Protection against Induced Overvoltages

To eliminate high short circuit currents associated with two- or three-phase lightning flashovers to ground, LFALs are recommended to be installed one arrester per pole with phase interlacing (Fig. 14).

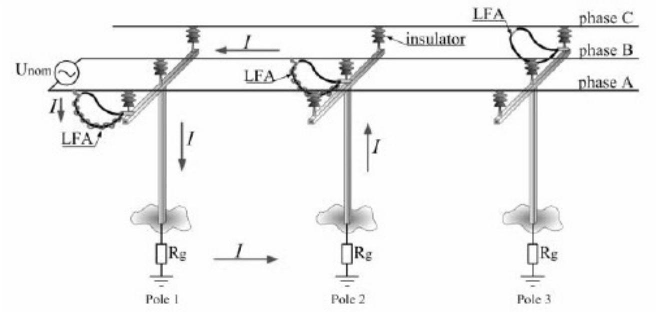

Fig. 14. Schematic of LFA-L installation on a Overhead Distribution Line [6]

With such an arrangement, a flashover to ground results in a circuit comprising two phases, two arresters and two grounding resistors that limit the fault current and ease arc quenching. The higher are the values of the grounding resistance, the more effective is LFA-L operation.

C. Protection against Direct Lightning Strokes

A direct lightning stroke causes flashover of all the insulators on the affected pole. Therefore, in order to protect the line against a direct lightning stroke, LFA-Ms should be mounted on the pole in parallel with each line insulator (Fig. 15). Phase-to-phase faults on a pole can give rise to follow-up current on the order of 10 kA or more. In order to quench such currents, flashover length of the LFA-M 13.8 kV should be 1.7 m, i.e. much higher than that of LFA-L (0.9 m) which intended to protect overhead lines against induced overvoltages.

Fig. 15. Protection of 13.8 kV overhead lines against direct lightning strokes by LFA-M arresters [6]

VII. CONCLUSIONS

The lightning stroke microlocation determined by the LLS could be used as information about the fault location on the MV overhead line, especially in cases where the function of fault location in the relay protection system is not available.

It is known that lightning strokes are the biggest cause of failures on overhead lines which has a significant impact on reliability of quality electricity supply. Outages of overhead power lines due to lightning strokes are one of the main causes of shortages of electric supplies and economic losses of power utilities. By correlating the data on lightning discharges with information about events in the power system it is possible to influence the improvement of reliability of electricity supply and increasing the electricity quality.

By statistical and spatial processing of the data on lightning discharges, it is possible to identify parts of the network with an increased risk of lightning strokes and determine the probability of certain lightning strokes, which can greatly help in selection of the MV overhead line routes and ways to protect them from lightning strokes.

Effectively implemented overvoltage protection and insulation coordination are the basic preconditions for high quality of the delivered electricity in all aspects of quality and reliability of supply through the overhead power network.

To avoid typical overvoltages that can occur on MV distribution lines that are protected only by conventional surge arresters, it is recommended to install long flashover surge arresters which may mitigate some adverse parameters of overvoltage on the line. Pole-top metal oxide arresters can protect distribution lines against induced over-voltages, but they can be destroyed in case of direct lightning stroke. Long Flashover Arresters (LFAs) have been developed and used successfully for this purpose and have no possibility of being destroyed because the current flows externally along its surface.

Installation of long flashover surge arresters represents higher investment costs compared to conventional solutions of overvoltage protection.

The results of the correlation analysis is used as an input for the statistical evaluation of the expectation of the outages of medium voltage overhead distribution lines due to lightning discharges. These results may be used by distribution system operators as a basis for decision making on possible investments in an additional overvoltage protection. It is therefore necessary to conduct a statistical analysis that will help the distribution system operators can prioritize and justify the investment based on the risk of exposure of each MV distribution line, all in order to ensure more reliable supply of quality electricity.

VIII. ACKNOWLEDGMENT

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IX. REFERENCES

[1] I. Uglešić, V. Milardić, M. Mandić, B. Filipović-Grčić, *Monitoring of atmospheric lightning for the purposes of power system management*, study, Zagreb, September 2007

[2] G. V. Podporkin, A. D. Sivaev, V. E. Pilshikov, *Application of long flashover arresters for lightning protection of overhead distribution lines*, in *Proc. 24th Int. Conf. Lightning Protection*, Birmingham, U.K., Sept. 14–18, 1998, pp. 605–610

[3] G. V. Podporkin, A. D. Sivaev, *Lightning Protection of Overhead Distribution Lines by Long Flashover Arresters*, IEEE Transactions on Power Delivery, vol. 13, n. 3, pp. 814-823, July 1998

[4] G. V. Podporkin, V. E. Pilshikov, A. D. Sivaev, "Application of long flashover arresters for improvement of lightning protection and operating voltage reliability of distribution lines", in *Proc. Elect. Dist. 15th Int. Conf.*, Nice, France, June 1–4, 1998, Rep. 1p-9

[5] IEEE Guide for Improving the Lightning Performance of Electric Power Overhead Distribution Lines, IEEE Std 1410TM- 2004

[6] O. O. Filho, D. Ramalho de Mello, G. S. Gomes de Oliveira, G. V. Podporkin, A. Wey, *Testing of Long Flashover Arresters designed for distribution lines*, IX International Symposium on Lighting Protection, Foz do Iguaçu, Brazil, 26th - 30th November, 2007

[7] B. Franc, M.Šturlan, I. Uglešić, Z. Hebel, *Application of Lightning Location System for power system management*, 10th HRO CIGRÉ Session, Cavtat, Croatia, November 6-10 2011

[8] B. Franc, *Application of Lightning Location System for power system management*, University of Zagreb, Faculty of electrical engineering and computing, 2012

[9] I. Uglešić, V. Milardić, B. Franc, B. Filipović-Grčić, J. Horvat, *Establishment of a new lightning location system in Croatia*, CIGRE C4 Colloquium on Lightning and Power System, Kuala Lumpur, Malaysia, May 16-19 2010

[10]S. Piliškić, B. Franc, *Analysis of the lightning impact to outages of transmission lines by comparing Lightning Location System and data from relay protection*, 10th HRO CIGRE Symposium on Power System Management, Opatija, Croatia, November 11-14, 2012

[11] EPHZHB d.d. Mostar, Power Distribution Division, Distribution Area South, *Dispatch reports on medium voltage overhead lines (MV OHL) outages in the DA South*, Mostar, January 2009 - December 2012

[12] G. V. Podporkin, V.E. Pilshikov, A. D. Sivaev, *Lightning Protection of Medium Voltage Overhead Lines by Modular Long-Flashover Arresters*, IEEE Transactions on Power Delivery, vol. 18, n. 3, pp.781-787, July 2003

[13] G. V. Podporkin, A. D. Sivaev and V. E. Pilshikov, *Application of Long Flashover Arresters for Lightning Protection of Overhead Distribution Lines*, Proceedings of 24th International Conference on Lightning Protection