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Assessment of lightning impact frequency for process equipment

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ABSTRACT

Fires and explosions triggered by lightning strikes are among the most frequent Natech scenarios affecting the chemical and process industry. Although lightning hazard is well known, well accepted quantitative procedures to assess the contribution of accidents caused by lightning to industrial risk are still lacking. In the present study, a quantitative methodology for the assessment of the expected frequency of lightning capture by process equipment is presented. A specific model, based on Monte Carlo simulations, was developed to assess the capture frequency of lightning for equipment with a given geometry. The model allows the assessment of lay-out effects and the reduction of the capture probability due to the presence of other structures or equipment items. The results of the Monte Carlo simulations were also used to develop a simplified cell method allowing a straightforward assessment of the lightning impact probability in a quantitative risk assessment framework. The developed approach allows an in-depth analysis of the hazard due to lightning impact by identifying equipment items with the highest expected frequency of lightning impacts in a given lay-out. The model thus supplies useful data to approach the assessment of the quantitative contribution of lightning-triggered accidents to industrial risk.

1. Introduction

The analysis of the effects of external events that could act as accident triggers is a relevant topic for the assessment of the safety and integrity of chemical and process plants. Natural events, such as earthquakes, floods and lightning strikes, can cause major accidents in the chemical and process industry, initiating so-called "NaTech" scenarios (Natural events triggering technological disasters) [1,2]. The potential severity and non-negligible frequency of NaTech accidents was highlighted in previous studies [3–5]. Rasmussen [6] estimated that industrial accidents triggered by natural events range among 3–5% of all recorded industrial accidents, depending on the data sources consulted. Lightning was shown to be among the most frequent causes of Natech accidents [7].

Several industrial standards address the protection from lightning strikes [8–11]. Metal tanks with fixed metal roofs and horizontal metal tanks generally have standard protections like bonding and grounding of all metal components. However, there is a general agreement that such ordinary protection systems are not able to protect a process item from the effects of all direct lightning strikes [11–13]. Evidence from past accidents proves that lightning is still a relevant cause of industrial accidents [7,14]. Vessel shell puncturing or internal sparking at the liquid/gas interface may take place if the tank suffers a direct lightning strike [10,15]. The study of Argyropoulos et al. [16] confirms that lightning is a major accident initiator and highlights the necessity of an effective lightning protection system for hydrocarbon storage tanks, which are the plant item most vulnerable to lightning impact [14]. Fires were identified as the most frequent final scenario caused by the impact of lightning on process equipment [14,17].

Although lightning hazard is well known, well accepted quantitative procedures to assess the contribution of accidents triggered by lightning to industrial risk are still lacking. In particular, approaches to the assessment of lightning strike probability and the damage caused by lightning strike are mainly qualitative or semi-quantitative and are mostly based on expert judgment [9,10]. In a previous study, a model was developed to assess the damage probability of storage tanks in case of lightning impact [15]. In the present study, a quantitative methodology for the assessment of the expected frequency of lightning impact on equipment items is presented. A specific procedure, based on Monte Carlo simulations, is presented to assess the frequency of lightning strikes attracted

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by the storage tank ("capture frequency") given the geometry of the equipment item considered. The results of the Monte Carlo simulations were used to develop a simplified cell method allowing a straightforward assessment of the lightning impact probability. This simplified method allows the definition of a "capture area" that may be used for a direct calculation of the expected lightning capture frequency.

The developed models allow the calculation of the overall expected frequency of a lightning strike on an equipment item having a given geometry, taking into account the effects of nearby structures and, when present, of specific lightning protection systems. In the framework of a general approach to the quantitative assessment of risk due to NaTech scenarios [18–21], the model presented for capture frequency may be integrated to the approaches proposed for damage probability calculation [15] and final scenario identification [22], providing a methodology for the quantitative assessment of risk caused by lighting in tank farms and process facilities.

