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Method of Lightning Warning Based on Atmospheric Electric Field and Lightning Location Data

Hantao Tao, Shanqiang Gu, Haitao Wang, Wanxing Feng, Juntian Guo, Yu Wang, Lei Zhang
Wuhan NARI Co., Ltd., State Grid Electric Power Research Institute
Wuhan, China
taohantao@sgepri.sgcc.com.cn

***Abstract*—In view of the shortcomings of traditional lightning protection measures in the initiative defense, it is necessary to research lightning warning technology, which can provide decision support for avoiding the lightning strike risks of infrastructures. This paper adopted atmospheric electric field and time-differencial calculation, combined with prediction of lightning moving trend based on Lightning Location System, achieved the technology of small-scale and short-time lightning warning for targeted areas. Finally, its effectiveness and practicality are verified by applying this method to transmission line in power grid.**

Keywords-initiative defense; lightning warning; electric field; time-differencial; moving trend prediction; Lightning Location System

I. INTRODUCTION

Lightning is a transient discharge phenomenon which occurs frequently in nature, the discharge process accompanied by strong electric field, magnetic field, current, light, and electromagnetic radiation, etc, seriously affects the safe and stable operation of electric power, oil, transportation and communication infrastructure industry. Meanwhile, lightning release enormous energy in a very short time, it also becomes a long-term threat to the safety of people's daily life.

In view of the urgent need to solve the problem of lightning protection, series of equipment like lightning rod, lightning arrester and lightning monitoring network has been developed in many countries, which effectively improves the level of lightning protection around the world[1]. However, all of these measures belong to "passive lightning protection", it is still lack of initiative methods. One of the keys to solve the "initiative lightning protection" is to study lightning warning technology, providing accurate and timely lightning warning information for protected facilities before the arrival of thunderstorm, then avoid or reduce the losses due to lightning[2-4].

The lightning warning method which is widely used in the present study is to use the atmospheric electric field instrument to carry on the lightning warning. In general, the electric field value will obvious random changes half an hour before the thunderstorm. The electric field intensity monitoring of the surface of the earth can directly reflect the condition of charge accumulation in the cloud, it can realize the lightning warning by setting the threshold value of the electric field intensity[5]. But, only the curve of electric field can be obtained by a single atmospheric electric field instrument, still unable to know the location of the thunderstorm and moving trend, and also don't know the electric field intensity which will continue to increase or stable at next time, so the effect of lightning warning only by electric field has a certain limitation.

Lightning Location System (LLS) can real-time monitor the location of lightning[6], it can significantly reduce the rate of false-alarm of lightning warning by combining this factor with electric field intensity. Meanwhile, on the basis of the electric field intensity and time-differencial threshold calculation, it can effectively reduce the rate of non-alarm. This paper researched the small-scale and short-time lightning warning method based on atmospheric electric field and trend prediction of LLS, finally verified the effectiveness and practicality of this method by applying to transmission line in China power grid.

II. WARNING OF ATMOSPHERIC ELECTRIC FIELD

A. Atmospheric Electric Field Threshold

lightning discharge phenomenon indicate of thunderstorm is about to happen, this weak discharge can be monitored by atmospheric electric field instrument. The main discharge process of cloud is about 15 ~ 30 minutes later than weak lightning discharge from historical meteorological data[7]. When the weak discharge of thunderclouds were detected by atmospheric electric field instrument, it can be learned that lightning will happen[8-9].

Atmospheric electric field instrument is a field mill which can measure continuous variation of atmospheric electric field at ground surface. The main technical parameters of electric field instrument are shown in Table 1.

Table 1 Technical parameters of electric field instrument

Parameter	Performance index
Range of electric field value	0~±100kV/m
Detection radius	I5km-30km
Measurement error	<±5%
Communication mode	GPRS/3G/4G
Baud rate	7200bps
Average power	3W
Environment temperature	-40'C-+8S'C
Installation distance from target	<15km
Spacing between instruments	>30km

Since the occurrence of lightning is always related to the atmospheric electric field, it can set different electric field intensity threshold to realizing lightning warning in advance by analysis the characteristic of the change of the electric field curve. The process of thunderstorm which preliminary produce, development and happen will take about 30 minutes normally, therefore, set 4th level threshold for lightning warning. The electric field value of 30 minutes before the thunderstorm happen is level 1, and 15 minutes before the thunderstorm happen is level 2, 5 minutes before the thunderstorm happen is level 3, the occurrence time of thunderstorm happen is level 4. Corresponding to the specific description of the 4-grades lightning warning as follows:

(1) Level-1: The threshold of electric field intensity is 1.5 kV/m, which performed electric field appears jitter, remind the cloud is charged, it should pay close attention to the change of electric field.

