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INTERNATIONAL STANDARD

colour inside

Protection against lightning – Thunderstorm warning systems

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PROTECTION AGAINST LIGHTNING – THUNDERSTORM WARNING SYSTEMS

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International Standard IEC 62793 has been prepared by IEC technical committee 81: Lightning protection.

The text of this standard is based on the following documents:

FDIS	Report on voting
81/508/FDIS	81/519/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Natural atmospheric electric activity and, in particular, cloud-to-ground lightning poses a serious threat to living beings and property. Every year severe injuries and even deaths of humans are caused as a result of direct or indirect lightning strikes.

Lightning:

- may affect sport, cultural and political events attracting large concentrations of people; events may have to be suspended and people evacuated in the case of a risk of thunderstorm;
- may affect industrial activities by creating power outages and unplanned interruptions of production processes;
- may interrupt all kinds of traffic (people, energy, information, etc.);
- has led to a steady increase in the number of accidents per year due to the wider use of electric components that are sensitive to the effects of lightning (in industry, transportation and communication);
- may be a hazard for activities with an environmental risk, for example handling of sensitive, inflammable, explosive or chemical products;
- may be a cause of fire.

During the last decades, technical systems including systems devoted to real-time monitoring of natural atmospheric electric activity and lightning, have experienced an extraordinary development. These systems can provide high quality and valuable information in real-time of the thunderstorm occurrence, making it possible to achieve information which can be extremely valuable if coordinated with a detailed plan of action.

Although this information allows the user to adopt anticipated temporary preventive measures, it should be noted that all the measures to be taken based on monitoring information are the responsibility of the system user according to the relevant regulations. The effectiveness will depend largely on the risk involved and the planned decisions to be taken. This International Standard gives an informative list of possible actions.

Lightning and thunderstorms, as with many natural phenomena, are subject to statistical uncertainty. It is not possible therefore to achieve precise information on when and where lightning will strike.

Other lightning protection standards do not cover the use of thunderstorm warning systems.

PROTECTION AGAINST LIGHTNING – THUNDERSTORM WARNING SYSTEMS

1 Scope

This International Standard describes the characteristics of thunderstorm warning systems and evaluation of the usefulness of lightning real time data and/or storm electrification data in order to implement lightning hazard preventive measures.

This standard provides the basic requirements for sensors and networks collecting accurate data of the relevant parameters, giving real-time information of lightning tracks and range. It describes the application of the data collected by these sensors and networks in the form of warnings and historical data.

This standard applies to the use of information from thunderstorm warning systems (systems or equipment providing real-time information) on atmospheric electric activity in order to monitor preventive measures.

This standard includes:

- a general description of available lightning and storm electrification hazard warning systems;
- a classification of thunderstorm detection devices and properties;
- guidelines for alarming methods;
- a procedure to determine the usefulness of thunderstorm information;
- some informative examples of possible preventive actions.

The following aspects are outside the scope of this standard:

a) lightning protection systems; such systems are covered by the IEC 62305 series;
b) other thunderstorm related phenomena such as rain, hail, wind;
c) satellite and radar thunderstorm detection techniques.

A non-exhaustive list of situations to which this standard could be applicable is given below:

- people in open areas involved in activities such as maintenance, labour, sports, competitions, agriculture and fisheries or situations where large crowds gather;
- wind farms, large solar power systems, power lines;
- occupational health and safety prevention;
- sensitive equipment such as computer systems, emergency systems, alarms and safety equipment;
- operational and industrial processes;
- storage, processing and transportation of hazardous substances (e.g. flammable, radioactive, toxic and explosive substances);
- determined environments or activities with special danger of electrostatic discharges (e.g. space and flight vehicle operations);
- operations in which the continuity of the basic services is very important (e.g. telecommunications, the generation, transport and distribution of energy, sanitary services and emergency services);
- infrastructures: ports, airports, railroads, motorways and cableways;

- civil defense of the environment: forest fires, land slide and floods;
- wide networks (e.g. power lines, telecommunication lines) may also benefit from having early detection of thunderstorms.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62305 (all parts), *Protection against lightning*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
alarm
information indicating that the target or the surrounding area is likely to be affected by thunderstorms and the accompanying lightning related events

3.1.2
cloud-to-ground lightning
CG
electric discharge of atmospheric origin that is comprised of one or more cloud-to-ground lightning strokes that propagate from cloud to ground or vice versa and lead to a net transfer of charge between cloud and ground

3.1.3
coverage area
CA
area where a given warning equipment has a sufficient detection efficiency and/or accuracy to give a warning

3.1.4
detection efficiency
DE
percentage of cloud-to-ground discharges (flashes or strokes) that are detected and located by a sensor or a network

Note 1 to entry: As cloud-to-ground flashes are often composed of several strokes, there is a difference between flash detection efficiency and stroke detection efficiency. A flash is reported (detected) if at least one stroke (first or subsequent) is detected and therefore flash detection efficiency is always equal or higher than stroke detection efficiency.

3.1.5
dwell time
DT
time that an alarm is sustained after all warning criteria are no longer met

3.1.6
effective alarm
EA
alarm where a lightning related event occurs in the surrounding area during the total alarm duration

3.1.7
time to clear
TTC
time between the occurrence of the last lightning related event in the monitoring area and the time when the alarm is released

3.1.8
failure to warn
FTW
occurrence of a lightning related event in the surrounding area for which no alarm occurred

3.1.9
failure to warn ratio
FTWR
ratio of failure to warn with respect to the total number of situations with lightning related events affecting the surrounding area

3.1.10
false alarm
FA
alarm not followed by lightning-related events within the surrounding area

3.1.11
false alarm ratio
false alarm rate
FAR
ratio of false alarms to the total number of alarms

3.1.12
field strength meter
FSM
device for continuous monitoring of the atmospheric electrostatic field associated with thunderstorms

EXAMPLE: Field mill.

3.1.13
cloud lightning
IC
discharge occurring within or among thunderclouds or between thunderclouds and air and which does not have a ground termination

3.1.14
lead time
LT
time between the start of an alarm and the effective occurrence of the first lightning related event in the target area

3.1.15
lightning flash
electric discharge of atmospheric origin consisting of one or more strokes

Note 1 to entry: This discharge may occur within or between clouds, between the clouds and air and between a cloud and the ground.

3.1.16
lightning related event
LRE
CG lightning flash to or near the structure to be protected, or to or near a line connected to the structure to be protected

3.1.17
lightning stroke
single electric discharge in a lightning flash to earth

3.1.18
median location accuracy
LA
median value of the distances between real stroke locations and the stroke locations given by the lightning location system

3.1.19
monitoring area
MA
geographic area where the lightning activity is monitored in order to provide a valid warning for the target area

3.1.20
physical damage
damage to a structure (or to its contents) due to mechanical, thermal, chemical or explosive effects of lightning

3.1.21
preventive actions
actions of a temporary nature, taken on the basis of the preventive information and framed within the emergency plans of each organization which covers all that is required

3.1.22
point of strike
point where a lightning flash strikes the earth or protruding objects (e.g. structure, lightning protection system, line, tree)

Note 1 to entry: A lightning flash may have more than one point of strike.

3.1.23
surrounding area
SA
geographic area in which a lightning related event (LRE) causes a potential danger and which surrounds and includes the target area (TA)

Note 1 to entry: Any lightning related event occurring in the surrounding area is potentially dangerous. This area is used when evaluating a thunderstorm warning system to determine the false alarm ratio and other performance parameters.

3.1.24
target area
TA
geographic area where a warning is needed in order to facilitate decision-making and to activate preventive actions before a lightning related event occurs in that area

3.1.25
thunderstorm
local storm produced by atmospheric activity and accompanied by lightning and thunder

3.1.26
thunderstorm detector
equipment capable of evaluating one or more parameters associated with the electrical characteristics of the thunderstorm

Note 1 to entry: Thunderstorm detectors may consist of a single detector or of a network of connected detectors.

3.1.27
thunderstorm warning system
TWS
system composed of thunderstorm detectors able to monitor the thunderstorm activity in the monitoring area and means of processing the acquired data to provide a valid alarm (warning) related to the lightning related events for a defined target area

Note 1 to entry: Some countries refer to TWS as 'lightning warning systems'.

3.1.28
total alarm duration
TAD
time between triggering and the end of an alarm

3.1.29
percentage of alarms delivered
POD_x
percentage of alarms delivered with a lead time of more than or equal to x minutes

EXAMPLE: POD_{10} is the percentage of alarms delivered with a lead time of more than or equal to 10 min.

3.2 Abbreviations

CA	Coverage area
CG	Cloud to ground
DC	Direct current
DE	Detection efficiency
DT	Dwell time
EA	Effective alarm
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
FA	False alarm
FAR	False alarm ratio
FSM	Field strength meter
FTW	Failure to warn
FTWR	Failure to warn ratio
HV	High voltage
IC	Intercloud, intracloud or cloud to air discharges
IP	Index of protection
LA	Location accuracy
LF	Low frequencies
LLS	Lightning location system
LPS	Lightning protective system
LT	Lead time
LRE	Lightning related event
MA	Monitoring area
MCS	Mesoscale convective systems
MDF	Magnetic duration finder
OI	Optical imaging
POD_x	Percentage of alarms delivered

RFI	Radio frequency interferometry
RFM	RF signal strength measurement
RF	Radio frequency
SA	Surrounding area
TA	Target area
TAD	Total alarm duration
TOA	Time of arrival
TTC	Time to clear
TWS	Thunderstorm warning system
UV	Ultraviolet
VHF	Very high frequencies
VLF	Very low frequencies

4 Thunderstorm phases and detectable phenomena for alarming

4.1 Introductory remark

Four distinct stages can be identified during the thunderstorm life time cycle regarding detectable phenomena:

1) initial phase;
2) growth phase;
3) mature phase;
4) dissipation phase.

4.2 Phase 1 – Initial phase (cumulus stage)

This is the phase of cloud electrification by means of electric charge separation within the cloud. The charges are distributed in regions within the cloud and produce a measurable electrostatic field at ground level. It is considered the first detectable phenomenon before a thunderstorm.

NOTE Electrostatic fields can produce potential dangers such as electrostatic discharges even in the case of no lightning activity.

4.3 Phase 2 – Growth phase

This phase, sometimes also called the development phase, is characterized by the occurrence of the first lightning discharge (IC or CG). The first intra-cloud (IC) flashes appear after a certain development of the charge regions in the cloud. However, in some situations there is no clear time delay between the first IC flash and the first CG flash.

NOTE IC flashes typically represent the majority of the total lightning activity generated by a thunderstorm. Significant variation in the IC/CG rate is observed for individual storms.

4.4 Phase 3 – Mature phase

This stage is characterized by the presence of both CG and IC flashes.

4.5 Phase 4 – Dissipation phase

This phase is characterized by the decaying of both IC and CG flash rates and the reduction of the electrostatic field to the fair weather level.

5 Classification of thunderstorm detection devices and their properties

Portable devices (a device where the sensor is not fixed) are outside the scope of this standard (calibration and testing for these devices may not be sufficient to provide efficient warning).

Thunderstorm detectors are classified in accordance with the detectable thunderstorm phases depending on the detectable phenomena. However, a thunderstorm detector can detect one or several phenomena.

