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A Case Study to Risk Assessment for Protecting Airports against Lightening

I. Tarımer
Faculty of Technology, Muğla University,
Muğla, Türkiye, phone: +90 252 211 1722, e-mail: itarimer@mu.edu.tr
B. Kuca, T. Kisielewicz
Warsaw University of Technology,
Warsaw, Poland, phone: +48502700961, e-mails: kucab@ee.pw.edu.pl, t.kisielewicz@usk.waw.pl

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Introduction

The dangerous effects of strikes to airport can include actuation of safety systems, and loss of fire protection. With the advent of digital information systems and low-voltage electronic devices in safety systems, lightning protection is becoming increasingly more important to the operations of an airport [1, 2].

There are no devices and methods capable of preventing for lightening discharges [3]. Appearance of the lightning flash creates an impulsive fast surge which could be a source of damage for "critical" structures in APs. The type of damage depends both on the position of the point of the strike relative to the AP and on its characteristic and systems involved [2]. The occurrences which are caused by lightning can threat people, critical structures, internal electrical and electronic systems due to electromagnetic effects of lightning current, so that the selection of adequate protection measures for airports has a high priority [3–10].

Parameters of lightning current

Lightning parameters were investigated from the middle of the last century and these parameters are usually obtained from measurement taken on high objects. The most important parameters for the purpose of designing protection systems [6] are peak value of the first stroke, maximum rate of rise (inductive effects of lightning current and dangerous sparking), flash duration and total charge in the flash, specific energy in a flash [2–4].

In the risk assessment it is crucial the knowledge of the average lightning flash density (N_g) of the AP region and the connected electrical and data lines are placed. Ng values (expressing the number of flashes per km^2 per year) can be assessed by different methods – thunderstorm days maps, lightning flash counters – and, more recently, by lightning location systems [7, 8].

Risks of lightning strikes

For the purposes of lightning protection APs may be classified as "critical structures" due to the very heavy consequential effects of lightning flash which can cause damage to the structure [5]. Fig.1 shows a case during lightning at an airport [1].

Fig. 1. Issues for lightning protection in an Airport

Cloud-to-ground lightning strokes present a clear and immediate danger for ground personnel involved in outdoor ramp operations. When this danger presents, airport ramp operations and airport staff engaged in outdoor activities are suspended until the threat has passed [1]. The impact of lightning events in the vicinity of, and on, airport operating areas has long been recognized as both a safety and an operational issue by airport and airline operators. Although the number of aircraft ramp injuries and deaths attributed to lightning events is thought to be low, there has been no effort to collect such data into a systematic database because of there is no requirement to report such incidents to authorities [1].

Direct and nearby cloud-to-ground discharges can be hazardous to structures, persons, installations and other systems within or on structures. So, the application of lightning protection measures must be considered. The decision for the need for protection and the selection of protection measures in AP should be determined in terms of risk; it means that these measures should be adequate to reduce the risk to a tolerable level.

The decision for the need for protection of the critical structures and the selection of protection measures should be determined in terms of risk, which means that these measures should be adequate to reduce the risk to a tolerable level. The modern approach is that of risk management which integrates the need for protection and the selection of adequate protection measures taking into account the efficiency of the measures. In the risk management approach, the lightning threats that create risk are identified, the frequencies of all risk events are estimated, the consequences of the risk events are determined and, if these are above a tolerable level of risk, protection measures are applied to reduce the risk (R) to below the tolerable level (R_T).

The criteria for design, installation and maintenance of lightning protection measures may be distinguished as protection measures to reduce mechanical damages, fire, explosion danger and life hazard due to direct lightning flashes to the structure; protection measures against the electromagnetic effects of lightning on electrical and electronic systems within a structure; protection measure to reduce the loss of services entering the structure, power, telecommunication and data lines.

It should be stressed that the selection of adequate protection measures aim to reduce not only the risk by direct flashes to the structure but even the risk for low-voltage and electronic systems against indirect flashes, it means the risk due to flashes to ground near the structure, flashes direct to the lines or flashes to ground near the lines entering the AP.

Influence of lightning flashes in AP

Current of a lightning striking an AP can result in damage to the structure itself and to its occupants and contents, including failure of equipment and especially of electrical and electronic systems. The damages and failures may also extend to the surroundings of the structure and may even involve the local environment. The scale of this extension depends on the characteristics of structure and lightning flash which is corresponding to location of AP.

