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HOW TO QUALIFY AND USE LOCAL STORM DETECTORS FOR RISK ASSESSMENT ?

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Abstract – Lightning detection techniques becomes very popular. The risk evaluation standard IEC 62305-2 published late 2006 will probably push forward that use. As a matter of fact, this risk evaluation technique means that you should provide protection measures until you decrease the calculated risk below a certain tolerable level. But in some cases, the risk is too high and standard lightning protection techniques cannot reduce it enough. This is particularly the case for large buildings with high risks, building with explosive atmosphere or place in the world where keraunic level is very high. What to do in such case? Basically, one of the only remaining option is to reduce the risk duration. This means to implement lightning detection measures such as local storm detector. If the storm detector is providing a signal early, it is possible to evacuate people from a dangerous zone, to stop a dangerous process or even to disconnect from the network and operate on independent power generators. You need then to characterize the device to know what it its efficiency. You need to be sure that a) the device will warn you enough in advance b) that the warning is reliable (no false warning) and c) that the warning will occur in any circumstances. It is then needed to establish testing procedures to evaluate the key parameters for the storm detection devices. Basically parameters a) and b) are important for the operation of the device and parameter c) is the one needed in the risk evaluation. Purpose of this paper is to present how these devices may be tested and how the results may be used in the risk assessment procedure.

1 - INTRODUCTION

Lightning detection techniques becomes very popular. The risk evaluation standard IEC 62305-2 published late 2006 will probably push forward that use. As a matter of fact, this risk evaluation technique means that you should provide protection measures until you decrease the calculated risk below a certain tolerable level. But in some cases, the risk is too high and standard lightning protection techniques cannot reduce it enough. This is particularly the case for large buildings with high risks, building with explosive atmosphere or place in the world where keraunic level is very high. What to do in such case? Basically, one of the only remaining option is to reduce the risk duration. This means to implement lightning detection measures such as local storm detector. If the storm detector is providing a signal early, it is possible to evacuate people from a dangerous zone, to stop a dangerous process or even to disconnect from the network and operate on independent power generators. You need then to characterize the device to know what it its efficiency. You need to be sure that a) the device will warn you enough in advance b) that the warning is reliable (no false warning) and c) that the warning will occur in any circumstances. It is then needed to establish testing procedures to evaluate the key pa&&&rameters for the storm detection devices. Basically parameters a) and b) are important for the operation of the device and parameter c) is the one needed in the risk evaluation. Purpose of this paper is to present how these devices may be tested and how the results may be used in the risk assessment procedure

2 - PRESENTATION OF THE STORM DETECTION TESTING PLATFORM AT THE SHANGHAI LIGHTNING PROTECTION CENTER

The SHanghai Lightning Protection Center (SHLPC) has been created in 2004 in Shanghai. The climate of Shanghai belongs to the north semitropical climate. The yearly average number of lightning days is fifty. Shanghai lightning Protection Center is a direct subordinate enterprise to Shanghai meteorological bureau with a business range of lightning protection technological service, application and research. In 2004, with the support of China meteorological administration and Shanghai municipal government, Shanghai lightning protection product-testing center had been founded in Shanghai songjiang high scientific technology garden. The level of the equipments of Shanghai lightning protection product-testing center (mainly SPDs) meets the request of the IEC61643, UL1449 and China national standard GB18802. The center has imported the most advanced low-voltage SPD impulse-experiment instruments in the world and became a top-ranking testing institution in China and even all over the world.

A Vaisala SAFIR system was already used in the Shanghai area and the data coming from that system are collected at SHLPC to study lightning activity in Shanghai area. As we needed a proved system to be used as a reference to compare the other local lightning detectors, we decided to use the well proven SAFIR system as a reference. This system has three branches which are set in three corners of Shanghai. The following figure 2 shows the three stations. The SAFIR system is able at least to locate 95% of all lightning strikes including the intra-cloud strikes. Detection accuracy for strike to ground is much greater. Ability to locate cloud to ground strikes and intra-cloud strikes will allow the system to determine the early warning capacity of tested local storm detectors as well as the failure rate. The location accuracy is at least 500 m. There is even a project to install a fourth sensor in order to be sure that at any time three sensors will be working to offer a 100% operational reference system.