There are several ways to look at the means to detect thunderstorms in general, and lightning strikes in particular. One way is to look at the phase of the thunderstorm for which a detector is designed to operate. Another way is to compare the frequency range of the electromagnetic radiation emitted by a lightning strike with the frequency range detectable by a sensor. A third way is to look at techniques that a sensor uses to detect a lightning strike and to calculate its position.

For the classification of thunderstorm or lightning strike detectors the following classes are defined:

- class A: detect a thunderstorm over its entire lifecycle (phases 1 through 4);
- class B: detect IC and CG flashes (phases 2 through 4);
- class C: detect CG flashes only (phases 3 and 4);
- class D: detect CG flashes (phase 3) and other electromagnetic sources with very limited efficiency.

The classes are explained in more detail in Annex B. The classes are not related to the efficiency of the system.

The frequency ranges that are used in lightning detection are as follows:

- DC: static and quasi static electric fields;
- VLF: very low frequencies (3 kHz to 30 kHz);
- LF: low frequencies (30 kHz to 300 kHz);
- VHF: very high frequencies (30 MHz to 300 MHz).

All these phenomena to be measured result in different sensor and location techniques. Those techniques may be distinguished as follows:

- MDF: magnetic direction finder;
- TOA: time of arrival;
- RFI: radio frequency interferometry;
- FSM: field strength meter;
- RF: radio frequency signal strength measurements.

This list is not exhaustive.

These detection techniques are described in some detail in Clause B.2.

Table 1 shows the connection between the frequency range in which a detector may operate and the phases, classes and typical ranges of operation for those detectors.

Table 1 – Lightning detector properties

Technique	Physical detectable phenomenon	Frequency	Phase(s)	Main class	Secondary class	Typical sensor range km	Application
FSM	Electrification process	DC	1, 2, 3, 4	A		20	Short range early warning systems
MDF	Electric charges motion	VLF	2, 3	C	B	No limit	Low detection efficiency and location accuracy – very long range detection
MDF, TOA	Electromagnetic radiation (lightning current)	LF	2, 3	C	B	600 to 900	Long range – high location accuracy for CG detection. A fraction of IC processes are also detected
TOA	Breakdown and leader processes (IC/CG)	VHF	2, 3	B	C	200	Medium range – high location accuracy for both CG and IC
RFI	Breakdown and leader processes (IC/CG)	VHF	2, 3	B	C	300	Medium range – high location accuracy for both CG and IC
RF	Electromagnetic radiation (lightning current)	LF	3	D		100	Meteorological interest
NOTE The main class is the class for which the detector is designed. The secondary class is the class or the classes for which the sensor is also appropriate.							

TWS may also be classified based on their detection range (typically from a few km to 500 km or more).

More information on the properties and guidance in choosing a sensor for a certain purpose is given in Annex B.

6 Alarm method

6.1 General

In order to let the user take all possible preventive actions, a thunderstorm warning system (TWS) shall provide an alarm for a target area where the lightning related event (LRE) represents a threat. The identification of the lightning related event (LRE) is deduced from the description of dangerous situations provided in Clause 9. An alarm derives from monitoring the lightning activity, either or both CG and IC but also other parameters such as the electrostatic field in the monitoring area (MA). Combinations with additional meteorological observations are usually employed (e.g. meteorological radar). For detection systems able to provide mapping information (lightning detection networks, radars, etc.) it is possible to track potentially dangerous thunderstorm cells thus improving the performance of TWS. Information about TWS is given in Annex B.

The set-up of an alarm includes three steps:

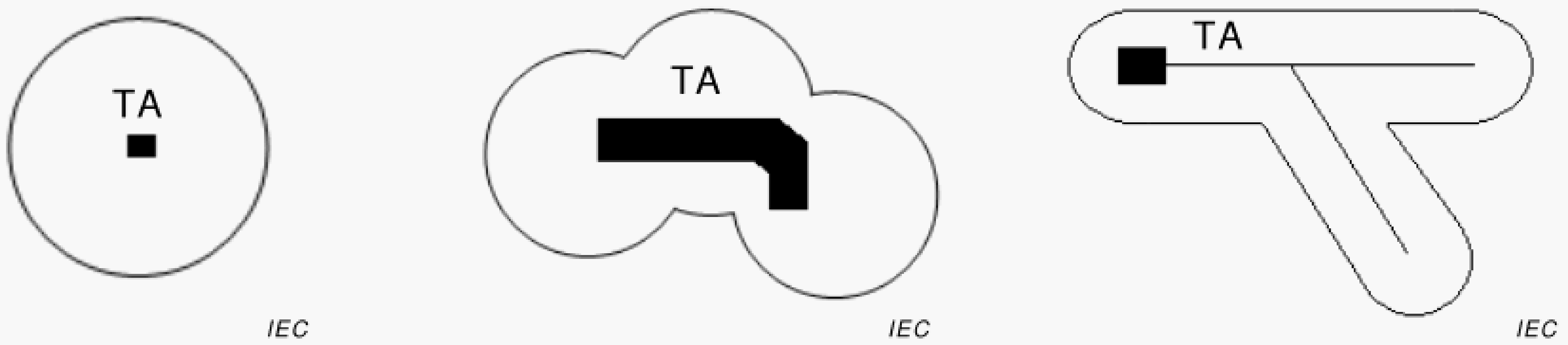
- areas definitions;
- alarm triggering criteria;
- alarm information delivery.

All three steps should be documented. Guidelines to set up an alarm are presented in this Clause 6 and some examples are included in Annex E.

6.2 Areas

6.2.1 Target area (TA)

A precise description of the area should include the physical extension where the warning is needed. The target area can be limited to a single point (Figure 1a)), for example tower on which workers are operating, limited size factory or can be extended (e.g. large buildings, wind farms, golf courses: Figure 1b)). It is however recommended to use larger areas for safety reasons. In many cases, it may appear simpler to limit the lightning related event (LRE) to the occurrence of CG flashes and therefore adapt the size and shape of the target area in order to take into account all possible induced effects. For example, a system sensitive to overvoltages on the power line can be set up or the occurrence of CG flashes in a target area encompassing not only the site but also the power line and its vicinity (Figure 1c)). Therefore, each CG flash occurring in this target area will be treated as a lightning related event (LRE) able to cause the overvoltage. Thus, the target area also depends on the type of lightning related event (LRE) and the effects that it could cause (see Clause 7).



a) Single point b) Arbitrary shape c) Including services

Figure 1 – Examples of different target area shapes

6.2.2 Surrounding area (SA)

In the process of evaluating a TWS it is advisable to introduce a surrounding area (SA) encompassing the target area as shown in Figure 2 in order to confirm the efficiency of the alarm. Where the target area receives a warning even though it does not see an LRE, the occurrence of an LRE in the close neighborhood of the target area (as defined by the surrounding area) indicates that the risk is high and this situation should not be treated as a false alarm (FA). On the other hand, a target area receiving a warning with no LRE being recorded, clearly indicates a malfunction of the equipment and should be treated as a false alarm (FA). Moreover, the introduction of the surrounding area (SA) allows for taking into account the limited location accuracy (LA) of the validation data set.

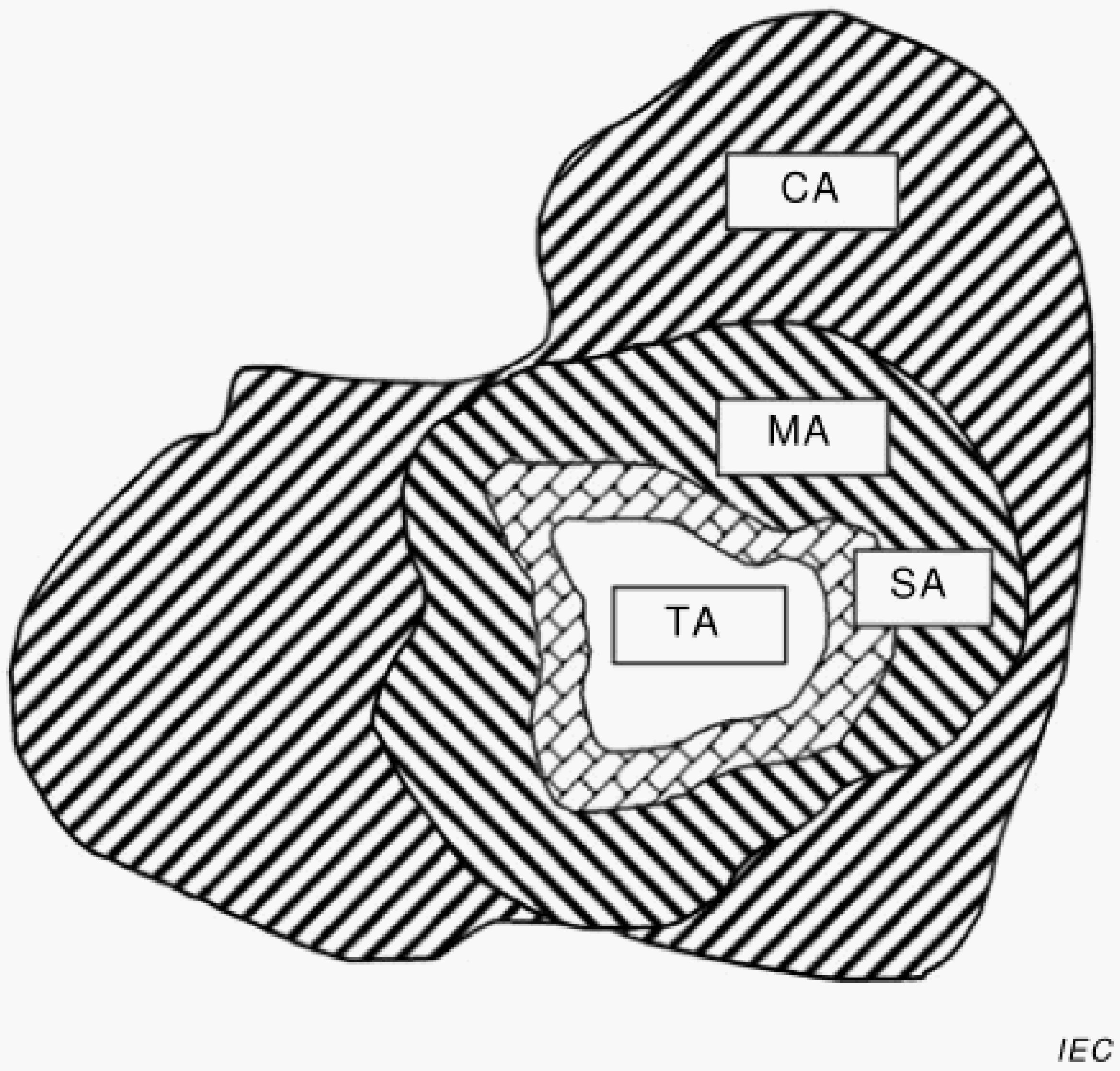


Figure 2 – Example of the distribution of the coverage area (CA), the monitoring area (MA), the target area (TA), and surrounding area (SA)

6.2.3 Monitoring area (MA)

The size and the shape of the monitoring area should be adjusted according to the type of the TWS (see Annex B), its capabilities (see Annex B, e.g. detection efficiency and location accuracy), the shape of the target area, the objectives and the performance of the alarm system.

