Prediction of Lightning Incidence to Tall Structures Before Construction

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Abstract: A new approach is presented to evaluate lightning incidence for the cases when wind turbines are located close to each other and in complex terrain. Lightning incidence to a wind turbine park consisting of 16 wind turbines and located on the Mont-Crosin Mountain in Switzerland is analysed. A significant increase in the number of upward flashes is observed following the construction of the new wind turbines and replacement of the old wind turbines in the area of Mont Crosin.
Keywords : Lightning, Lightning incidence, Upward flashes, Wind turbines

1. INTRODUCTION

The estimation of the lightning incidence to wind turbines is a prerequisite to an appropriate design of protection systems. The procedure for the estimation of lightning incidence to an isolated wind turbine located on flat terrain has been standardized [1]. However, there is a lack of methodology for the estimation of lightning incidence to multiple wind turbines located in mountainous terrain. Such situations are very common because mountainous areas are characterized by higher wind speeds and, therefore, they are more favourable for the placement of the wind turbines. Furthermore, these tall structures located in mountainous terrain are prone to initiate a high number of upward flashes (e.g., [2]), the estimation of which can be achieved using, for example, data from lightning location systems [3].

Predicting lightning incidence to tall structures before construction is an important task for an appropriate design of lightning protection systems, which, to the best of the authors' knowledge, has not been addressed in the literature. In this paper, we present a possible methodology that could be used to estimate the lightning incidence to tall structures before their erection. The proposed approach can be applied to clusters of tall structures (wind turbine parks) located in complex geographical locations.

2. WIND TURBINE PARK AT MONT CROSIN

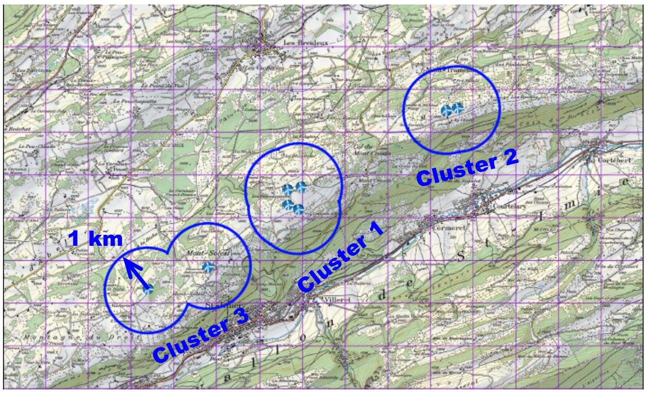
2.1 SITUATION

Switzerland's largest wind turbine park is located in the Jura Mountains, near the border with France, on the Mont-Crosin ridge as shown in Fig. 1. The Chasseral Mountain (elevation 1607 m ASL) is one of the highest peaks in the area and it is located opposite to the Mont Crosin (elevation 1263 m ASL).

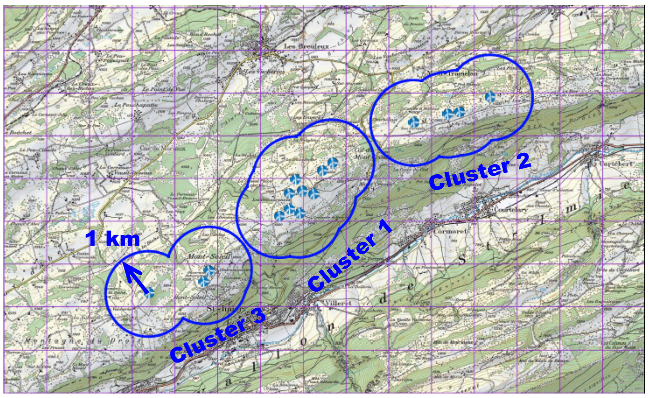
2.2 WIND TURBINES

Currently, there are 16 wind turbines constituting the Mont Crosin wind turbine park and their locations are shown in Fig. 1. However, they were not constructed simultaneously and some of the original turbines have been replaced in the past.

For the purpose of this study, wind turbines were grouped into three clusters based on their location. For a given time period and for all the wind turbines in operation, a circle of 1 km radius is drawn around each wind turbine in Figure 1. The area, resulting from the intersection of these circles gives rise to a cluster of wind turbines. During the period 2000-2016, the number and the size of the clusters, and the number of the wind turbines within a given cluster changed considerably. These transformations are summarized in Tables 1-3. Cluster 1 is located in the center of Mont Crosin, Cluster 2 to the North-East (close to Mont-Tramelan) and Cluster 3 to the South-West (close to Mont-Soleil). The wind turbines from Cluster 3 were united with the wind turbines of Cluster 1 after 2013 according to the adopted methodology to define the clusters.



a) Clusters in 2004-2009.