Figure 1 – Nanhui station

The distance between the three branches and the distance between every branches and SHLPC ranges between 60 km to 150 km. The systems parameters are as follows:

- Average time of sampling: 100 µs
- Average time of sampling interval: 333 times per second
- Distance range of testing: about 200 kilometres

This system can also inspect the lightning density in the given area or in the given time. For example, it can inspect the lighting density in about 10 square kilometres or inspect the lightning density in a twenty minutes period. Using analyzing tools, it is possible to forecast the moving directions of thunder clouds with high level of confidence.

The information from SAFIR system and from the local detectors under tests are transmitted to SHLPC control center (see Figure 2).

The facility is now operational and two field mill local storm detectors are under test in this open air laboratory. One of them can be seen on Figure 3.

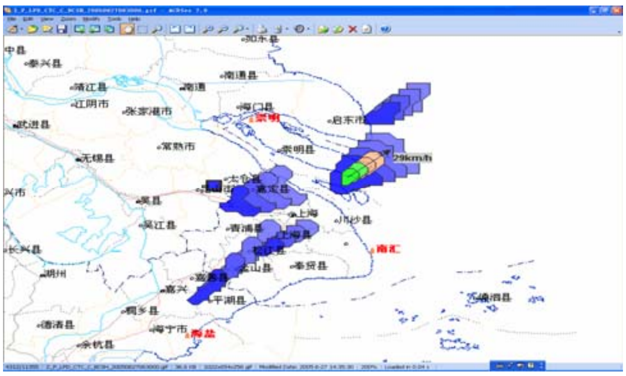

Figure 2 – information transmitted by the system SAFIR to SHLPC control room

Figure 3 – one of the local storm detectors in test in the open air laboratory

3 - DISCUSSION ON ELECTRICAL FIELD MILLS PRESENTLY USED AT THE TESTING STATION

There are a lot of influencing factors on the electric field and distinctive differences of monitoring data between different electric field mills do exit. So it is clear that false warnings and missing warnings will occur. In order to solve this problem, a new method should be implemented to judge the occurrence of thunderstorm.

3.1 - Influencing factors for the electric field

Because of numerous influencing factors on the electric field, there are obvious limitations to give thunderstorm warning based on a threshold level. When electric field is influenced by other factors than real thunderstorm, the electrical field can reach threshold level and thunderstorm warning will be issued by warning system, but actually there is no thunderstorm occurring at that time.

For example, Figure 4 shows the variation curve of electric field measured by electric field mill in Jiuting Town during two periods. The thresholds of different warning levels are set as follows: 3kV/m, 5kV/m and 8kV/m. Figure A shows that the value reached 10kV/m at 17:14, which exceeded the threshold of 8kV/m. Thunderstorm warning should be issued at that time but actually there was no thunderstorm observed. Figure B shows that electric field also reached the threshold of 8kV/m and there were electric field pulses in the curve. The warning system issued thunderstorm warning. Data from lightning positioning system and radar echo map showed that there was in that case thunderstorm really occurring over Jiuting Town.

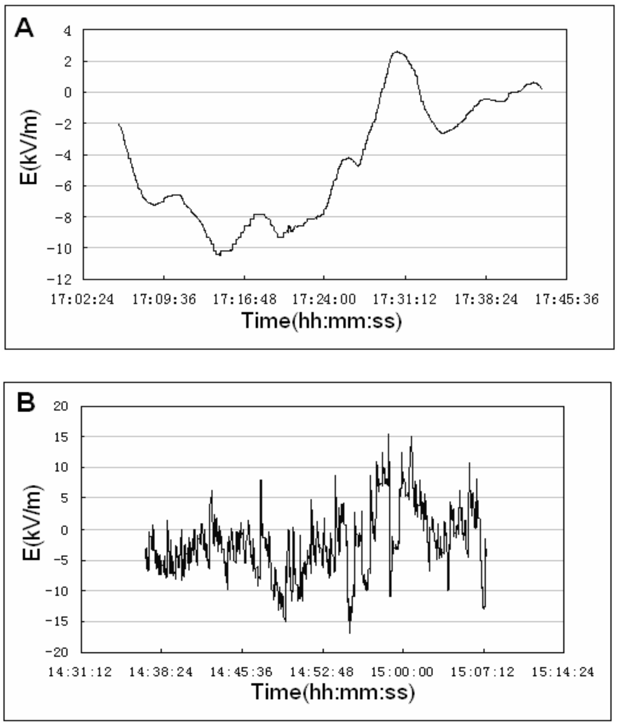

Figure 4 – Variation curve of electric field observed in Jiuting Town during two different periods

