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# Key issues to define a method of lightning risk assessment for wind farms

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ABSTRACT

This paper describes a methodology and key issues of lightning risk assessment for wind farms. Methodology is based on IEC standard for wind turbines. Key issues comprise: influence of local terrain, the particularity of having multiple tall structures in a limited area, the influence of winter lightning activity, the percentage of upward lightning to wind turbines, aspects to consider concerning lightning data, seasonal variation of lightning and the need of methodology validation.



## 1. Introduction

Lightning risk assessment for wind farms is described in IEC 61400-24 standard [1]. Modern wind turbines are highly exposed to lightning flashes, even in places where normal convective thunderstorms are not frequent. This is highly influenced by the height of these structures, typically ranging from 60 up to 150 m for onshore locations. Moreover, these structures are erected on mountainous terrain where the electric field is enhanced respect to a reference flat terrain. Lightning risk assessment for wind farms shall be the first step to be accomplished for lightning protection engineers. But, in its present edition, IEC standard does not disposes of a well described methodology. It lacks an estimation of the percentage of upward lightning or the specific degree of winter lightning in a given area. In the same way, IEC standard does not address how to deal with lightning data from Lightning Location Systems (LLS), or multiple strikes from the same flash to different wind turbines, in case of downward lightning or multiple upward lightning from different wind turbines simultaneously. Also, it does not address how to account for terrain effects. Because of this, four years ago, the company developed internally a method to estimate the total number of lightning strikes to wind turbines of a wind farm during a certain time period. The method is based on IEC standard [1], as it defines the fundamentals of the analysis. However, the method described in the standard needed to be reviewed, extended and validated. The main objectives of this paper are to describe: a) the methodology used for risk assessment as well as b) to identify and describe in detail key issues for lightning risk assessment for wind turbines. The paper describes method developed and validated with those considerations [2].

The percentage of upward lightning experienced by these structures has been reported to be high in some special locations. For example, during Japanese winter season, wind turbines trigger multiple upward lightning along the west coast of Japan [3–5]. This phenomenon, called “winter lightning” has been recently analyzed and documented worldwide [6,7]. Winter lightning can enhance the exposure of wind turbines to upward lightning and expose wind turbine’s lightning protection system to unexpected events which can reduce the lifetime and maintenance periods.

## 2. Lightning risk assessment for wind farms: methodology

In 2012, it was decided to develop a methodology for lightning risk assessment for wind turbines. This method has also been described in previous papers [2,8,9]. The starting point was IEC standard for wind turbines, which defines a single equation to estimate the total number of lightning attaching wind turbines during a certain time period:

$$N_D = N_g \cdot A_c \cdot C_d \quad (1)$$

Being $N_g$ the ground flash density, $A_c$ the collection area and $C_d$ the environmental factor.

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From this formula, new parameters were introduced resulting as [2]:

$$N_D = N_{sg} \cdot N_g \cdot A_c \cdot (C_{dc} + C_{wl} + C_{hasl}) \quad (2)$$

where $N_D$ is the estimated total number of lightning flashes to a wind farm during a time period, $N_{sg}$ refers to number of ground strike terminations, and the environmental factor was split into $C_{dc}$ for terrain complexity, $C_{wl}$ for winter lightning and $C_{hasl}$ for the height above sea level.

So, total number of lightning to wind turbines in a wind farm during a certain time period can be estimated using (2). With this equation, the user is able to estimate the total number of lightning flashes during a certain time period without discerning between upward and downward flashes (see Section 3.4 for information regarding upward lightning percentages). The parameters in (2) shall be estimated separately. In next sections, those parameters are described in detail.

### 2.1. Number of ground termination points ($N_{sg}$)

This parameter refers to the possibility of having more than one termination points for the same flash. This is one of the key points analyzed in Section 3.2. In general, the value of this parameter is established as 2 in IEC standard for downward lightning [10]. As described in Section 3.2, in case of upward lighting, a value of 2 may also be reasonable.