(2) Level-2: The threshold of electric field intensity is 3.0 kV/m, which performed thunderstorms are close to the field instrument or thunderstorms in the local formation.

(3) Level-3: The threshold of electric field intensity is 5.0 kV/m, which performed thunderstorm is approaching, it has lightning occurred near the electric field instrument, or the center of the thunderstorm has moved closer.

(4) Level-4: The threshold of electric field intensity is 8.0 kV/m, which performed thunderstorm has occurred, indicates that the monitoring regions will appear high probability of lightning strike.

The above threshold can satisfy the reference value in most environments. Since the atmospheric electric field value is the relationship between environmental, altitude of the installation location and geographical differences, the practical application of threshold can be appropriately adjusted according to the operation condition of the atmospheric electric field instrument, in order to improve the accuracy of lightning alarm.

B. Time-Differencial of Electric Field

The thunderstorm cloud electrification is very rapidly when condition is ripe, and the amount of charge is changing quickly. If lightning causes a sudden change in the electric field, the slope of the electric field is relatively steep. This situation on the ground is performed as a pulsed type changes, and the ground atmospheric electric field grows exponentially in the process of thunderstorm electrification. The intensity of cloud-to-ground lightning can not be determined only by its peak value, but should be determined by the change of electric field. The variation rate of the atmospheric electric field is used to distinguish the characteristics of the electric field, and the variation of the electric field value can be calculated by the time-differencial of the electric field. The atmospheric electric field instrument is used to measure the intensity of the electric field frequency of once per second. The obtained numerical value is a discrete quantity. The expression of the first-order difference between the atmospheric electric field and the time can be expressed by the following formula:

$$E(t)' = \frac{E(t_1)-E(t_0)}{t_1-t_0} \tag{1}$$

In formula (1), t_1 and t_0 are any adjacent time respectively, interval time for electric field instrument sampling is 1s, $E(t_1)$ and $E(t_0)$ are corresponding to the electric field value, $E(t)'$ is the corresponding time-differencial value.

In order to achieve lightning warning ahead of half an hour, select the change rate of electric field before thunderstorm 5 minutes, 15 minutes, 30 minutes and the occurrence time to analysis, find that the corresponding atmospheric electric field time-differencial value mainly concentrated in the 0.5 kV/(m•s), 1.5 kV/(m•s), 2.0 kV/(m•s) and 3.0 kV/(m•s) four point range. So, the above 4 thresholds can be set to the warning level of the time- differencial of the atmospheric electric field.

When monitoring the rapid change of atmospheric electric field before the occurrence of lightning, the contact of lightning activity and electric field intensity over time rate of change is more closely related than the contact of lightning activity and electric field value, so adopts atmospheric electric field time-differencial calculation instead of only by electric field can significantly reduce the rate of non-alarm.

III. TREND PREDICTION OF THUNDERSTORM

A. Lightning Location System

Lightning Location System(LLS) is the most widely used technical means of lightning detection in the field of lightning engineering technology. LLS is a set of lightning detection system with the characteristics of full-automatic, large area, high precision and real-time. It can detect and displays the time and place of cloud-to-ground lightning, magnitude and polarity, lightning current, number of strokes, and the parameters of every stroke. China Power Grid has been built more than 600 detection stations(covered 33 provinces), formed a wide-area lightning detection platform. It uses the combined location method of direction finding and time of arriving, which reached the technical index that lightning flashover checking rate is greater than 90%, location error is less than 800m, lightning amplitude peak value error is less than 15%[10].

Lightning is accompanied by strong convective weather, with the characteristics of randomness and explosive, and thunderstorm cloud is the carrier of lightning, high density lightning area can reflect the position of the thunderstorm cloud. Based on the monitoring data of LLS, it can easily get every thunderstorm process by clustering of target area lightning data and excluding sparse points in thunderstorm cloud distribution, then calculation the movement direction and the speed of clustering thunderstorm, so as to realize the trend prediction of thunderstorm cloud, which can provide technical support of small-scale and short-time lightning warning, to a certain extent, can effectively reduce the target areas of lightning warning false-alarm rate[11-12].

B. Thunderstorm Clustering Algorithm

For the identification of the high density region of lightning location information, clustering algorithm based on density is the best, and the classical algorithm is DBSCAN[13-15]. Its design idea is to scan the entire data set, arbitrarily find a core point, find all density connected data points to expand this core point and gather into clusters, not included in any of the clusters of data points in the data set as discrete points.