6.2.4 Coverage area (CA)

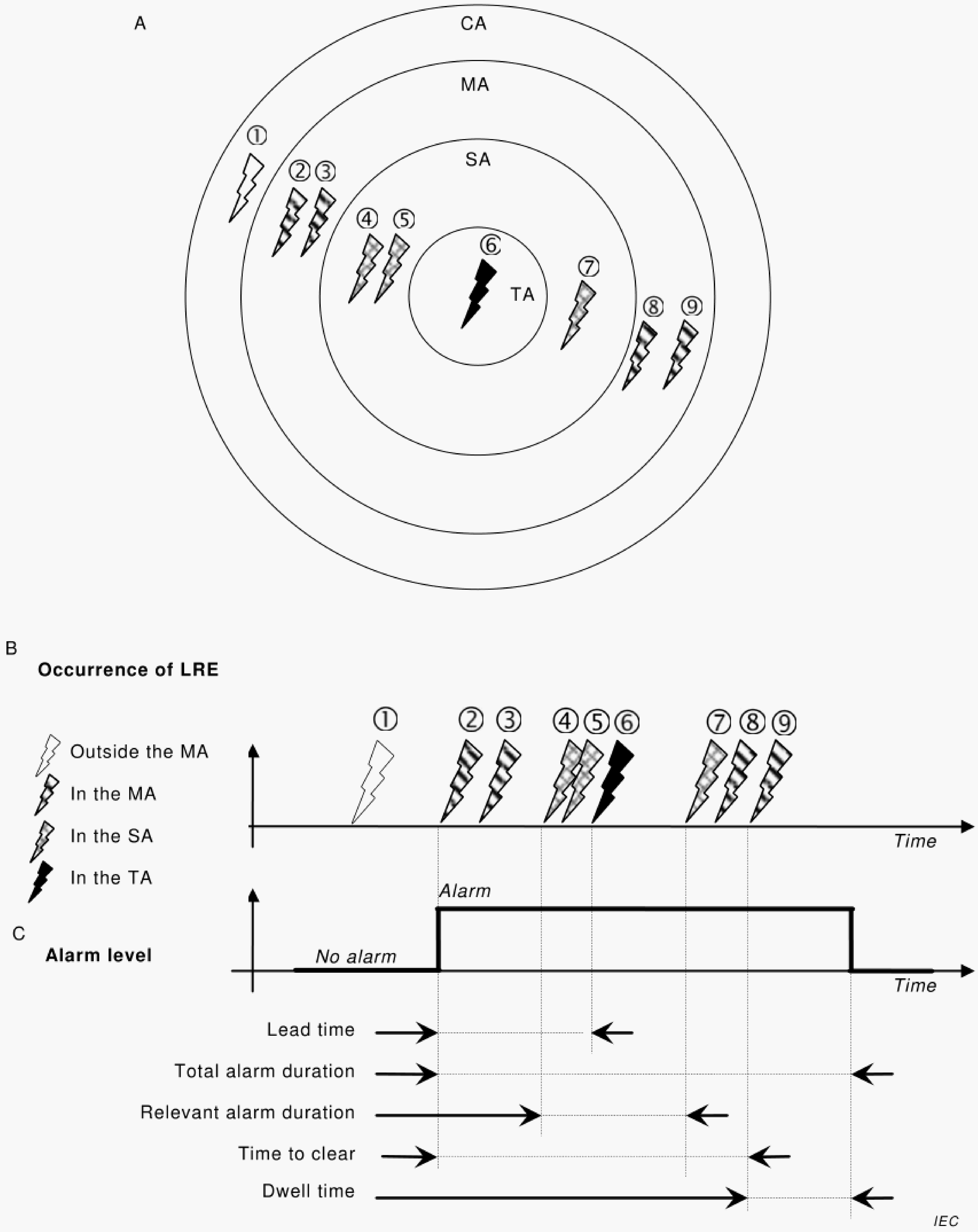
Once the monitoring area (MA) is defined, the detection system should have a coverage area (CA) that includes the monitoring area (MA). When the coverage area (CA) does not cover the whole monitoring area (MA) necessary to elaborate a reliable warning on the target area, it will be essential to juxtapose several elementary systems. The detection efficiency (DE) and/or the location accuracy (LA) of the detection system within the range of the monitoring area (MA) should be known and their influence on the alarm performance should be considered.

Generally, for detection networks, MA = CA.

6.3 Alarm triggering

In general, an alarm is triggered when the monitored information provided by the TWS is detected within the monitoring area (MA). The criteria of triggering should be defined and depends on the characteristics of the TWS and its performance within the monitoring area (MA) (e.g. one or several CG flashes, one or several IC flashes, a certain electrostatic field level, electrostatic field polarity and combinations of some criteria).

An example of a timing of an alarm is displayed in Figure 3.



Key

A Locations of the lightning related events (LRE) in the defined areas (coverage area CA, monitoring area MA, surrounding area SA and target area)

B Temporal occurrence of the lightning related events (LRE)

C Timing of the alarm according to the occurrence of the lightning related events (LRE) in the defined areas

Figure 3 – Example of an alarm

The lead time (LT) is the time available to conduct the preventive actions before the first lightning related event (LRE) in the target area may occur.

In order to avoid switching the warning level frequently, the lightning warning system shall use a dwell time (DT) to sustain the alarm even when the alarm criteria are no longer met. If the value set for the dwell time is too large, the time to clear (TTC) will rise significantly, thus making the alarm costlier (depending on the application). Note that systems able to accurately detect the end of an alarm by means other than the occurrence of lightning flashes in the monitoring area (such as class A field strength meter (FSM) systems), may not use the dwell time to release the alarm but rather the occurrence of this end-of-alarm condition.

The total alarm duration corresponds to the interval between the alarm trigger and the end of the dwell time (DT).

6.4 Alarm information delivery

A clear alarm delivery procedure and protocol should be defined to ensure that the alarm information will be properly received by the end user.

It is necessary to monitor faults of the thunderstorm detectors and communication links and notify the end users of all possible detected faults that may affect the availability and the quality of the alarm.

7 Installation and maintenance

Any thunderstorm detectors shall be installed according to the manufacturer's instructions and in the best conditions for ensuring the fewest disruptions produced by its environment. For this purpose, it is highly recommended to make a prior study of the proposed location in order to adapt the sensors of the system to the specific conditions of the site.

The installation of thunderstorm detectors is prone to be affected by multiple factors, so, any new installation may need a prior adjustment period before it is considered to be working at its optimum level. This adjustment shall be made by the system's manufacturer or by a technician specifically authorized by this manufacturer.

Maintenance of the systems integrated in a TWS, including alarm delivery, is indispensable. The precision of the information provided by a TWS is directly determined by the physical conditions of its sensors, their environment (i.e. growing vegetation, buildings, towers, etc.), communications links between the sensors and the TWS as well as between TWS and end users. Therefore it is considered necessary to carry out the maintenance tasks every year or even at shorter periods according to the manufacturer's recommendations.

All these installation and maintenance recommendations are really a key factor for a successful warning system.

NOTE Maintenance tasks can include for example: cleaning, readjusting of parameters, verification of good operation, communication ability, etc.

8 Alarm evaluation

8.1 General

By evaluating the operation of the TWS, it is possible to optimize its parameters and then improve the quality and the reliability. The alarm can thus be better adapted to the end user applications.

Performance evaluation results in extremely valuable information for future alarm settings, preventive action improvements, and increases the knowledge of the target area lightning environment.

It is recommended that an evaluation procedure be established by the installer. In this procedure the user should provide information about previous experiences when available (e.g. number of alarms, potential failure to warn, false alarms, damages) during a particular alarm set-up.

The evaluation can be performed in different ways depending on the availability of validation information, such as:

- cross-correlation with other sources of information with a better accuracy than the tested device: data from other lightning location systems, meteorological radar, satellite, etc.;
- processing archived data for systems that are able to record all the information useful for elaborating warnings; this is the only way to fine tune and verify the settings of the alarm parameters;
- experience: climatology, local observations, unrealistic alarm durations, etc.

The main performance data of a specific TWS are as follows:

- the false alarm ratio (FAR) determined as the ratio of the observed false alarms (FA) to the total observed alarms (FA + EA);

$$\mathrm{FAR} = \frac{\mathrm{FA}}{\mathrm{FA} + \mathrm{EA}} \tag{1}$$

- the failure to warn ratio (FTWR) determined as the ratio of the number of failures to warn (FTW) to the expected total number of alarms (FTW + EA);

$$\mathrm{FTWR} = \frac{\mathrm{FTW}}{\mathrm{FTW} + \mathrm{EA}} \tag{2}$$

- the distribution of lead time (LT);
- the distribution of time to clear (TTC).

Table 2 summarizes how effective alarms (EA), false alarms (FA) and failure to warn (FTW) are counted.

Table 2 – Contingency table

Event	LRE did occur in the SA	LRE did not occur in the SA
Alarm was delivered	EA	FA
No alarm was delivered	FTW	–

The main parameters that can be adjusted to improve the performance of a TWS are as follows:

- the alarm trigger criteria in the monitoring area (MA);
- the size and shape of the monitoring area (MA);
- the dwell time (DT).

A change in parameters will always lead to compromises, for example:

- increasing monitoring area (MA) size will increase the number of alarms, the lead time (LT), along with the false alarm ratio (FAR) and time to clear (TTC);
- reducing monitoring area (MA) size is likely to increase the failure to warn ratio (FTWR) but decrease the false alarm ratio (FAR) and lead time (LT);

- increasing the sensitivity of the triggering criteria will decrease the failure to warn ratio (FTWR) and increase the lead time (LT) but could increase the false alarm ratio (FAR);
- reducing the dwell time (DT) will reduce the time to clear (TTC) but also tend to artificially increase the number of alarms.

According to the warning applications, the goal of performance optimization can be different:

- a minimum false alarm ratio (FAR) and a minimum time to clear (TTC) are required in applications where the cost of service interruption is huge;
- a minimum failure to warn ratio (FTWR) is required in applications where human safety is involved;
- a sufficient lead time (LT) is required in applications where preventive actions require a long time to activate.

8.2 Evaluation of TWS by using lightning location data

Lightning location data is available from many sources (lightning detection networks, satellite observations, etc.) almost everywhere with different quality in terms of detection efficiency (DE) and location accuracy (LA). These data can be used to evaluate the performance of the TWS keeping in mind the limitation due to the given detection efficiency (DE) and location accuracy (LA). Indeed, a poor detection efficiency (DE) of the validation data set will have a tendency to artificially increase the false alarm ratio (FAR).

8.3 Fine tuning of TWS by processing archived data

Some TWS have the ability to save raw data (lightning locations, electric field, etc.) over a long period that can be used to optimize the warning parameters. According to the targeted performance of TWS (low failure to warn ratio, long lead time, etc.) it will be possible to check the sensitivity of desired metrics when the warning parameters (size and shape of monitoring area (MA) and triggering criteria) are adjusted.

In the case of a TWS based on field strength measurements (FSM) the only adjustable parameter will be the triggering criteria. Indeed, in that case, the size and shape of the monitoring area (MA) are strictly merged with coverage area (CA). The optimization will then consist of adjusting threshold values, field variation analysis, peak detections, etc. This will require a sufficient time resolution for the archived data.

In the case of TWS based on lightning detection network it would be possible to adjust the size and shape of the monitoring area (MA), as well as the triggering criteria in order to achieve the optimum performance.

NOTE For some TWS, it is not possible to adjust MA.