### 2.2. Lightning flash density ($N_g$)

Lightning flash density can be obtained from Lightning Location System (LLS) networks. These networks can be found throughout the globe, and can provide lightning data in different formats. However, it is important to bear in mind that the out coming data from those networks may not be completely reliable. In a generic way, the user shall always consider two aspects for flash density estimation: Detection Efficiency (DE) of the lightning data in the specific location and the size of the grid used to obtain the ground density. While the first parameter is explained in more detail in Section 3.5, the influence the grid size may have on final results, shall not be forgotten. The standard does not fix a grid size to obtain the ground flash density. The Author analyzed in Refs. [2,9] the influence the grid size have on 10 wind farms for 5 different time periods (this is a total of 50 cases). It was found that for a reference grid of 5 × 5 km, the average percentage variation of the lightning flash density was of 10%, 23% and 30% as grid size was increased to 10 × 10, 20 × 20 and 30 × 30 km respectively. Thus, any methodology must take into account the variation of the $N_g$ for different grid sizes.

### 2.3. Wind farm collection area ($A_c$)

Collection area is defined in IEC standard [1] as a circumference with a radius being three times the height of the wind turbine. This parameter has been adapted to wind turbines from buildings standard [10]. In case of single wind turbine, this is defined as a circle with a radius being three times the height of the structure. However, wind farms are composed by multiple wind turbines in which the collection areas of these usually overlap. IEC standard establishes that in such cases, the collection area should be the resulting from the total 1:3 slope intersections. This situation is depicted in next Fig. 1:

The simplest way to obtain the total collection area is representing the wind turbines to be placed in the same ground plane and with its own height. An easy algorithm can be developed to calculate the total collection area as represented in the right side in Fig. 1. Of course, the user could adopt the additional proposal in Ref. [1], in which the collection area could be obtained from the projection

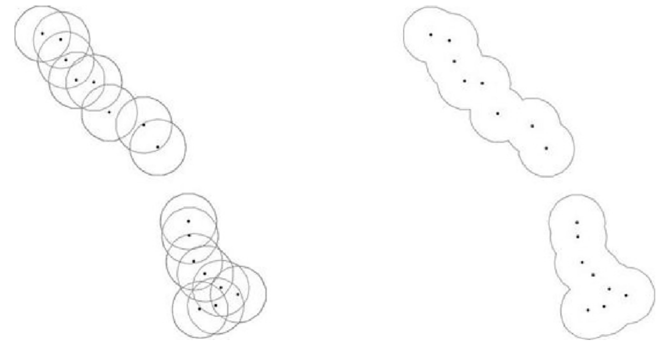

**Fig. 1.** Collection area of a wind farm without overlapping and with overlapping (black points represent wind turbines).

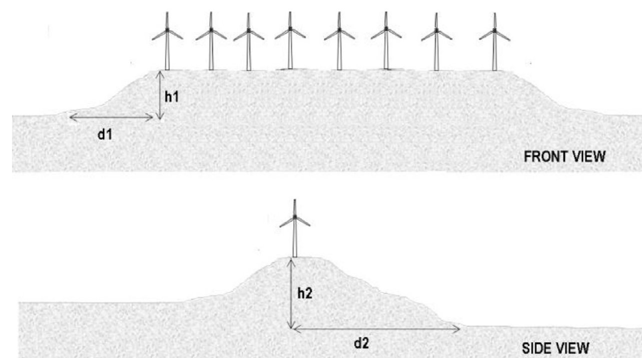


**Fig. 2.** Terrain complexity by means of terrain slopes of the wind farm.

on the terrain of the 1:3 slope from wind turbine tip considering terrain variations. An example of the problems related using this method can be found in Ref. [8].

### 2.4. Environmental factors ($C_{dc}$, $C_{wl}$, $C_{hasl}$)

Environmental factor is probably the most difficult parameter to estimate and to understand in this kind of assessments. In the original IEC standard, this factor collects all the influences from the environment. However, these influences vary widely from different sites and are also submitted to yearly variations. For example, location of wind farm is fix and does not vary throughout years but the degree of winter lightning can highly change over two consecutive years.

As first step for methodology development, it was decided to divide the environmental factor in three different sub-factors to separately consider all environmental effects:

- Complexity of local terrain
- Height above sea level
- Winter lightning activity

The first term, considers the shape and height of the location where the wind farm is erected. The degree of complexity of a mountain or hill must be quantified. As known from research in instrumented towers and in lightning research in general, the shape of the mountain has a high influence in the local electric fields ("sharp effect"). In this way the proposed approach is to measure the terrain slope at the vicinity of the wind farm and use tabulated values for its quantification.

Fig. 2 shows an example of a wind farm composed by 8 wind turbines. As seen, front and side views lead to different slopes h1/d1 and h2/d2. This slope is related with this sub-factor, which could be understood as local "sharp effect" of the terrain. There are