3.2 - Analysis of difference of measured electrical field on different weather conditions

Shanghai Lightning Protection Center is equipped presently with two field mills. With data obtained and numerous thunderstorms monitored during two years, several cases on different weather are selected to analyze temporal difference of electrical field

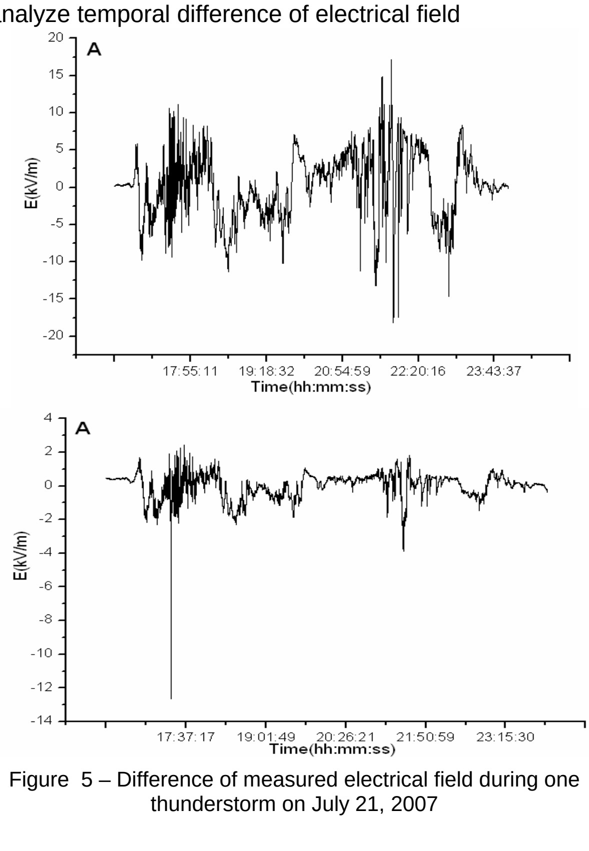

Figure 5 – Difference of measured electrical field during one thunderstorm on July 21, 2007

We can first note that even in clear weather, the field recorded are not always exactly the same. In case of thunderstorm the difference becomes larger.

For example, during one event on July 21, 2007, there were obvious distinctions between data from the two devices under test. The maximum and the minimum of electric field observed by one of them were 2.5kV/m and -12.7kV/m respectively when for the other they were ranging between 11.1kV/m and -11.75kV/m respectively as can be seen in Figure 5. Figure 6, shows the intra cloud and the cloud to ground recorded by the SAFIR system during the same event.