The process of thunderstorm clustering based on DBSCAN algorithm is as follows:

Input: a certain period of lightning coordinate collection A, neighborhood radius ε, minimum cluster number of points MinPts.

Step1: select a core point unprocessed from A randomly;

Step2: traverse the core point within the range of radius ε, find all density connected points until there is no more point can be expanded;

Step3: gather the core and expand points into clusters, then all points in the clusters marked as has been processed;

Step4: repeat the above steps 2-4 until all points have been processed in the collection.

Output: all lightning clusters that meet the requirements of the density.

C. Thunderstorm Linear Prediction

Obtained by clustering in continuous time of thunderstorm lightning set, it can calculate the center point of clustered thunderstorm for each time by the following formula:

$$\begin{cases} G_x = \frac{1}{n}\sum_{i=1}^{n} x_i \\ G_y = \frac{1}{n}\sum_{i=1}^{n} y_i \end{cases} \tag{2}$$

In formula (2), G_x and G_y are respectively the latitude and longitude of the center of clustered thunderstorm cloud, x_i and y_i are the latitude and longitude of the lightning location within the scope of this clustered thunderstorm cloud.

The future position of thunderstorm can be obtained by linear fitting the center of clustering thunderstorm cloud of continuous time interval, least squares method can be used for linear fitting of clustering thunderstorm cloud, so as to describe the trend of thunderstorm cloud movement. Respectively, the establishment of a separate line for each thunderstorm center to fit, it's easy to find a suitable set of a and b for all the given data points (x_i, y_i), i=1⋯n, which make the linear fitting closest to the every center point of clustered thunderstorm.

In the actual software programming, the monitoring data of the lightning location system for continuous 30 minutes were divided into 3 groups, each group lasted for 10 minutes, using clustering method for each set of thunderstorm data based on DBSCAN algorithm, then get the thunderstorm center of these three periods, and linear fitting of thunderstorm development trajectory, so the movement direction and velocity of the thunderstorm can be calculated, it is easy to know where the next position of the thunderstorm will happen.

D. Distance Warning of Thunderstorm

On the basis of above calculation of distance between the position lightning will happen and protected objects. When it within 10 ~ 15 km, as warning of level 1, as level 2 when it within 5~ 10 km, and as level 3 when it within 0~5 km.

IV. Comprehensive Warning Level

Single-station ground electric field instrument can monitor the electric field intensity in real-time, but the disadvantage is that the electric field instrument is a non-directional detection equipment and unpredictable of lightning moving tendency. Yet LLS can real-time monitor the location of lightning occurs, so it can significantly reduce the rate of false-alarm by LLS combine with the electric field intensity for lightning warning. In this paper, comprehensive lightning warning level calculated based on above two aspects, as shown in Table 2.

Table 2 Addition of two warning levels

Warning level of thunderstorm distance	Warning level of time-differencial of electric field			
	1	2	3	4
1	2	3	4	5
2	3	4	5	6
3	4	5	6	7

According to the probability of lightning occurrence by experience of meteorological department and existing research literatures, divided comprehensive lightning warning into 4-grades which listed in Table 3[16-17], warning probability is less than 25% (the plus result of two type warning equals to 1) as lightning blue warning (no lightning); probability is between 25% and 50%(plus result equals to 2 or 3) as lightning yellow warning; probability is between 50% and 75%(plus result equals to 4 or 5) as lightning orange warning; and probability is greater than 75%(plus result equals to 6 or 7) as lightning red warning.

Table 3 Comprehensive lightning warning level

Comprehensive lightning warning level	1	2	3	4
Warning signal	blue (no lightning)	yellow	orange	red
Probability of lightning occurrence	0%-25%	25%-50%	50%-75%	75%-100%
Plus of two type warning	1	2 or 3	4 or 5	6 or 7

V. Typical Application

There was a trip-out event of 220kV overhead transmission line tower No.74# in China power grid at 16:42 on August 24th, 2015. The monitoring records of atmospheric electric field instrument(1km away from the tower of this transmission line) on August 24th 15:00 ~ 20:00 as shown in Figure 1. It can be seen from the figure, atmospheric electric field began to change at 16:10, drastic changes occurred around 16:25, and lightning warning by time-differencial of electric field threshold reaches to level 2, changes gradually stabilized until about 18:00. Meanwhile, division of 30 minutes monitoring data between 15:55 and 16:25 from LLS into 3 groups, thunderstorm clouds are clustered respectively according to the above clustering algorithm, lightning location data are shown in Figure 2. Then the moving tendency of thunderstorm can be obtained by linear fitting the center point of this clustering thunderstorm cloud, as shown in Figure 3. The distance of the tower 74# is 12km by calculating the possible location of thunderstorm 10 minutes later, lightning distance warning reaches to level 1. Lightning Warning System sent lightning yellow warning information to management staff of power grid at 16:25 aim at tower 74# by comprehensive calculation of atmospheric electric field and distance warning level.

