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Application of lightning location systems for fault detection on transmission and distribution lines

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Abstract - **The lightning location systems were installed in many countries during last twenty years. The paper presents the SAFIR system called PERUN, which was built in Poland in 2002. The lightning location systems are used for different purposes including among other things meteorology, weather forecasting and aviation. A brief review of fault detection on transmission and distribution lines made abroad and the first experience of the Polish National Grid PSE was shown.**

Keywords: **lightning, overvoltage, SAFIR system, lightning caused outage**

1. INTRODUCTION

The adverse weather conditions and especially storms decrease considerably the reliability of electrical power system. Therefore long years ago the power utilities started to use the meteorological information to improve the power delivery. The storm warning information from meteorology stations, airports and electrical substations were applied in 1920s [1]. The meteorology uses today many technical achievements like: Doppler radars, automatic measurement net, lightning location systems and professional computer software. The special offer give the short-term prognoses. The so-called now-casting helps in deciding process of power system staff [2].

The storm activity was noted at meteorology stations based on visual and acoustic phenomena. The number of storm days (keraunic level) was a classical parameter. The mean distance between meteorology stations in Poland is 70 km but the storm cloud dimensions are in the range of 10 km. Therefore, the station staff did not detect many storms. There were some trials with radio-pelengators carried out in 1980s.

Lightning is responsible for many outages of distribution and transmission lines. The high voltage lines (110, 220 and 400 kV) in Poland are protected by ground wires, the ground resistance of the pole should be smaller than 10 Ω. Additionally, these lines have the efficiently grounded neutral point. There are also high voltage lines without ground wire on the world, usually these lines have the wood poles [3]. Sometimes there are even such 230 kV or 500 kV lines with metal poles [4]. The lightning fault indicator for overhead power lines amounted 1,0 per 100 km/year for 110 kV lines, 0,6 for 220 kV lines and 0,1 for 400 kV lines in Poland in 1980s. The lightning is responsible for about 50% of line faults in Japan [5]. In other countries this factor is usually lower, e.g. 29% in South Africa [6]. It is interesting to note that in this country even 38% of line fault causes are unknown.

The static wave method of earthig location in overhead lines were applied after the Second World War. These methods use the wave propagation along the cable line without the operating voltage. The measurement of wave propagation time to the fault place and its comeback allow the calculation of fault place. The static methods were widely used for insulated cables. The dynamic methods can locate the fault during transient time between the fault while and the voltage switching-off time.

2. LIGHTNING LOCATION SYSTEMS

The lightning discharge produces the electromagnetic wave with a broad frequency band (fig. 1).

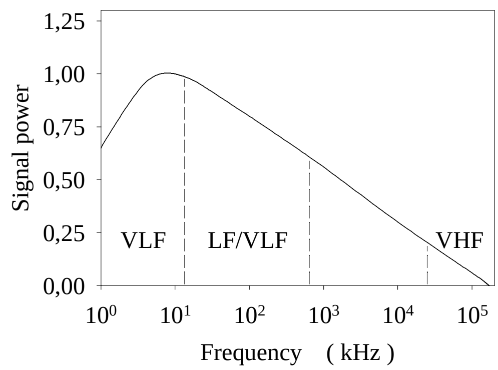

Fig. 1. The spectrum of waves caused by lightning [7].

The wave emitted by cloud to earth lightning have the greater energy at the very low frequency (VLF) and low frequency (LF) bands. Uman and other proposed the emission and propagation models of electromagnetic waves generated by return discharges. It is assumed that at the beginning of return discharge (before the current reaches its maximum value), the electromagnetic field can be described by the so-called long transmission line model [8],

$$E(t) = -\frac{\mu_0 \cdot v \cdot I(t - D/c)}{2\pi \cdot D} \qquad (1)$$

where:

E – the vertical component of electromagnetic field at ground level (which have infinitive low resistivity) in time t

μ_0 – vacuum magnetic permitivity

ν - propagation speed of return discharge near to ground

I - current at the bottom of lightning channel

D - the distance from the lightning channel

The measured electrical field E at the distance D allow to calculate current I from equation (1). The typical lightning generate the field of 5 – 10 V_{peak}/m with the return discharge speed of 1,5 $\cdot 10^8$ m/s. Using these values the simple calculation gives the current amplitude of 27 kA [9].

The lightning counters, the primitive radio receivers were built at the beginning of XX century [10]. Today, few methods can be applied for detecting the lightning discharges. Different physical values can be measured: (1) electric field amplitude, (2) magnetic field direction, (3) electromagnetic wave time of arrival, (4) radar wave, (5) light direction, (6) acoustic wave of arrival [11]. The best accuracy has the system consisting of at least few antennas located at different places of a controlled area. The National Lightning Detection Network NLDN enveloping the whole territory of USA belongs to the largest lightning location systems [9]. In Europe some national systems were also connected to the greater networks. One example is the EUCLID system consisted of Austrian ALDIS, the French MTEORAGE and the German BLIDS.