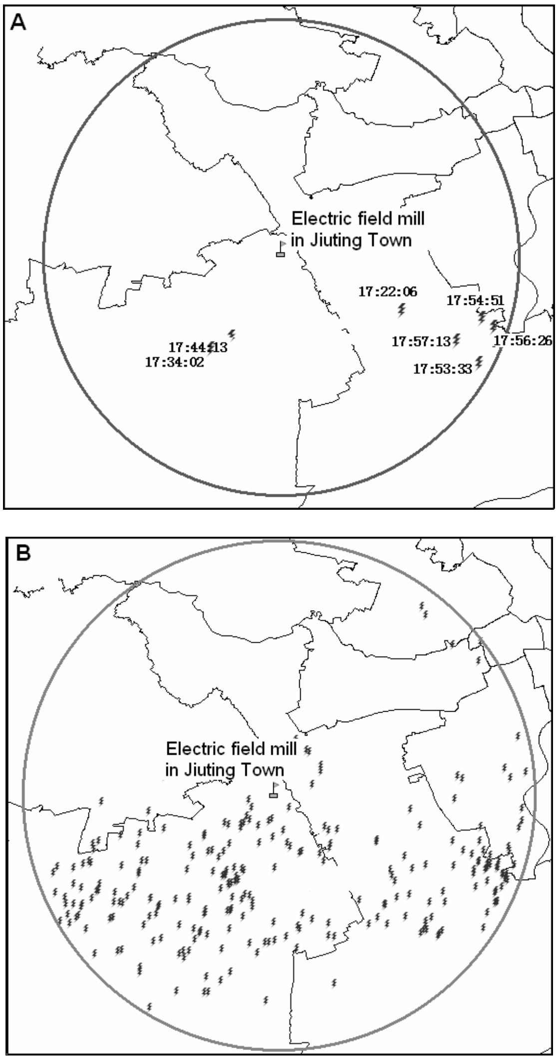

Figure 6 – Location map for cloud to ground flashes on the left (A) and intra-clouds flashes on the right (B) on July 21, 2007

In future studies, the SAFIR system will be used to determine if the event recorded by the electrical field variation as shown on Figure 6 are consistent with the events recorded by the reference system. There is even a project to enhance the SAFIR system by adding one more sensor to be sure than in any case at least three sensors are working.

4 - PARAMETERS TO CHARATERIZE THE STORM DETECTORS

As can be seen in previous chapter, false warning may occur. Also, even if the basic measuring device (field mill) seem the same for all field mills, the electronic treatment and numerical treatment may differ leading to different conclusions and this different level of reliability.

Parameters measured at the open air testing platform are :

a) time being warning and event in minutes (corresponding to the needed parameter p1)
b) number of warnings which occurred without any event (as shown by SAFIR system) in % of total number of alarms (corresponding to the needed parameter p2)
c) failure rate (not detected events, in spite of event being registered by SAFIR system) in % (corresponding to the needed parameter p3, used later on in the lightning risk assessment process)

Basically, as previously said, parameters a) and b) are important for operation. Parameter a) characterize the time the storm detector will offer to the industrial to stop his dangerous process or evacuate people from a dangerous zone. Depending, on the type of process or site parameters (high tower for example) a 10 minute warning or a much longer warning (30 minutes) will be needed.

5 - APPLICATION OF THE TESTED PARAMETERS IN THE RISK ASSESSEMENT

5.1 - Strom detector categories for risk assessment

As previously said the three main parameters are p1, p2 and p3.

p2 is a criterion which will make the user more confident in the system. However, this parameter cannot be included in the risk calculation for the human loss R1 as per IEC 62305-2. As a matter of fact, unnecessary alarms will not modify the risk value because there is no event. p2 could be used for the economical loss risk calculation (not discussed in that paper), because too numerous false alarms may lead to a lack of productivity of the plant due to the fact that some process have to be stopped or secured. p2 is then an unwanted parameter.

p1 is a wanted parameter, as you need to be informed in advance and this is a characteristic of the real efficiency of the device. But one more time this is a deterministic approach: either the time offered is sufficient for you to do something for safety sake (risk prevention measures that you may implement in that delay) or it is not. So it is an important parameter but not for the statistical calculation of the risk.

In the same way that efficiency of the lightning protection system is characterized by a probability that you will not catch lightning, storm detector can be characterized by a failure rate (we will not call it a probability as the duration of the testing being relatively short and number of recorded events being not so large), it is more a parameter characterizing the device than a probability : there is a % p3 that the event is not detected with the agreed time (p1 in table 1). For example, a storm detector who will allow the plant owner to evacuate a dangerous zone or to avoid the occurrence of a dangerous event, will reduce the duration of presence of people in a dangerous zone. That the danger doesn't exist anymore or that it stills exist and has no impact on people because they are in a safe shelter has exactly the same influence on the risk assessment for the people. This is commented below with some examples.

Let's assume that the storm detectors are classified in a future standard by 4 categories (there are 4 levels for lightning protection levels) as shown in Table 1. Category one is the most efficient as it is for lightning protection systems with an efficiency of detection of events fixed at 93% and the category 4 has an efficiency fixed at 50% only.