2. Model for capture frequency calculation

2.1. Modeling approach

The approach used to develop the model for estimating lightning capture frequency is summarized in Fig. 1. The model is aimed at assessing the expected equipment capture frequency in a specific lay-out. The preliminary step (Step 1 in Fig. 1) is the definition of the main geometrical features of the area of interest, of the lay-out and of the specific characteristics of the considered equipment items. A Monte Carlo model is then used to generate a wide number of events each representing a lightning strike (Step 2 in Fig. 1). Events are randomly generated with different perspective striking points (i.e., the strike location at ground without the presence of any structure), polarities and peak values of the lightning current waveform at the channel base. Probability distribution functions available in the literature [23,24] or derived from lightning location systems (e.g. [25]) are used to define polarity and current parameters, while a uniform distribution is assumed for the initial striking position. The final striking point of

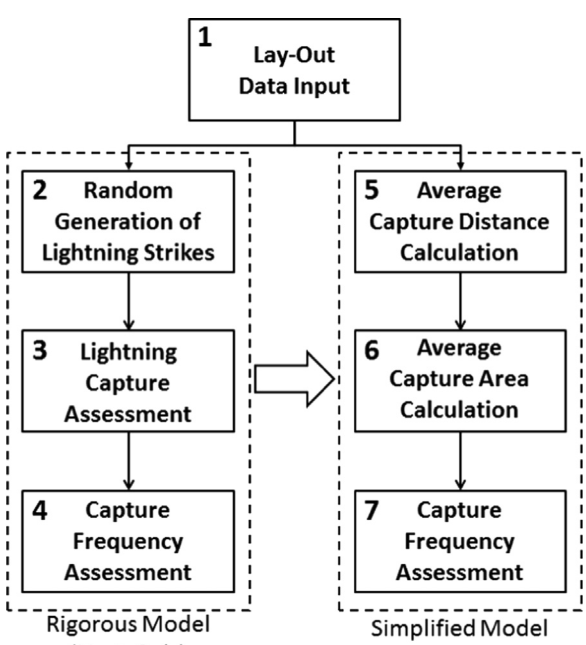

Fig. 1. Modeling approach: Monte carlo simulations and simplified model.

the lightning is then determined on the basis of the perspective striking point and of the lightning current amplitude (Step 3 in Fig. 1). The results of the Monte Carlo simulations are then used to assess the expected capture frequency of each equipment item (Step 4 in Fig. 1). A simplified model, based on the calculation of an average attraction distance, was derived from the complete model developed (Steps 5–7 in Fig. 1), in order to provide a tool more suitable for use in a quantitative risk assessment (QRA) framework. The features of the model and the approach needed for its application are described in detail in the following.

2.2. Preliminary definition of geometrical features and lightning generation

Before model application it is necessary to define the features and the limits of the area of interest, *A*. The position, shape and height of each item present in the area of interest need to be defined. In the case of equipment items for which structural damage may be of interest, also data on type and thickness of the shell need to be collected. It should be remarked that the area of interest should be extended to include any element having a relevant height above ground with respect to that of the equipment items considered (e.g. buildings, stacks, flares and trees).

In the application of the Monte Carlo method, the number of simulations needed to obtain stable results is usually in the range between 10^5 and 10^8, and depends on the complexity of the system analyzed. Random generation of flash polarities and of peak values of the lightning current is carried out taking into account the statistical data for lightning distribution. In particular, the log-normal distributions having mean value, μ_{ln}, and standard deviation, σ_{ln}, proposed by Anderson and Eriksson [23] are assumed for the lightning peak current intensity I_p of both positive and negative first strokes of the flashes. Multiple stroke locations for the same flash were not considered in the model, assuming that their probability is negligible for the purposes of this calculation. The ground impact position in the absence of attraction due to structures is then randomly defined assigning uniformly random generated values to the *x* and *y* coordinates of the strike location within the area *A* of concern. For each generated event, the triplet of values (x, y, I_p) attributed by the Monte Carlo procedure is then checked with respect to a capture condition described in the following.

2.3. Lightning capture assessment

In order to evaluate whether a lightning flash is attracted by one of the relevant items defined in the area of interest, a specific capture model is applied, derived from the Electro-Geometrical Model (EGM) [26], initially developed for the protection of power lines [27–29]. The model calculates a maximum attraction distance for the item of concern as a function of the lightning peak current intensity and of the height of the structure. When the distance between the lightning strike original impact position and the nearest point of equipment perimeter is lower than the attraction distance, the lightning strike is assumed to be captured by the item. The theoretical background of the EGM and its limitations are discussed in the literature (e.g. see [26,30–32] and references cited therein). The overall attraction distance, r_s, may be calculated as follows [26,31,32]:

$$r_s = 10 I_p^{0.65} \quad (1)$$

where I_p is the peak return stroke current associated to the lightning strike by the Monte-Carlo method (expressed in kA), and r_s is the attraction distance from the structure, or lightning final jump, (expressed in m). The attraction distance from the