The main characteristics of APs of relevance to lightning effects include construction, function, occupants and contents, entering installations, measures to limit consequential effects of damages and scale of the extension of danger. The lightning current is the source of damage. The causes of damage depend from the position of the striken point in relation to the AP. The lightning flashes direct to an AP can cause immediate mechanical damage, fire and/or explosion due to the lightning channel itself, and its charge; fire and/or explosion initiated by sparks caused by overvoltages resulting from resistive and inductive coupling; injuries to people by step and touch voltages resulting from resistive and inductive coupling; failure or malfunction of electrical and electronic systems due to the flowing of part of the lightning currents and to overvoltages (i.e. up to 100 million volts of electricity).

The flashes direct to the connected lines, radar, mains, telecommunication, data lines and other services can cause fire and/or explosion triggered by sparks due to overvoltages on the structure; injuries to people due to overcurrents and to overvoltages; failures or malfunction of electrical and electronic systems due to overvoltages.

The flashes to ground near the incoming lines and services can cause failures or malfunction of electrical and electronic systems due to overvoltages induced in external lines connected to the structure. In APs due to lightning it is possible to distinguished following typical damages [6, 7, 8, and 10]:

– A loss of offsite power occurs and feeding the airport to the power system is disconnected by circuit breakers;
– A lightning strike on a transmission line creates a surge on the line;
– Failure of data, radar and telecommunication systems due to inductive overvoltage could be seen;
– Physical damage of meteorological and other outdoor equipment due to direct strike could be seen.

Each type of damage, alone or in combination with others, may produce different consequential loss in an AP. It is possible to distinguished loss of human life, loss of service to the public and loss of economical value.

Basic criterion for assessment of risk due to lightning

The lightning hazard impending over an AP is a random process composed of a set of effects which are correlated with the parameters of lightning discharge, the characteristics of the AP, its content, the installation internal to the structure, the lines and other services entering the structure. If the time of observation is fixed as 1 year, it is possible to demonstrate [1, 3] that the risk, defined as the probability to have an annual loss in an AP due to lightning, may be calculated by the following expression

$$R = 1 - e*(- N*P*L), \quad (1)$$

where N is the average yearly number of flashes influencing the AP and its content, P is the damage probability of the AP due to single flash and L is the average amount of loss, with consequential effects, due to single flash.

The quantity PL is the level of risk or the number of annual loss in an AP due to lightning. It is evident that if $P*L << 1$ (in practice $P*L < 0.1$), the risk and the level of risk are coincident. The International Standard [4] defines the risk as the probable annual loss in a structure due to lightning, and suggest evaluating it by the following general formula

$$R = N* P* L. \quad (2)$$

It is generally accepted to evaluate the number N by the product of the lightning ground flash density N_g by an equivalent collection area A of the structure. The lightning ground flash density, in number of lightning flashes per

km^2 and per year, should be determined by measurements. Networks of flash counters or, more recently, of lightning location systems are installed in several countries to build maps of N_g. The value of Ng may be taken from the international standard [4] using the following relation

$$N_g = 0.04 * T_d * 1.25, \quad (3)$$

where T_d may be obtained from the isokeraunic maps.

Isokeraunic map shows mean annual number of days with thunderstorms. The equivalent collection area of the structure, i.e. the surface crossed by all the lightning flashes (upward and downward) which hit the structure, depends on the height, the position with respect to the other, the type of the incoming and out coming line, environmental characteristics and lightning characteristics.

Probability of damage, loss and risk components: There are different difficulties in order to evaluate the probability of damage P. It is important to note that in some cases the probability of a damage due to single stroke is a result of the product of two probabilities of two events related in series sequence, while in some other cases the probability of damage has to be calculated as the parallel combination of two probabilities of two events in parallel sequence. The first case is relevant to the probability of fire calculated as the product of the probability of a sparking (ps) and the probability that a spark could trigger a fire (pf)

$$P = ps * pf, \quad (4)$$

While the second case is related to the probability of failure of electronic system due to overvoltages by direct flash to a structure, calculated by the following relation

$$P = [1 - (1 - pr) * (1 - pi)], \quad (5)$$

where pr is the probability of system failure due to overvoltage by resistive coupling of the current flowing into the earth and pi is the probability of system failure due to overvoltage by inductive coupling of the internal loop installation with the lightning current flowing.

The values of consequent loss L depend on the use to which the AP is assigned, the number of inhabitants of dangerous zone, the number of attendance time of persons, the type of service provided to public, the value of goods affected by damage, measures provided to limit the amount of damage. The following types of risks can be taken into account, corresponding to the types of loss:

1. R_1 – risk of loss of human life;
2. R_2 – risk of loss of services to the public;
3. R_3 – loss of cultural heritage exist;
4. R_4 – risk of loss of economic value.