Category	p1 (minutes)	p2	Pst = 1 –p3
1	30	0,02	0,07
2	20	0,05	0,15
3	15	0,1	0,3
4	10	0,2	0,5

Table 1 – proposed categories for storm detectors

We do believe that it is of the interest of the user to have all parameters characterized by a single category. Of course a device being very efficient (high value for p3) could offer a time between detection and event (p1) large or small and can have a percentage of fake alarms large or not. If parameters are completely independent in the classification the fear is that a detector with small p1 or high p2 will be very considered as very efficient. As a matter of fact if you wait until the last moment to signal an alarm or if you signal an alarm any now and then, the probability that you don't miss any event becomes de facto quite large ! But the device is not really practical. Globally, a device having a high p3 (so a low Pst) and large p1 and a low p2 would be the perfect one.

Values in Table 1 are hypothesis from our side just to show how this could work and start a debate because these parameters are no standardized yet and in some case even not provided by the manufacturers of the devices.

5.2 - Risk calculation R1 with storm detector

Example N°1 : A fireworks production plant

The unit manufacturing fireworks has the following characteristics :

- Dimensions : 10 x 5 m (height : 4 m), buried power line (150 m)
- Flash ground density : 3,4
- Explosion risk with people present for a total duration of 3000 h per year.

Application of risk calculation R1 according to IEC 62305-2 gives values as listed in table 2

In this example, it is assumed that the factory under study doesn't meet the characteristics that will allow to use probabilities Pb smaller than 0,02.

Structure protection level	Pb (as per IEC 62305-2)	Storm detector category	Pst	Time of presence in the dangerous area in hours per year	Total risk R (as per IEC 62305-2)
none	1	none	1	3 000	$510\ 10^{-5}$
1	0,02	none	1	3 000	$12\ 10^{-5}$
1	0,02	4	0,5	1 500	$5{,}8\ 10^{-5}$
1	0,02	3	0,3	900	$3{,}5\ 10^{-5}$
1	0,02	2	0,15	450	$1{,}7\ 10^{-5}$
1	**0,02**	**1**	**0,07**	**210 h**	**$0{,}8\ 10^{-5}$**
2	0,05	1	0,07	210	$1{,}1\ 10^{-5}$

Table 2 – risk calculation for a fireworks manufacturing plant

In this first example, a Lightning Protection System alone cannot reduce the risk below the tolerable risk value fixed by standard at 10^{-5}. A storm detector category 1 (efficiency 93%) is then needed in addition to the LPS. The main reason is that presence in dangerous areas is quite large (3000 hours per year) in this plant until an appropriate storm detector is used to remove people from dangerous zones in case of a storm approaching.

Figure 7 shows in blue the parameters of risk without protection, in orange risk reduction obtained by the LPS (level 1: Pb = 0,02) and in green risk reduction with storm detector (category 1) in addition to LPS level1.

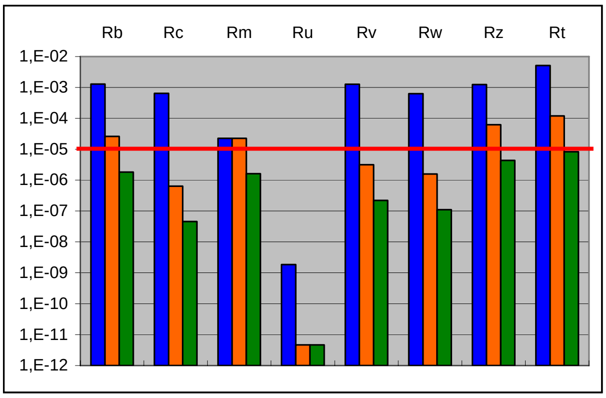

Figure 7 – Influence of LPS and storm detector on risk parameters in example N°1

Example N°2 : A flammable product loading unit

This unit has the following characteristics :

- Dimensions : 20 x 10 m (height : 7 m), buried power line (60 m)
- Flash ground density : 3,4
- Explosion risk with flammables vapours with people present for a total duration of 60 h per year.

Application of risk calculation R1 according to IEC 62305-2 gives values as listed in table 3. In this second example, it is also assumed that the factory under study doesn't meet the characteristics that will allow to use probabilities Pb smaller than 0,02.

In this case also, a Lightning Protection System alone cannot reduce the risk below the tolerable risk value fixed by standard at 10^{-5}. Two solutions are investigated :

- A storm detector category 2 (efficiency 85%) is then needed in addition to the LPS level of protection 1.
- A storm detector category 1 (efficiency 93%) is then needed in addition to the LPS level of protection 4.