9 Thunderstorms warning systems application guide

9.1 General

In general terms, TWS are useful to control, prevent or reduce loss of life, damage to goods/services or properties (with the economic losses associated) and environmental hazards. Risk management for the application of TWS shall consider a wide range of situations. In general terms, a TWS is intended to reduce risks due to dangerous events (LRE) by means of anticipated temporary preventive measures allowing for reduction of the exposure time to the threat and/or isolation of lines which might conduct surges into the structure. More specifically, a TWS is not able to replace a lightning protection system nor is it able to protect against lightning surges, as specified in the IEC 62305 series.

A TWS provides real-time information on atmospheric electric activity, thus the statistical data concerning thunderstorms might have no direct relation with the evaluation of the prevention advisability. Thus, the advisability of implementing lightning safeguard procedures in a certain area depends on the characteristics of the activity performed, the public zones exposed to thunderstorms, its human presence and the possibility of taking effective preventive actions as a consequence of the information provided by the TWS.

IEC 62305-2[17][1] should be used for evaluating the risk on structures.

NOTE How to use a TWS to reduce the risk inside structures is under consideration.

In some cases, for example open air applications, the risk method described in IEC 62305-2 generally cannot be used and a procedure is proposed below.

9.2 Procedure

9.2.1 General

Evaluation of advisability of the use of TWS includes three steps:

1) hazardous situations identification;
2) type of loss determination;
3) risk control: options to reduce the risk (selection, implementation and follow-up of the proper measures for the control and reduction of risk).

This standard does not address any details on preventive actions. For examples of possible recommended preventive actions, however, see Annex D.

9.2.2 Step 1 – Identification of hazardous situations

Identify one or several hazardous situations among the different possibilities of Table 3. In the event of a situation that is not covered in the table, select "Other situations".

Table 3 – Identification of hazardous situations

No.	Situation
1	People in open areas without an appropriate lightning protected shelter available (according to the IEC 62305 series or other IEC standards): outdoor activities, sports (football, golf, etc.), competitions, crowded events, farming, ranching or fishing activities, beaches, leisure areas
2	Safeguard of sensitive goods: computer systems, electric or electronic controls, emergency, alarm and safety systems
3	Losses in operations and industrial processes
4	Structures containing dangerous substances (inflammable, radioactive, toxic and explosive materials)
5	Basic services whose continuity, quality or fast recovery shall be guaranteed (telecommunications, energy generation, transport and distribution, sanitary and emergency services)
6	Infrastructures: ports, airports, railroads, roads, motorways, cableways
7	Safety at workplace (activities that imply a risk at workplace in case of a thunderstorm)
8	Zones that need civil or environmental protection: prevention of forest fires, etc.
9	Buildings, transport or facilities with their external areas open to the public
10	Other situations

9.2.3 Step 2 – Determination of type of loss

For each selected situation of Table 3, evaluate the different losses concerning people (Table 4), goods (Table 5), services (Table 6) and environment (Table 7) to determine the category of loss (A, B, C or –).

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[1] Numbers in square brackets refer to the bibliography.

Table 4 – Loss concerning people

Loss	Category of loss
Loss of human life	A
Serious injuries to people	B
Minor injuries to people	C
No injuries to people	–

Table 5 – Loss concerning goods

Loss	Category of loss
Loss of valuable goods	A
Loss of common value goods	B
Minor losses of goods	C
No loss	–

Table 6 – Loss concerning services

Loss	Category of loss
Loss of valuable services	A
Loss of common services	B
Minor losses of services	C
No loss	–

Table 7 – Loss concerning environment

Loss	Category of loss
Environmental disaster	A
Damages to environment	B
Minor environmental damage	C
No loss	–

9.2.4 Step 3 – Risk control

Determine if the information given by a TWS helps to take temporary preventive actions (as given in Annex C) in order to reduce the risk. If negative, the TWS is not useful (independently of the type of damage). If affirmative, each situation (selected from Table 3) and type of loss (selected from Tables 4 to 7) determines the appropriateness of TWS (see Table 8). In case of several different solutions, the final solution will be given by choosing the safest solution.

Table 8 – Risk control

Worst loss severity (as result of Tables 4 to 7)	Implementation of adequate TWS
A	Very highly recommended
B	Highly recommended
C	Recommended
–	Not recommended

Annex A
(informative)

Overview of the lightning phenomena

A.1 Origin of thunderclouds and electrification

Lightning is produced by electrified clouds, but not all clouds are electrified. Thunderclouds produce lightning and are usually characterized by substantial vertical (deep) development and the simultaneous presence of supercooled cloud drops, ice crystals, and graupel (soft hail) particles. Thunderclouds can also produce high winds and severe weather on the ground (hail, tornados).

Thunderstorms or cumulonimbus clouds are produced by buoyancy forces that are set up initially when sunlight heats the earth's surface and the air in the planetary boundary layer. The thermodynamic basis for the formation of convective clouds is a conditional temperature instability and an initial trigger to start this process. The trigger can be produced by a variety of mechanisms: boundary layer thermals, frontal and gust-front boundaries, orographic lifting (typical in mountains) and frontal surfaces. When buoyant air parcel ascends and enters a lower pressure environment, the parcel expands and cools until the temperature reaches the dew point. After that, the condensation of water vapor produces a cloud, and the latent heat released by the condensing vapor enhances the parcel buoyancy. If the parcel reaches subfreezing temperatures, the conditions for the formation of ice crystals and graupel that are fundamental for cloud electrification and lightning will be present.

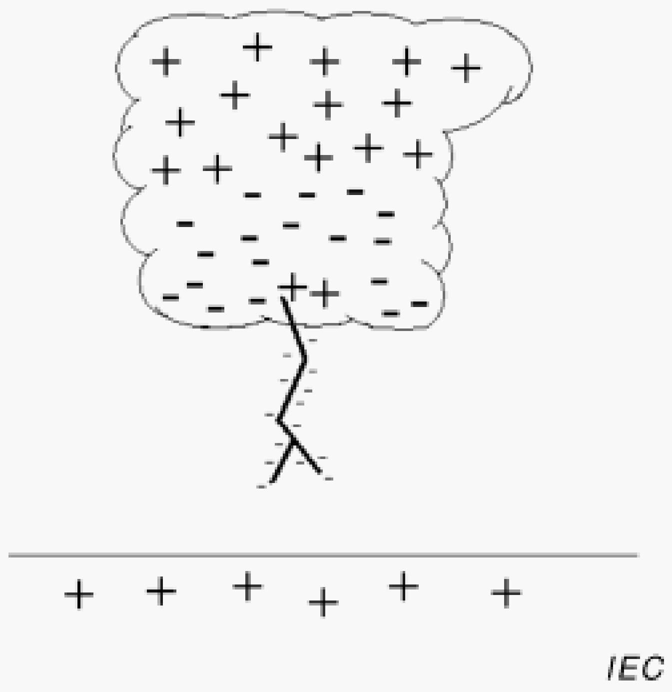
Typical thunderstorm cells are characterized by diameters of 10 km, cloud top altitudes of 12 km, and a life cycle of less than 30 min. But other types of thunderstorms such as multi-cell lines, cluster, super-cells, and mesoscale convective systems (MCS) have larger dimensions and durations that can reach several hours. Different types of thunderstorms tend to occur in different geographic regions.

A model of the charge distribution of a simple thundercloud consists of three charge regions, a concentrated negative layer in the middle of the cloud with a more disperse positive layer above that and a small pocket of positive charge below the negative region. Lightning tends to begin at or near the edge of the negative region, and if it begins near the top of the layer, it usually develops into an intra-cloud (IC) discharge involving the main negative and positive regions. If a discharge begins at or near the lower edge of the negative layer, it can produce a downward-propagating, negative leader and a cloud-to-ground (CG) discharge.

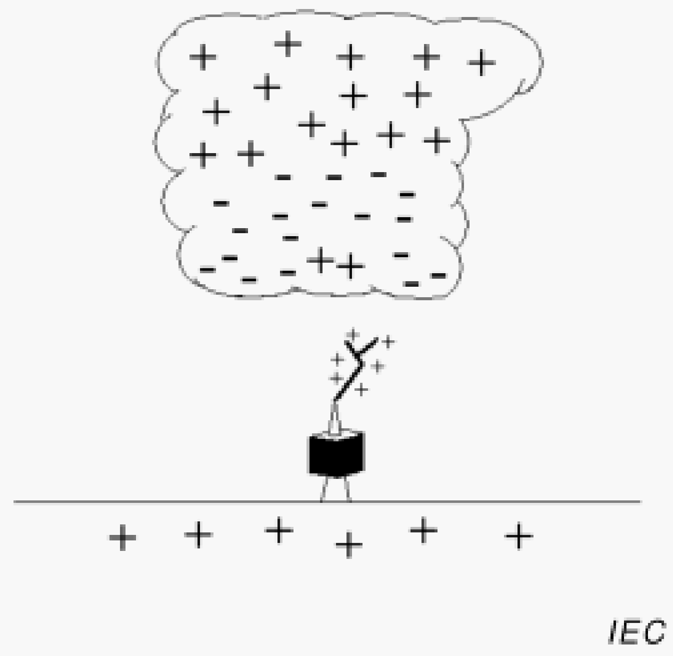
A.2 Lightning phenomena

Although cloud-to-ground (CG) lightning is the most dangerous type for human activities, most of the lightning produced by a thunderstorm does not reach the ground. These flashes are commonly called intra-cloud (IC).

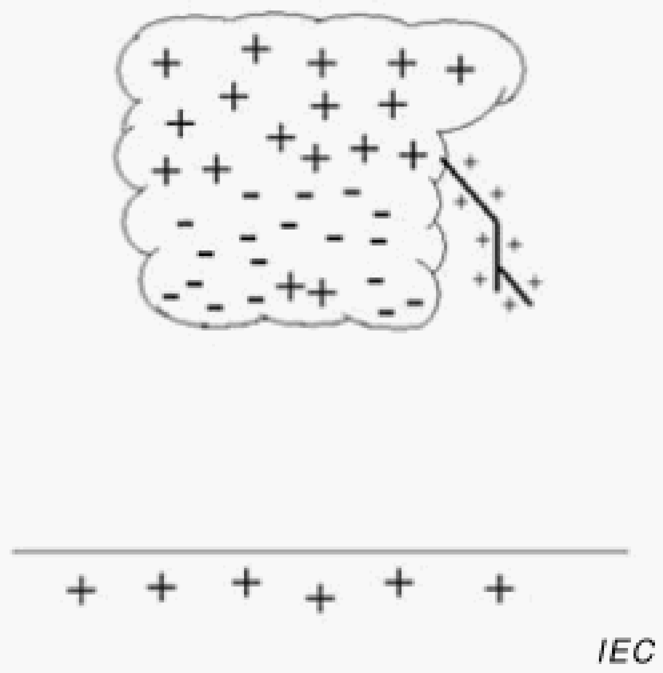
Lightning appears after the thundercloud acquires a certain level of electrification. Intra-cloud flashes usually appear several minutes before the first cloud-to-ground flash, but this is not always the case. The polarity of lightning is defined by the polarity of the electric charge delivered to the ground. Lightning can also be characterized by the direction of the initial leader, downward in the case of cloud-to-ground or upward in the case of ground-to-cloud. Figure A.1 shows the standard lightning classifications. Downward flashes are the most common and upward flashes are usually initiated by tall structures (i.e. structures higher than 100 m or smaller structures in mountainous terrain).