Each type of risk may be calculated as the sum of different risk components, each expressed by formula (2), depending on the cause of damage:

1. Lightning flashes direct to the structure may generate:

– component R_A related to shock of living beings due to touch and step voltages,

– component R_B related to fire, explosion, mechanical and chemical effects inside and outside the structure,

– component R_C related to the failure of electrical and electronic systems AP safety related due to overvoltages on internal installations and incoming services.

2. Lightning flashes to ground near the structure may generate:

– component R_M related to the failure of electrical and electronic systems AP safety related due to overvoltages on internal installations mainly caused by magnetic field generated by the lightning current.

3. Lightning flashes direct to the incoming line may generate:

– component R_U related to shock of living beings due to touch and step voltages,

– component R_V related to fire, explosion, mechanical and chemical effects inside and outside the structure,

– component R_W related to the failure of electrical and electronic systems AP safety related due to overcurrents and overvoltages.

4. Lightning flashes to ground near the incoming line may generate:

– component R_Z related to the failure of electrical and electronic systems of AP.

For each type of losses, the value of risk R is then given by the sum of its components and may be calculated with reference to the point of strike

$$R = R_D + R_I, \quad (6)$$

where

$$R_D = R_A + R_B + R_C, \quad (7)$$

where R_D is the risk due to direct flashes to the structure and

$$R_I = R_M + R_U + R_V + R_W + R_Z, \quad (8)$$

where R_I is the risk due to indirect flashes to the structure.

Aim of the protection against lightning is to reduce the risk R to a maximum level R_T which can be tolerated for the structure to be protected

$$R \leq R_T. \quad (9)$$

If more than one type of damage could appear in the structure, the condition $R \leq R_T$ shall be satisfied for each type of damage. The values of tolerable risk R_T where lightning involve loss of social values should be under the responsibility of national body concerned. The values of tolerable risk R_T, where lightning strikes involve only private economic loss, could be fixed by the owner of the structure or by the designer of protection measures.

Procedure for selection of protection measures: For the AP to be protected, the lightning protection system is always necessary. The suitable protection measures and its main steps to be followed are to identify the structure to be protected and its characteristics, the types of damage and relevant risks due to lightning in the structure. For each type of damage; the risk R must be evaluated, the tolerable value of the risk R_T must be selected, R must be compared with R_T:

– If $R \leq R_T$ lightning protection is not necessary;

– If $R > R_T$ protection measures shall be adopted in order to reduce $R \leq R_T$.

All protection measures which reduce $R \leq R_T$ must be selected, the most suitable protection must be selected according to the technical and economical aspects.

Conclusions

The following conclusions can be inferred:

– It is possible to introduce the lightning risk assessment of APs in the frame of reliability and probability theory, mathematical statistics;
– The rational risk assessment should be based on the evaluation of the numbers of dangerous events, the probability of damage, the amount of consequential loss;
– Important element of the calculation of risk is lightning current characteristics for each location of AP;
– The detailed data on AP location, structure and system are essential to perform risk evaluation.

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I. Tarımer, B. Kuca, T. Kisielewicz. A Case Study to Risk Assessment for Protecting Airports against Lightening // Electronics and Electrical Engineering. – Kaunas: Technologija, 2012. – No. 1(117). – P. 49–52.

An airport has numerous structures, systems, buildings, runways and components that are susceptible to lightning strikes. The effects of strikes can include actuation of safety systems, and loss of fire protection. Flashes to the structure, runway roads, the lines connected to the structure can cause injury to people, physical damage of takeoff and landing runways and aircraft's ramps, failure of internal electrical and electronic systems. Hence the need for protection of critical structures and selection of protection measures should be determined in terms of risk. If the lightning threats, all risk events estimated, the consequences of the risk events determined are above a tolerable level of risk, protection measures are applied to reduce the risk (R) to below the tolerable level (R_T). In this study, the criterions for reducing physical damages and life hazard due to direct lightning flashes have been determined. Ill. 1, bibl. 10 (in English; abstracts in English and Lithuanian).

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Oro uostai turi daug struktūrų, sistemų, pastatų ir komponentų kurie yra jautrūs žaibams. Dėl žaibo išlydžio gali įsijungti saugos sistemos ir bus prarasta apsauga nuo gaisro. Išlydžiai į struktūras, kelius, linijas, sujungtas su struktūra, gali sužeisti žmones, fiziškai pažeisti kelius ir nusileidimo takus, sugadinti elektros ir elektronines sistemas. Taigi kritinių struktūrų apsaugos poreikis ir apsaugos priemonių parinkimas turi būti numatytas rizikos vertinimo sąlygose. Turi būti nustatyti kriterijai, mažinantys fizinius gedimus ir pavojų gyvybei dėl tiesioginio žaibo poveikio. Il. 1, bibl. 10 (anglų kalba; santraukos anglų ir lietuvių k.).