It is interesting to note that an efficient storm detector can, in that case, be used in conjunction with a LPS to reduce the needed protective level of the LPS and still allow the risk to be below the tolerable risk.

Figure 8 shows in blue the parameters of risk without protection, in orange risk reduction obtained by the LPS (level 1) and in green risk reduction with storm detector (category 2) in addition to LPS level 1. In yellow is an other possibility to reduce the risk with a LPS (level 4 : Pb = 0,2) in addition to a storm detector (category 1).

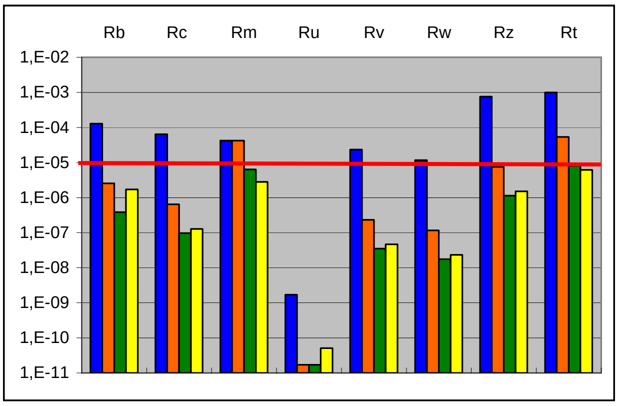

Figure 8 - Influence of LPS and storm detector on risk parameters in example N°2

Even if the distribution of risk components is different between case represented in green and case represented in yellow, it appears that the total risk is almost the same in both cases. So this means that the two solutions (LPS level 1 + storm detector category 2 and LPS level 4 + storm detector category 1) are almost equivalent from the user risk point of view and the main difference will be in the cost.

Structure protection level	Pb (as per IEC 62305-2)	Storm detector category	Pst	Time of presence in the dangerous area In hours per year	Total risk R (as per IEC 62305-2)
None	1	none	1	60	$100\ 10^{-5}$
1	0,02	none	1	60	$5,3\ 10^{-5}$
1	0,02	4	0,5	30	$2,7\ 10^{-5}$
1	0,02	3	0,3	18	$1,6\ 10^{-5}$
1	**0,02**	**2**	**0,15**	**9**	**$0,8\ 10^{-5}$**
1	0,02	1	0,07	4	$0,4\ 10^{-5}$
4	**0,2**	**1**	**0,07**	**4**	**$0,6\ 10^{-5}$**

Table 3 – risk calculation for a flammable loading unit

6 – CONCLUSIONS

In this paper, we have presented the state of the art of an in-situ testing station for storm detector. The station is already operational and tests such devices since a few years. The preliminary results obtained are showing that data collected are different from one device to another, mainly due to the software used internally to get the electrical field and take decisions in terms of alarms. From the user perspective, he needs to have a reliable device as the storm detector is a safety device. In addition, to include such a device in the risk assessment process it is necessary to determine the efficiency of the system in real use. Attempts to develop laboratory tests in standards for such products exist. Such standards are necessary and need to be developed. But our preliminary results are showing that, due to many parameters occurring in real conditions, only in-situ testing is able to validate the efficiency of the device and as such, should be included in the standards under development. Of course, include such open air – long term tests in a standard is not an easy task and validation of the proposal, both by the scientific and standardization community is really needed to go further. Purpose of that paper is to seek advice from both of them. Nowadays, LF detection networks such as Vaisala's LS series are able to provide the necessary information for such validation tests and most of these networks have been subject to many studies and scientific publications confirming that the location accuracy and the detection efficiency are perfectly in accordance with the validation purpose of this paper. There is an ongoing program with them to establish what should be the reference characteristics. This will be presented in a future conference. The paper is also showing how the data obtained from the testing may be used for calculation of lightning risk evaluation for human losses, R1 according to IEC 62350-2 standard. The parameters needed for characterizing the devices are discussed and their influence shown in some examples. It appears that three parameters are most needed, one of them being critical for risk evaluation. However, there is a proposal to link these three main parameters in categories in order to facilitate the user choice.

7 – ACKNOWLEDGMENTS

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