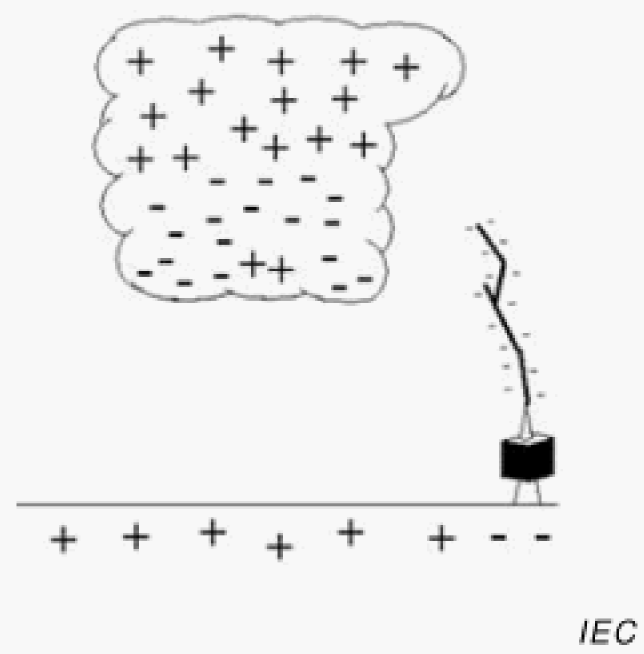
a) Downward negative



b) Upward negative



c) Downward positive



d) Upward positive

Figure A.1 – Standard lightning classifications

The most common type of lightning is negative, downward (typically around 90 %), but not in particular cases such as winter thunderstorms, severe thunderstorms or in the stratiform regions of mesoscale convective systems (MCS) where there can be a preponderance of positive CG flashes. Typically, a downward negative flash begins with a preliminary breakdown process within the cloud that, in turn, produces a downward leader that develops in an intermittent, highly branched and stepped fashion as it propagates toward ground. This process is known as the stepped-leader. When any negative stepped-leader channel gets close to the ground, the electric field under the leader produces one or more upward, connecting discharges that usually emanate from the sharpest extremity of the nearest grounded conductor. When attachment between both leaders occurs, the return stroke begins. The return stroke is an intense pulse of current that transfers current into the ground, and it propagates up the pre-ionized leader channel at roughly a third of the speed of light. The peak temperature of a return stroke is about 30 000 K, and it is the brightest lightning process. The duration of a return stroke is several hundred microseconds to tens of milliseconds, depending on the duration of any continuing current. A subsequent return stroke often appears a few tens of milliseconds after the first return stroke, and there are three to four leader/return stroke sequences in a typical lightning flash.

See [9] for more details.

A.3 Electric thunderstorm and lightning characteristics useful for prevention

A.3.1 Electrostatic field

The electric charge within a thundercloud produces a large electrostatic field at the ground which usually is much larger than the fair-weather electric field. Thus, measuring the electric field of a thunderstorm as it develops or approaches can provide an element of warning but with some limitations. One of these limitations is that the electric field at ground level is not the true field produced by the cloud charge because there are significant layers of space charge between the cloud and the ground. Therefore, it is not possible to define a precise field threshold that corresponds to an imminent lightning strike. The second limitation is that the electric field can only be measured up to a few kilometers from the thunderstorm.

CG and IC flashes produce abrupt changes in the electric field that can be used to detect lightning flashes, and if the field changes are measured at several sites simultaneously, the centroid of the lightning-caused change in the cloud charge can be located. However, locating lightning flashes using changes in the electrostatic field is not a common method.

A.3.2 Electromagnetic fields

A.3.2.1 General

A lightning discharge radiates electromagnetic energy because of the large and rapidly changing currents at the source. This radiation is commonly used to detect and locate lightning using several techniques either individually or combined. Annex B describes several techniques that are in use today.

By locating IC, CG or both types of lightning, a thunderstorm can be tracked for purposes of warning and lightning damage prevention.

A.3.2.2 Detection of IC flashes

In a thunderstorm, IC flashes usually appear before the first CG discharge; thus, cloud discharges are commonly used for warning purposes.

On average, thunderstorms produce two or three times more IC flashes than CG, and this in turn provides more sources for monitoring and tracking the electric activity of a thunderstorm.

The higher IC activity compared with the CG activity also requires more data processing capacity. There can be tens of thousands of sources of electromagnetic radiation in the very high frequency (VHF) range, and this high rate can limit detections to just a few hundred kilometers.

A.3.2.3 Detection of CG flashes

Detection of CG flashes is commonly performed in the low or very low frequency range (LF/VLF), and the range is several hundred kilometres in this frequency range.

A.3.3 Other parameters useful in lightning detection

A.3.3.1 Inter-lightning intervals and lightning rates

The times and distances between flashes provide information about the thunderstorm activity. A lightning rate is the number of flashes per time unit, and this parameter is commonly used to describe the lightning activity of a thunderstorm.

A.3.3.2 IC to CG ratio

The number of IC discharges relative to CG provides information about the lightning activity and type of thunderstorm.

A.3.3.3 CG polarities

Positive flashes are common in winter thunderstorms and in the stratiform regions of mesoscale convective systems (MCS). Moreover, a high percentage of positive CG relative to negative CG may be an indicator of severe weather.

All these parameters are very sensitive to the performance of the lightning location systems used.

Annex B
(informative)

Thunderstorm detection techniques

B.1 Introductory remarks

Annex B explains the classification of thunderstorm detection techniques. Furthermore, it describes the technical methods used in thunderstorm detection and gives guidance in choosing the right type of detector and/or detection system to accommodate the need for lightning information.

B.2 Detection techniques and parameters to qualify a sensor

B.2.1 General

Thunderstorm detectors are classified in relation to the thunderstorm phases depending on the detectable phenomena. However, a thunderstorm detector can detect one or several phenomena. The following subclauses give a description and a brief explanation for every class of detector.

B.2.2 Class A

The purpose of class A detectors is to detect the first sign of a thunderstorm (phase 1), useful for an early warning to take preventive actions, before the occurrence of any intra-cloud or cloud-to-ground lightning and during all the time when the risk of lightning exists. Detection is conducted by the measurement of the electrostatic field produced by the thunderstorm.

The electrification of a thunderstorm, or its simple presence produces an alteration of the fair weather electrostatic field. The atmospheric electrostatic field at ground level during fair weather has a positive value of about 100 V/m to 150 V/m (atmospheric electricity sign convention) in a flat area, as the atmosphere above the earth is positively charged. Under the electrified cloud of a thunderstorm, the electric field at ground level can reach several kilovolts per metre. Commonly the electrostatic field at ground level is screened from the field produced by the cloud due to the presence of screening layers and hence the electrostatic field usually remains below 10 kV/m.

An electric field sensor, for detection purposes, should have a minimum resolution of 200 V/m and should be able to measure an electric field of at least ±20 kV/m. Electrostatic field changes during the initial phase are relatively slow and sampling of the field every few seconds is sufficient. If for the application of the sensor, information concerning changes in the field is needed, a minimum sampling rate of one sample per second is recommended.

The detector device should provide information about the electric field level. Some devices can also provide information about the field evolution in time.

Detectors of class A are able to detect the presence, or not, of an electrified cloud. However, there is no clear electrostatic field threshold that defines the electrostatic field level at which the first lightning discharges are initiated. The monitoring area is strongly constricted by the rapid decrease of the electrostatic field with distance. The measurement of the electrostatic field, therefore, should cover a range of a maximum of 20 km from the border of the charge region. Because it is dependent on the topological environment, it is used as a local detector.

As any nearby lightning causes rapid changes in the electrostatic field, Class A detectors can also provide some information during phases 2, 3, and 4.

In any case, the manufacturer or the service provider should give information about the levels and warning methods, as those levels also depend on the conditions at the installation site, when the measurement is affected by local field enhancement.

B.2.3 Class B

Detectors of class B detect intra-cloud (IC) and cloud-to-ground (CG) flashes (phases 2 to 4). IC discharges produce a large number of RF sources in the VHF frequency range. Typically, IC discharges are detected and located from measurements in this frequency range (around 100 MHz).

A detector for IC flashes should have detection efficiency in accordance with the needs of the application intended by the user (see Annex E). Since the location of the IC activity is important for preventive actions, the manufacturer or the service provider should give the range of detection and the location uncertainty. The location uncertainty for CG flashes should be in accordance with the needs of the application intended by the user (see Annex E).

Information about detection methods and warnings should be given by the manufacturer or the provider.

B.2.4 Class C

Detectors of class C detect cloud-to-ground flashes and also certain intra-cloud flashes. Cloud-to-ground flashes produce significant radiation in the LF frequency range (10 kHz to 500 kHz).

A detector for cloud-to-ground flashes should have flash detection efficiency for the monitoring area higher than 90 %. Since the location of the cloud-to-ground activity is important for preventive actions, the manufacturer or provider should give the range of detection, and the location accuracy. The 50 % location accuracy should be less than 1 km for the monitoring area.

Information about employed detection methods and warnings should be given by the manufacturer or the lightning data provider.

B.2.5 Class D

Detectors of class D detect CG flashes (phase 3) but also other electromagnetic pulses with poor capability of discrimination between lightning events and other signal sources (EMI).

B.3 Location techniques

B.3.1 General

Thunderstorm detectors may be divided according to their application into two kinds of location techniques. To determine where lightning will strike a multi-sensor lightning location system is needed. When only general information about lightning activity and/or a course distance and bearing of a thunderstorm is wanted, a single sensor lightning detector may be appropriate.

B.3.2 Multi-sensor location techniques

There are four kinds of multi-sensor location (ML) techniques:

ML1 Magnetic direction finder (MDF):

The principle of magnetic direction finding is to use two orthogonal magnetic loops measuring the Hx and Hy components of the magnetic field. The magnetic flux into a loop being proportional to the incidence angle, one of the loops will be related to the cosine of the azimuth of the source, while the other will be related to the sine, the ratio of the two providing the tangent of the azimuth.

With two or more magnetic direction finders, locations of lightning strikes can be determined by calculating the cross bearing of the azimuths of the direction finders.

ML2 Time of arrival (TOA):

The principle of time of arrival is to use the delay necessary for a pulse to travel from the source of radiation to the sensors: closer sensors will see the signal before further ones. The time of arrival method can be used in the VLF and LF frequency range as well as in the VHF frequency range.

ML3 Interferometry (RFI):

Interferometry consists in measuring a phase difference between closely spaced antennas. The main difference with time of arrival is that it can operate on continuous wave and therefore there is no need to identify pulses.

ML4 Optical imaging (OI):

Space (satellite)-based sensors are able to detect fast changing optical effects produced by lightning and map them accordingly. This technique is not very accurate but gives the possibility of lightning research over areas where an earth based detection system is not possible, such as over the oceans.

B.3.3 Single sensor techniques

The single sensor (SS) techniques are as follows:

SS1 Field strength measurements (FSM):

The rise of the electric field during the build-up of a thunderstorm may be used to give a warning of an upcoming lightning activity. The fast change in field strength that occurs during a lightning strike is used to determine the actual lightning strikes.