The modern lightning location systems register the wide band of electromagnetic field from VLF up to UHF and VHF. The changes of electromagnetic field are measured and different detection methods are applied as MDF (Magnetic Direction Finder) or TOA (Time of Arrival) [9]. The interferometric method, based on phase shift signal measurement is used at VHF band (about 110 MHz). The SAFIR system of Vaisala-Dimensions Company working on this method was installed in Poland in 2001. The systems using VHF band can traced the lightning not only in two dimensions but also in three dimensions. Because the VHF signal propagate in the space along the lines, therefore these systems can have a very high accuracy in the range of 100 – 200 m [12]. The system consists of 8 antennas installed in Warsaw, Włodawa, Sandomierz, Częstochowa, Kalisz, Gorzów Wielkopolski, Toruń and Olsztyn. The antenna of SAFIR system called PERUN is shown in the fig. 2.

Fig. 2. Antenna of the PERUN system

3. APPLICATION OF LIGHTNING LOCATION SYSTEMS (LLS) FOR FAULTS DETECTION ON OVERHEAD LINE

LLS are used by military and civil aviation, meteorology, forestry, industry and assurance agencies [13]. The tracing possibility of electrical phenomena inside of clouds allows predicting the intensive rain precipitations or hurricanes. The LLS together with weather radars allow forecasting of very dangerous situations like heavy rains in Klodzko Valley in July 1998. The Tampa Electric Company has used LLS for fault location on transmission line for the first time in 1979 [9]. Due to the positive experience of this trial the Electric Power Research Institute (EPRI) supported the building of National Lightning Detection Network (NLDN) in USA. The application of LLS gives following advantages for the power utilities:

fault detection on lines in the whole country using the network consisted of few antennas. The fault location systems e.g. LAS-2 can locate the earthing place on these lines where that systems were installed. Hundreds of systems had to be installed to control all 110 – 400kV lines in Poland.

The fault location time is shorter due to limitation of line inspection distance to about 1 km. The fault repair time and time without the operating voltage can be shorter.

The repair group working on the lines can be warned about the coming storms. The people security will be increased.

Control of lightning caused outages and detection of lines or their fragments that have especially high lightning outage rate. Based on this study the lightning protection of weakest lines or their fragments can be upgraded [14].

The access to LLS data, especially to lightning density and lightning current parameters for the given region and time period.

The detailed analyses of given lightning strokes (the distance from the line, current amplitude, occurrence time) and their comparison with the breakers operation time can divide the faults caused by lightning and faults caused by other reasons. The results of this analysis depends on the lightning location and lightning current parameter accuracy. Cummnis K.L, Krider E.P and Malone M.D. have described widely the application of lightning data by electric power utilities and have discussed the lightning location errors [9]. The so-called confidence regions have an elliptical shape and the location accuracy can be characterized by giving the length of the semi-major and semi-minor axes and the orientation of the error ellipse (fig. 3). The location accuracy are in the range of 500–1000 m and can be enhanced to 200 m after corrections taking the ground configuration and resistivity into account [9]. Flash timing to about a second is normally required to correlate a specific cloud-ground flash with a power outage or interruption. The LLS stroke times are now accurate to a few microseconds due to the use of GPS. The detection efficiency of the LLS depends on the number of antennas and the lightning distance from the nearest antennas. The distant antennas can not record the weak lightning with the current lower than 5 kA. The detection efficiency of SAFIR system installed in Poland shall be higher than 95%.

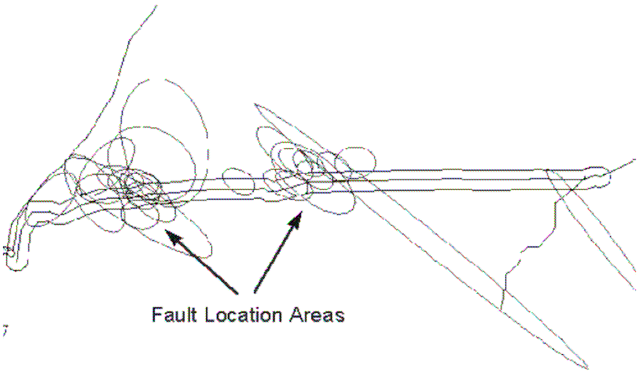

Fig. 3. The location of return strokes and the associated confidence regions that were time correlated with faults on a 115 kV line [9]

The error of current amplitude estimation can amount 20-30% and depends on the wave propagation over grounds with different propagation losses. The calibration carried out in Austria has shown that the current amplitude estimated by LLS differs 10% from the real current [16]. The positive lightning charge is proportional to the current amplitude. This relation does not exist for the negative polarity lightning because of different number of strokes in negative flashes. The newest LLS can estimate the stroke number in multiple flashes and their polarity. Unfortunately, the LLS are not able to measure so important parameters like the current increase rate or the DC component amplitude.

3. EXAMPLES OF LLS APPLICATIONS BY POWER UTILITIES

Diendorfer compared the faults on high voltage lines in Austria for which the reasons were unknown or which could be caused by lightning with the lightning events registered by ALDIS lightning location system [15]. The analysis was done for the years 1996-1999. It was assumed that the disturbance could be caused by lightning strokes placed not further to the line than 5 km and which occurred no earlier or later than 5 s than the fault. Between 100 correlated events "line fault – lightning stroke", 90 flashes occurred in the time window ± 1 second (0 means the fault time).