After the transmission line is tripped, operation and maintenance personnel found that lightning are very intensive near the tower 74# at the trip time by querying LLS, and there are obvious discharge trace below the C-phase insulator string by actual scene patrol, finally, the qualitative reason of this trip-out is lightning accident. In the whole process, lightning warning effect is significant based on the above method.

According to the lightning protection operation experience of power grid shows that, Once lightning yellow warning occurs, it is suggested that the grid staff should pay close attention to the weather condition of the thunderstorm, the possibility of the occurrence of the lightning trip-out fault is great. When lightning orange warning occurs, prompting that the grid operation and maintenance personnel to do emergency repair plan, in order to ensure the power grid will quickly recover after the failure because of the lightning strike. Most seriously, when lightning red warning, the dispatch personnel should transfer the load to another line to prevent lightning strikes damage of the power grid transmission facilities.

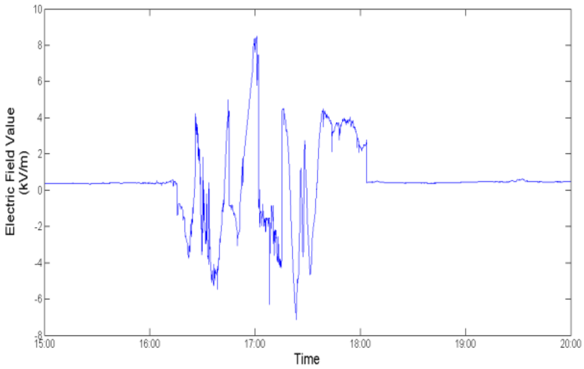

Figure 1 Curve of electric field value between 15:00~20:00

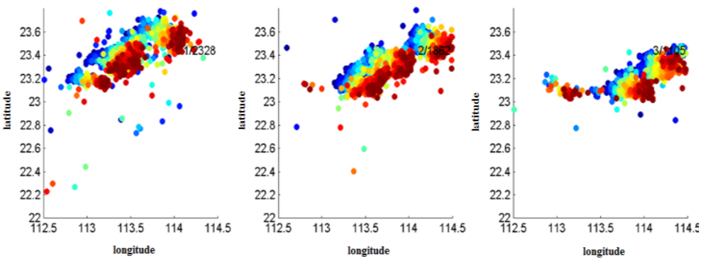

Figure 2 Cloud-to-ground flash coordinates in continuous time intervals

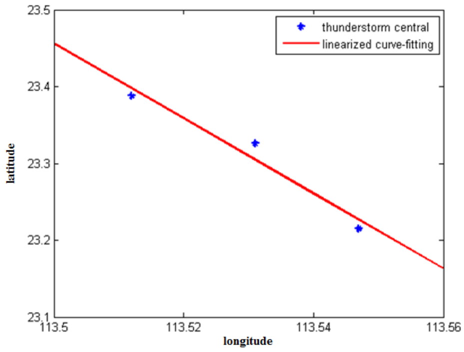

Figure 3 Curve of thunderstorm central point by linear fitting

VI. Conclusions

On the basis of atmospheric electric field of the warning threshold, this paper introduced time-differencial threshold calculation, it can effectively reduce the rate of non-alarm. Meanwhile, by combining with the lightning data clustering and linear trend prediction based on LLS, the lightning distance warning for target areas are calculated, it also can significantly reduce the rate of false-alarm. These two aspects combined to define lightning warning into 4-grades: lightning blue, yellow, orange and red warning, then achieved initiative defense of lightning disasters.

Based on this method, a Lightning Warning System for transmission line in power grid is developed, and pilot applied to State Grid Corporation of China. Application effect shows that the system can send lightning risk warning level nearly 15 minutes ahead of the arrival of thunderstorm for transmission line tower section, by comparing with the transmission line actual trip-out data and lightning data based on LLS, lightning warning information is accurate and reliable.

The next step will combine weather radar and satellite image information to improve the lightning warning method, and continuously enhance the level of lightning warning technology. Furthermore, as the gradual accumulation of warning data, the evaluation work of lightning warning effect and quantitative statistics of accuracy rate, non-alarm rate and false-alarm rate of lightning warning will be studied.

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