SS2 Magnetic direction finder (MDF):

The magnetic direction finder technique used in lightning detection networks may also be used as a single sensor system giving the azimuth of occurring lightning strikes, providing it has a technique present to determine the distance roughly by measuring the signal strength and/or the signals waveform.

SS3 RF signal strength measurements (RFM)

Measuring the signal strength of the lightning signal on an antenna in itself is not a valid method because of the large variety in lightning current characteristics. Elaborate signal processing and combination with optical detection is able to improve the possibility of determining the distance of a lightning strike significantly. However, the method is, in essence, inaccurate.

All available lightning detection techniques have their own application.

The location methods ML1 to ML3 find their use in lightning detection networks for very practical as well as scientific purposes. They are often exploited as commercial networks making the data available to the general public. These networks can be found all over the world.

Location method ML4 is mostly installed for scientific purposes and installed and owned by universities and governmental organizations.

The single sensor techniques also have distinct properties with different applications.

Type SS1 sensors are useful for early warning at the local level before lightning occurs and over the entire thunderstorm lifecycle.

Detectors according to type SS2 give information on the bearing and distance of actual lightning strikes. They find their users in companies who need accurate, real-time information for safety purposes and who do not want to be dependent on a commercial lightning detection network to provide them with the data needed. However, the users should bear in mind that the information from these sensors is not very accurate, compared with multi-sensor lightning detection networks.

Lightning detectors of type SS3 may be divided in two levels of quality. The more sophisticated sensors have elaborate signal processing on board, determining the distance of the lightning with some accuracy. Some types also use optical sensors to confirm that the signal detected indeed is related to a lightning flash.

The less sophisticated sensors use a simple measurement of the signal strength on a small antenna and have only limited signal processing on board, giving only a very crude indication of lightning activity in the local area. They are fit for purposes of general interest only in lightning activity but not for lightning warning purposes whatsoever.

B.4 Thunderstorm detectors evaluation

For a warning system to be accurate and efficient, it is important that the thunderstorm detector(s) used to elaborate the warning has some level of performance. Several methods can be used in order to verify those characteristics, such as:

- theoretical calculations based on the system configuration and detection technique;
- laboratory tests;
- comparisons between different systems;
- experimental validation with instrumented towers or time-stamped video or picture recordings;
- *in situ* validation.

B.5 Choosing a thunderstorm detection system

According to the risk evaluation presented in Annex C and the preventive actions described in Annex D, it is possible to choose thunderstorm detectors in order to build a TWS. Depending on the warning application and the availability of lightning information, several detection techniques can be suitable. The final decision requires a detailed analysis of the warning needs (necessary lead time, acceptable failure to warn and false alarm ratios), the allowed budget and what each detection technique can provide.

As an example, a very good description of what has been done for airport safety can be found in [4].

Annex C
(informative)

Examples of application of thunderstorm warning systems

NOTE In the tables in Annex C the relevant selection(s) is/are shown with a white background. The selection(s) not relevant is/are shown with a grey background.

C.1 Example n° 1 – Telecommunication tower

C.1.1 Step 1: Identification of hazardous situations

Identify one or several hazardous situations among the different possibilities of Table C.1. In case of a situation not covered in the table, select "Other situations".

Table C.1 – Identification of hazardous situations

No.	Situation
1	People in open areas without an appropriate lightning protected shelter available (according to the IEC 62305 series or other IEC standards): outdoor activities, sports (football, golf, etc.), competitions, crowded events, farming, ranching or fishing activities, beaches, leisure areas
2	Safeguard of sensitive goods: computer system s, electric or electronic controls, emergency, alarm and safety systems
3	Losses in operations and industrial processes
4	Structures containing dangerous substances (inflammable, radioactive, toxic and explosive materials)
5	Basic services whose continuity, quality or fast recovery shall be guaranteed (telecommunications, energy generation, transport and distribution, sanitary and emergency services)
6	Infrastructures: ports, airports, railroads, roads, motorways cableways
7	Safety at workplace (activities that imply a risk at workplace in case of a thunderstorm)
8	Zones that need civil or environmental protection: prevention of forest fires, etc.
9	Buildings, transport or facilities with their external areas open to the public
10	Other situations.

C.1.2 Step 2: Determination of type of loss

For each selected situation of Table C.1, evaluate the different losses concerning goods (Table C.2), services (Table C.3), and environment (Table C.4) to determine the category of loss (A, B, C or –).

The loss of human life is not considered in this example.

Table C.2 – Loss concerning goods

Loss	Category of loss
Dangerous goods (chemical, explosive)	A
No loss	–

Table C.3 – Loss concerning services

Loss	Category of loss
Loss of valuable services	A
Loss of common services	B
Minor losses of services	C
No loss	–

Vital equipment can be destroyed by direct and nearby lightning thus interrupting the service.

Table C.4 – Loss concerning environment

Loss	Category of loss
Environmental disaster	A
Damages to environment	B
Minor environmental damage	C
No loss	–

C.1.3 Step 3: Risk control

The loss of human life is not considered in this example. The loss of goods is negligible and there is no loss concerning the environment. The loss concerning services is in the highest category and therefore this determines the selection of loss severity of A in Table C.5 with TWS very highly recommended.

The installation of a TWS can enable action to be taken to reduce substantially the loss of service resulting from a direct strike to the power lines (by disconnecting the power supply from the external network, ensuring that there is adequate separation distance to avoid flashover of any lightning current, and, if available, connection to a local standby generator). However the use of a TWS cannot assist in reducing the risk arising from a direct strike to the structure.

Table C.5 – Risk control

Severity of the loss (as result of Tables C.3 to C.4)	Implementation of adequate TWS
A	Very highly recommended
B	Highly recommended
C	Recommended
–	Not recommended

C.2 Example n° 2 – Golf course

C.2.1 Step 1: Identification of hazardous situations

Identify one or several hazardous situations among the different possibilities of Table C.6. In the case of a situation not covered in the table, select “Other situations”.

Table C.6 – Identification of hazardous situations

No	Situation
1	People in open areas without an appropriate lightning protected shelter available (according to the IEC 62305 series or other IEC standards): outdoor activities, sports (football, golf, etc.), competitions, crowded events, farming, ranching or fishing activities, beaches, leisure areas
2	Safeguard of sensitive goods: computer systems, electric or electronic controls, emergency, alarm and safety systems
3	Losses in operations and industrial processes
4	Structures containing dangerous substances (inflammable, radioactive, toxic and explosive materials)
5	Basic services whose continuity, quality or fast recovery should be guaranteed (telecommunications, energy generation, transport and distribution, sanitary and emergency services)
6	Infrastructures: ports, airports, railroads, roads, motorways, cableways
7	Safety at workplace (activities that imply a risk at workplace in case of a thunderstorm)
8	Zones that need civil or environmental protection: prevention of forest fires, etc.
9	Buildings, transport or facilities with their external areas open to the public
10	Other situations

C.2.2 Step 2: Determination of type of loss

For each selected situation of Table C.6, evaluate the different losses concerning people (Table C.7), goods (Table C.8), services (Table C.9) and environment (Table C.10) to determine the category of loss (A, B, C or –).

Table C.7 – Loss concerning people

Loss	Category of loss
Loss of human life	A
Serious injuries to people	B
Minor injuries to people	C
No injuries to people	–

During thunderstorm activity, there is a potential lightning threat for everyone outside in the open area of the golf course. Additional information can be found in [7].

Table C.8 – Loss concerning goods

Loss	Category of loss
Dangerous goods (chemical, explosive)	A
No loss	–

Table C.9 – Loss concerning services

Loss	Category of loss
Loss of valuable services	A
Loss of common services	B
Minor losses of services	C
No loss	–

Table C.10 – Loss concerning environment

Loss	Category of loss
Environmental disaster	A
Damages to environment	B
Minor environmental damage	C
No loss	–

C.2.3 Step 3: Risk control

The loss category A in Table C.7 determines the TWS selection ‘very highly recommended’ in Table C.11

The loss concerning people can be reduced by avoiding having people exposed to the lightning threat.

Table C.11 – Risk control

Severity of the loss (as result of Tables C.7 to C.10)	Implementation of adequate TWS
A	Very highly recommended
B	Highly recommended
C	Recommended
–	Not recommended

Annex D
(informative)

Catalogue of possible recommended preventive actions to be taken

Preventive actions resulting in a better knowledge of the lightning and/or storm electrification hazard strongly depend on the involved risk situation. These actions should therefore be evaluated and applied in a detailed plan of action.

There is a great variety of situations and facilities that may need the implementation of a thunderstorm detection system. Thus, the actions taken from an analysis resulting from the preventive information given by this system should be specifically defined by the final user or by a designer specifically focused on this implementation.

For this purpose, what should be taken into account is either the security and emergency plans or the possible technical modifications to be carried out in processes and systems.

It should be kept in mind that decisions on preventive actions can involve actions (automatic, manual, acoustic, etc.) systemized into their own processes.

In order to give guidance on possible preventive actions, some example directives that could be implemented from the preventive information given by the detection system are listed. These actions have a logical grading depending on the severity of the thunderstorm, which determines the activation level reached by the system:

No alert level:

- Normal operation in the target area

Level 1 – Alert:

- Primary preventive actions, consisting of informative notices, for example, remote, visual or acoustic messages, etc.
- Auxiliary power systems can be activated
- Do not plan or start activities in exposed zones

Level 2 – Emergency:

- Secondary preventive actions
- Auxiliary power systems can be activated
- Critical and sensitive systems can be disconnected
- Possible evacuation of exposed zones to safe areas protected by an LPS
- Check that previous actions have already been engaged efficiently
- Follow up the evolution of lightning activity
- No additional action when previous actions are already engaged

Level 3 – End of alert:

- Back to normal operation in the target area
- When an LRE has occurred, inspect the state of the LPS depending on the regulations

The procedure is summarized in the flow chart given in Figure D.1.