Lightning caused fault rate of 110 – 500 kV lines (defined as the number of lightning caused faults per 100 km per year) were calculated in South China [17]. The width of the narrow band along a transmission line is set to 12 km for the calculation of ground flash density. The correlation coefficient between lightning caused line fault rate N and ground flash density N_g was relatively low. It was determined as 0,64 for 110 kV lines and only 0,44 for 220 kV lines. For the same N_g = 10 the lightning caused fault rate for different lines can be found between 2 and 40. The relationship between lightning days T_d and ground flash density N_d was found as similar to other regions.

$$N_g = 0{,}0054 \cdot T_d^{1,5} \qquad (2)$$

Transmission system faults do not generally cause direct customer outages due to redundancy in the design of these systems. However, as faults on distribution systems occur, an outage to portion of the distribution network will cause outages of service to customers that are downstream on the feeder from this point of failure. These outages require the immediate dispatch of a repair crew to first locate the source of the outage and then to repair and restore service to customers. The paper [18] documents a study undertaken to monitor the faults on rural distribution lines in Minnesota using the LLS. The results of this study have shown that available lightning data combined with readily available disturbance monitoring could pinpoint the location of disturbances due to lightning within of a few spans on a distribution line.

The quick repair of lightning caused disturbances depends on the time needed for the correlation of LLS data with the line protection data. A server-client software written in JAVA programming language to automatically correlate power line outages and lightning location information was built in Slovenia [19]. One of the most important features of this program is a nearly real-time operation. It can be downloaded from the www server.

The LLS can be used not only for fault locations. The failure analysis of 400 kV capacitive voltage transformers was carried out in Venezuela [20]. The calculated over-voltages due to direct strokes or due to strokes close to line were lower than the basic impulse level of the equipment. The input data for the EMTP over-voltage calculation were delivered by LLS. The measurements of lightning induced voltages in a low-voltage system in Norway were compared with the calculations based on LLS data [21]. It was shown that the induced voltages strongly depend on the ground resistivity. A reasonable agreement between measurements and calculations was found for the ground resistivity of 1000 Ωm.

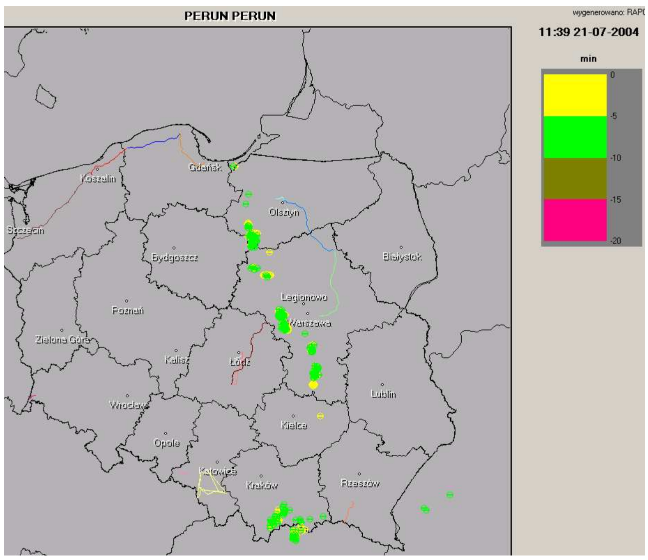

Fig. 4. The storm situation over t Poland from 21.07.2004

The Polish National Grid (PSE) receives data each 10 minutes about the storm situation in the country from the Institute of Meteorology and Water Management (fig.4, 5). The map consists of transmission grid fragments and allow to evaluate the stroke distances from the lines. The 5 minutes time window is of course to wide therefore, PSE company plans to build a professional program for better fault location.

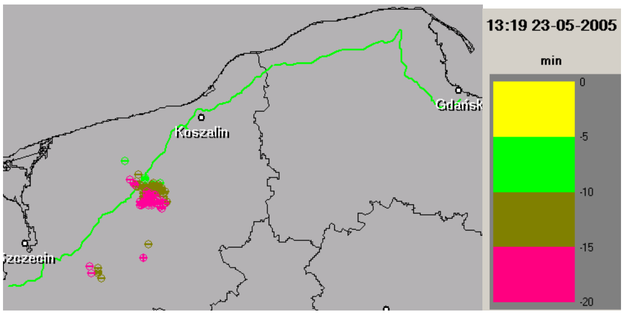

Fig. 5. The lightning close to 400 kV line in the Northern Poland on Mai 23, 2005

CONCLUSIONS

The lightning location systems (LLS) are used by power utilities for about 25 years. The modern LLS can operate in real-time mode and locate the faults on transmission or distribution lines within a few hundreds of meters.

The data delivered by LLS can also be used for different purposes e.g. they can be applied for the EMTP calculations of lightning caused voltages.

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