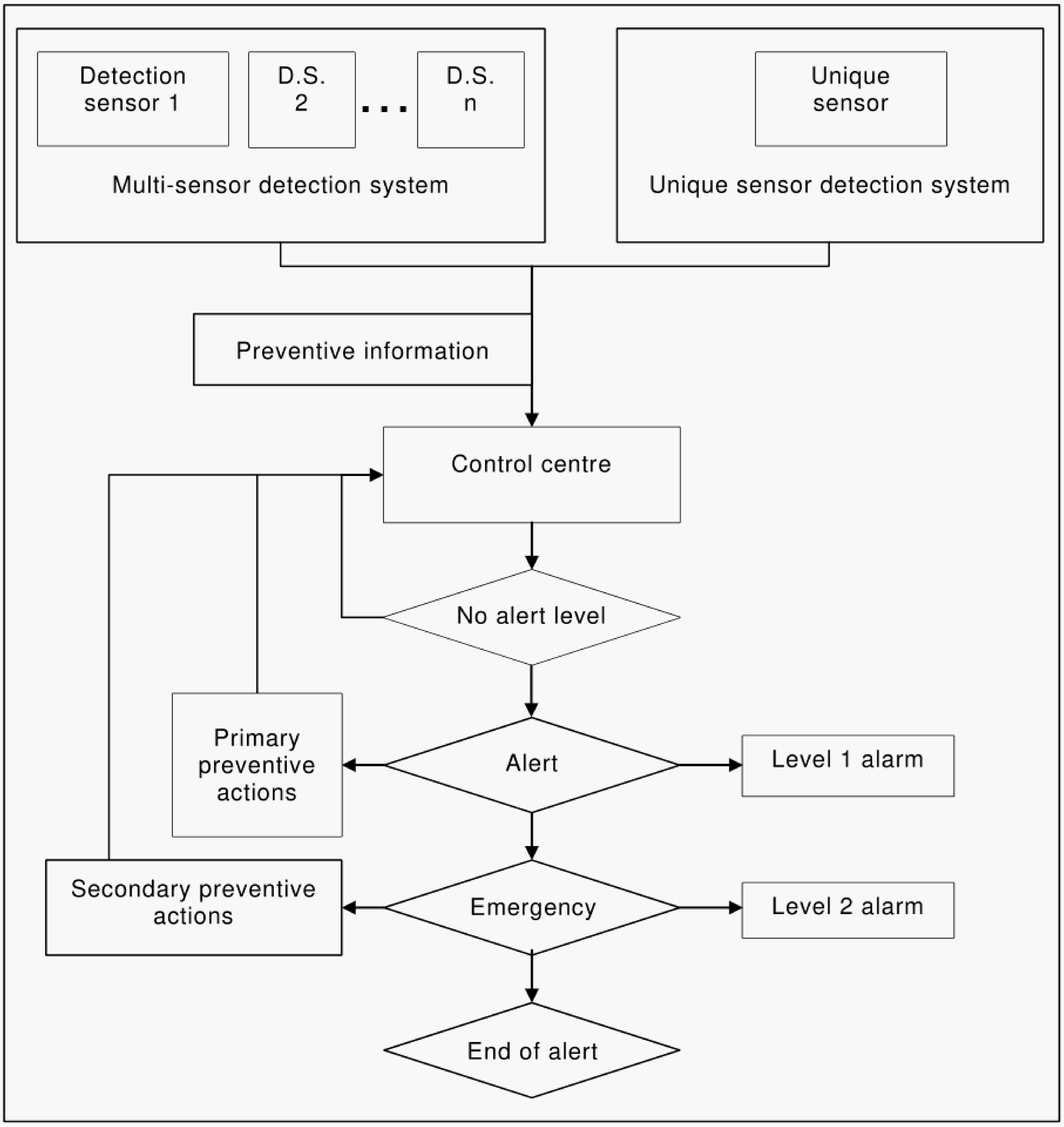


Figure D.1 – Procedure flow chart

Annex E
(informative)

Example of TWS evaluation on a wind turbine site

In this example, lightning data are used to trigger the warnings and also to evaluate the efficiency of the alarms by checking what really occurred at the site location. Figure E.1 shows the CG lightning activity 5 km around the site for a period of eight years.

NOTE A different approach can be used for TWS of class A.

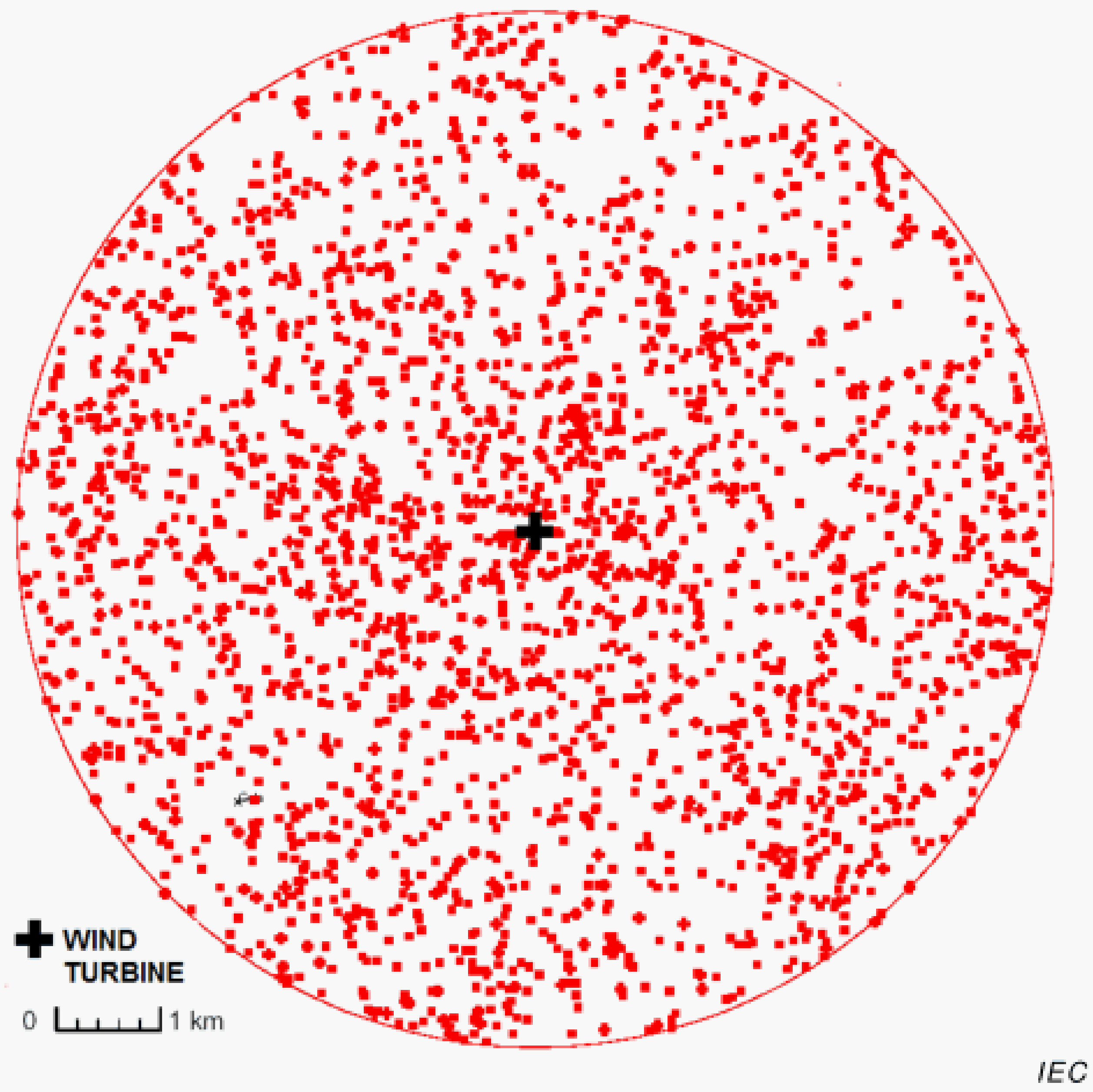


Figure E.1 – Lightning activity around the site for a period of eight years

The target area is a circular area of 1 km radius around the site. The surrounding area (SA) is assumed to be a circle of 5 km radius around the site (same area as displayed in Figure E.1). The monitoring area (MA) consists also of a circular area around the site.

In this example the varying parameters are as follows:

- radius of the monitoring area (MA) (10 km, 15 km and 20 km);
- triggering criteria (number of flashes and time between flashes);
- dwell time (DT) (10 min, 20 min, 30 min).

All results are presented in Table E.1.

Table E.1 – Results of TWS evaluation based on archived lightning data for an 8-year period (2000 to 2007), when some of the key parameters (size of MA, trigger parameters and dwell time) were varied

Radius MA (km)	**Number of flashes to trigger alarm**	**Time between strokes for triggering** (ms)	**Dwell time (DT)** (min)	**Number of alarms (FA + EA)**	**EA**	**FTW**	**FA**	**FAR** (%)	**FTWR** (%)	**POD_{10}** (%)[a]
20	2	5	30	285	102	1	183	64	1	89
15	2	5	30	220	102	2	118	54	2	85
10	2	5	30	145	102	4	43	30	4	73
20	1	5	30	571	102	1	469	82	1	93
20	2	5	30	285	102	1	183	64	1	89
20	3	5	30	229	102	2	127	55	2	93
20	5	5	30	165	102	5	63	38	5	88
20	2	2	30	264	102	2	162	61	2	93
20	2	4	30	281	102	1	179	64	1	89
20	2	5	20	321	102	1	219	68	1	89
20	2	5	10	420	102	2	318	76	2	86

[a] POD_{10} is the percentage of alarms delivered with a lead time of more than 10 min.

Annex F
(informative)

How to test thunderstorm detectors

F.1 General

Annex F only applies to outdoor thunderstorm detectors. Annex F does not apply to TWS where maintenance is the duty of the TWS operator and does not cover software and indoor hardware. A more complete Annex dealing with the testing of TWS is under consideration.

F.2 Laboratory tests

F.2.1 General

F.2.1.1 General conditions for the tests

Tests are carried out with the specimens assembled and installed as in normal use, according to the manufacturer's or supplier's instructions. The sensor is tested and the remote control, when it is needed for some tests, shall be located in the control room of the laboratory, unless otherwise specified by the manufacturer.

All tests are carried out on new specimens unless otherwise specified.

One specimen is subjected to the tests. The requirements are satisfied if all the tests are met. If the specimen does not satisfy a test due to an assembly or a manufacturing fault, that test and any preceding test which may have influenced the results of the test shall be repeated. The tests which follow shall also be carried out in the required sequence on a set of 3 specimens, all of which shall comply with the requirements.

F.2.1.2 Identification of the sensor or assembly (sensor + cable + remote control) submitted for testing

The detectors submitted for testing shall be identified by means of the following elements:

- marks and indications;
- assembly instructions with reference and date.

F.2.1.3 Assembly of the detectors

The detectors shall be mounted in accordance with the instructions specified by the manufacturer in his assembly instructions.

F.2.1.4 Conditions of ambient temperature and moisture

Unless otherwise specified, the tests are carried out at an ambient temperature ranging between 5 °C and 35 °C and shall not vary during the duration of tests by more than 30 K. The detectors shall be protected from heating or an excessive external cooling.

F.2.2 Resistance to UV radiation tests (for non-metallic sensor housing)

Non-metallic sensor housings for outdoor application shall withstand UV effects.

In order that a sensor meets the requirements of this standard, environmental tests shall be carried out according to IEC 62561-4 [10]. This test is necessary for detectors designed to be installed outdoors or in specific environments.

One sensor shall be assembled and mounted rigidly on an insulating plate (e.g. brick, Teflon) in accordance with the manufacturer's installation instructions.

The specimen shall be subjected to an environmental test consisting of an ultra violet light test as specified in IEC 62561-4.

Passing criteria

The specimen is deemed to have passed this part of the test if there are no signs of disintegration and no cracks visible to normal or corrected vision.

F.2.3 Resistance tests to corrosion (for metallic parts of sensor)

The specimen used for F.2.2 shall be subjected to corrosion tests according to IEC 62561-1 [9] consisting of a salt mist treatment followed by a humid sulphurous atmosphere treatment.

Passing criteria

After the parts have been dried for 10 min in a drying oven at a temperature of 100 °C ± 5 °C, they should not present any trace of rust on surfaces.

One does not take into account traces of rust on the edges, nor a yellowish veil disappearing by simple friction. White rust is not considered as corrosive deterioration.

F.2.4 Mechanical tests

The specimen used for F.2.3 shall be stressed three times by a mechanical test.

The sensor is subjected to mechanical test by applying mechanical impacts.

The impacts are carried out on the accessible parts of the sensor which may be mechanically stressed accidentally.

The specimen is assembled under its normal operating conditions specified in the manufacturer's documentation.

Testing device

The sensor is mounted on a pendulum hammer test apparatus according to Clause 4 of IEC 60068-2-75:2014. The striking element material shall be polyamide according to Table 1 of IEC 60068-2-75:2014, its mass shall be 200 g according to Table 2 of IEC 60068-2-75:2014.

Test procedure

The hammer is allowed to fall from a height of 200 mm so that one impact on each side is applied as far as possible perpendicular to the length of the arrangement. The drop height is the vertical distance between the position of the point of control, when the pendulum is released, and the position of this point at the time of the impact.

The point of control is located on the surface of the striking part where the line passing by the point of intersection of the axes of the steel tube of the pendulum and the part of striking, perpendicular to the plan crossing the two axes, comes into contact with the surface.

The impacts are not applied to the display window or to connectors.

Passing criteria

After the test, the sensor shall show no cracks or similar damage visible to normal or corrected vision without magnification and shall not present damage which can potentially affect its later use.

F.2.5 Index of protection confirmation (IP Code)

IP confirmation shall be performed in accordance with IEC 60529 [12], on the specimen used for F.2.4.

Passing criteria

The specimen shall be in compliance with IEC 60529 requirements.

F.2.6 Electric tests

F.2.6.1 General

After the test F.2.5, the specimen shall be tested with the following electric tests.

The tests are carried out in accordance with IEC 61180-1 [13].

F.2.6.2 Test under DC electric field

The sensor is mounted below a testing plate with dimensions such that the electric field in the area centered below it is homogeneous (variation around the linear electric field by less than 2 %). This can be demonstrated by a simulation or by measurement. The field effect at the edge of the plate should be taken into consideration to achieve the homogeneous rule.

The sensor should be mounted as in normal use and should be located so that its highest point is at 1 m above the ground plate located below the testing plate. Use of wooden support is allowed to obtain this distance above ground.

The testing plate should be at 2 m (so 1 m above the highest point of the sensor) with a tolerance of ± 1 cm.

The voltage applied on the plate should be a DC high voltage (negative polarity) to obtain an electric field at sensor head varying from 1 kV/m to 10 kV/m.

The voltage is increased to obtain at the sensor head 10 values equally distributed between 1 kV/m and 10 kV/m.

Detectors are mounted with their cable and attached remote control.

Passing criteria

No detectors should be disturbed by this test. This is checked by monitoring the data collected on the remote control.

A sensor that does not lead to a valid indication (warning or measurement of electric field to meet the criteria defined by the manufacturer) on the remote control for that test should provide such a valid indication for the F.2.6.3 test. Failure to do so is considered as a failure of that test.

Failure to meet one or more of these criteria means that the test has failed.

F.2.6.3 Test with high current impulse

The sensor is mounted as in normal use and located at least 5 m from a discharge path created between two electrodes with a distance of at least 1 m between them and with a Marx generator, organized in such a way that the impulse current meets the criteria of a 8/20 μs shape.

The sensitivity of the sensors should be tested in a laboratory able to generate electromagnetic fields according to the manufacturer's specifications.

Passing criteria

No detectors should be disturbed by this test. This is checked by monitoring the data collected on the remote control.

A sensor that does not lead to valid electric indications (according to the manufacturer's specifications) on the remote control for that test, it should provide such a valid indication for the test mentioned in F.2.6.2. Failure to do so is considered as a failure of that test.

Failure to meet one or more of these criteria means that the test has failed.

F.2.7 Marking test

All specimens used, and complying with the tests of F.2.6, shall be subjected to marking tests.

Applicability

Marking made by molding, pressing or engraving is not subjected to this test.

Marking test

The marking is checked by inspection and by rubbing it by hand for 15 s with a piece of cloth soaked with water and again for 15 s with a piece of cloth soaked with white spirit.

Passing criteria

After the test the marking shall be legible. Marking shall allow the identification of the sensor. It should not be possible to remove the labels easily.

F.2.8 Electromagnetic compatibility (EMC)

F.2.8.1 Electromagnetic immunity

Detectors shall fulfil the requirements of IEC 61000-6-4 [14].

F.2.8.2 Electromagnetic emission

Detectors shall fulfil the requirements of IEC 61000-6-4.

F.3 Optional tests on an open air platform under natural lightning conditions

Due to the difficulty in representing the lightning conditions in a laboratory, the design and use of a thunderstorm detector should be validated either by field application under a valid testing scheme, using if possible third party approval, or to test it on an open air platform.

The platform should be located in an area prone to lightning, as the testing period should not exceed one year (ideally six months). A typical site should have a yearly average number of thunderstorm days of twenty or above (see IEC 62858-1 [16] for adjusting testing period to the lightning activity of the site).

A lightning monitoring system should be used by this platform as a reference. This monitoring system should be validated by other means (to be determined and justified by the open air laboratory team, for example the parameters of the reference system may be checked under triggered lightning conditions) and will be used as a reference for the experiment. It may be a proven system, to be used as a reference to compare the other thunderstorm detectors. It is also possible to make inter-comparison of two thunderstorm detectors and to see how they react under the same event.

The lightning monitoring system should have a known efficiency for lightning detection, including as far as possible intra-cloud discharges. Ability to locate cloud-to-ground discharges and determine the ratio of intra-cloud discharges to all discharges will allow the system to determine the early warning capacity of tested thunderstorm detectors as well as the failure rate. The location accuracy should be at least 500 m. This is to be demonstrated by the open air laboratory team using ground truth data. If intra-cloud discharges are detected by the device under test, then it should also be detected by the lightning monitoring system

This reference lightning monitoring system should also provide the lightning density in the given area at the given time. Using analyzing tools, it should be possible to forecast the direction(s) of movement of thunder clouds with a high level of confidence.

The thunderstorm detectors under test should be located on an open air platform in conditions defined by the manufacturer.

There are a lot of influencing factors on the electric field. Distinctive differences of monitoring data between different thunderstorm detectors also exist. So it is clear that false warnings and missed warnings will occur. For example, Figure F.1 shows the variation curve of the electric field measured by two different thunderstorm detectors (A and B) during the same lightning event. In this example, the time scale is different for the two detectors.

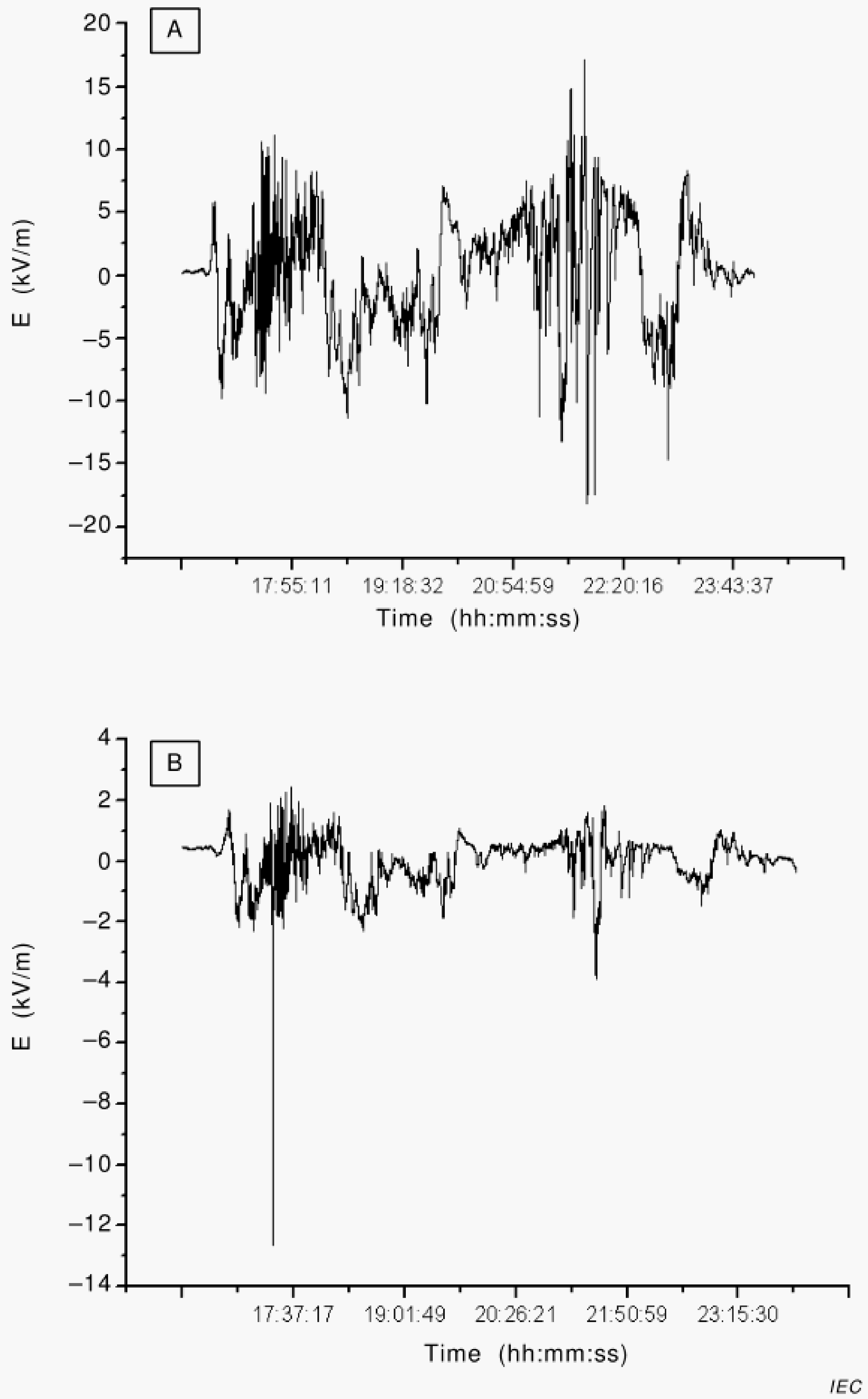


Figure F.1 – Difference in electric field measurement during one thunderstorm event

It is noted that, even in fair weather, the fields recorded are not always exactly the same. In the case of thunderstorms, the difference becomes greater. The software and techniques used by the thunderstorm detectors is proprietary but the warning provided to the user should be similar or at least consistent with what is declared in the thunderstorm detector data sheet.

For example, during the above event, there were obvious distinctions between data from the two devices under test. The maximum and minimum values of the electric field observed by one of them was +2,5 kV/m and −12,7 kV/m respectively, while for the other they were ranging between +17 kV/m and −17 kV/m respectively, as can be seen in Figure F.1. The basic test for a thunderstorm detector is to check if the events recorded by the thunderstorm detector under test are consistent with the events recorded by the reference system. Failure to do so regularly, will give an indication of the inability of the thunderstorm detector to perform as announced. Thus, many events are needed and it is foreseen that at least 10 thunderstorm events are needed to validate the operational quality of the thunderstorm detector. This means that the testing duration is usually between six months to one year. It may be extended after agreement between the laboratory and the manufacturer of the thunderstorm detector under test.

False warnings may occur and also need to be evaluated. Even if the measuring system is the same, the electronic treatment and numerical treatment may differ, leading to different conclusions and to different levels of reliability.

Parameters measured at the open air testing platform are as follows:

- LT
- POD_x
- FAR
- FTWR

These parameters should be related to the area defined by the manufacturer's data sheet.

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