b) Clusters in 2010-2012

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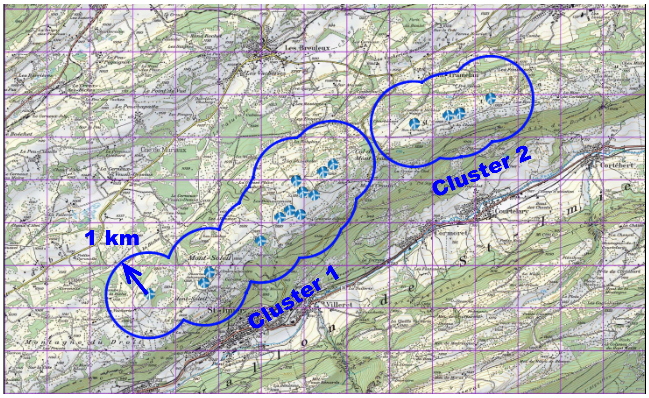
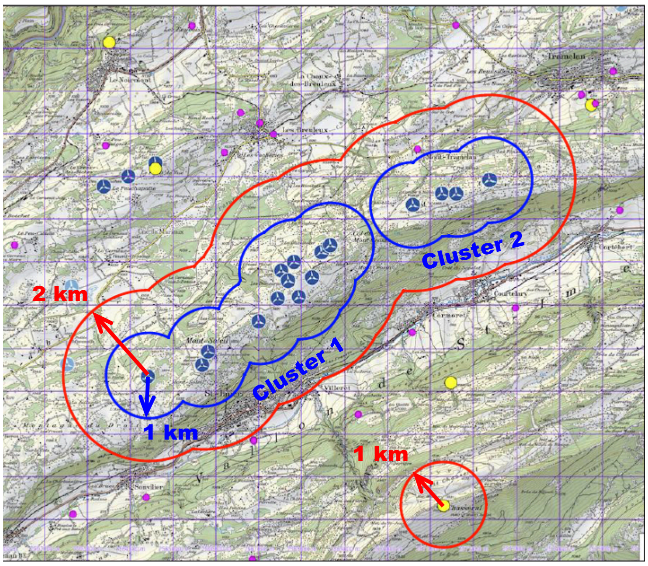


c) Clusters in 2013-2015



d) Clusters in 2017

Fig. 1. Location and clustering of the wind turbines (blue circles), telecommunication towers (yellow circles), GSM towers (magenta circles). The Chasseral Mountain is within the red circle in the right bottom corner. The telecommunication towers, the GSM towers and the Chasseral are shown only in Fig. 1d although they were present in previous years.

Table 1. Wind turbines of cluster No 1.

Period	Wind turbine	Height, m	Quantity	Surface, km^2
2000-2009	Vestas V44	67	3	4.7
	Vestas V47	69	1	
2010-2012	Vestas V44	67	3	7.4
	Vestas V47	69	1	
	Vestas V90	140	5	
2013-2015	Vestas V66	100	2	14.4
	Vestas V90	140	10	
2016	Vestas V90	140	10	14.4
	Vestas V112	150	2	

Table 2. Wind turbines of cluster No 2.

Period	Wind turbine	Height, m	Quantity	Surface, km^2
2001-2009	Vestas V52	76	2	3.7
2010-2015	Vestas V52	76	2	7.4
	Vestas V90	140	2	
2016	Vestas V90	140	2	6.9
	Vestas V112	150	2	

Table 3. Wind turbines of cluster No 3. In Fig 1c

Period	Wind turbine	Height, m	Quantity	Surface, km^2
2004-2009	Vestas V66	100	2	5.9
2010-2012	Vestas V52	76	2	6.2
	Vestas V90	140	2	

3. LIGHTNING INCIDENCE STUDY

3.1 SINGLE WIND TURBINE

According to IEC 61400-24 [1], the estimation of lightning incidence to a single wind turbine can be performed using the following formula:

$$N = N_g \cdot A = N_g \cdot \pi \cdot \left(3 \cdot h\right)^2 \cdot 10^{-6}, \tag{1}$$

where N_g [flashes/km^2/year] is the lightning density,
A [km^2] is the collection area,
h [m] is the height of the wind turbine.

However, this formula can't be used in the case of wind turbine parks where wind turbines are located close to each other. In such cases, the individual circles of radius $3h$ around each wind turbine (defined as their collection area) would intersect. A special procedure is therefore needed to estimate the collection area for a group of tall structures.

3.2 GROUP OF WIND TURBINES

In practical situations with multiple wind turbines where formula (1) cannot be applied, the following approach can be used to estimate the number of upward flashes based on the method proposed in [2]:

$$N_{up} = N_{total} - N_g \cdot A, \tag{2}$$

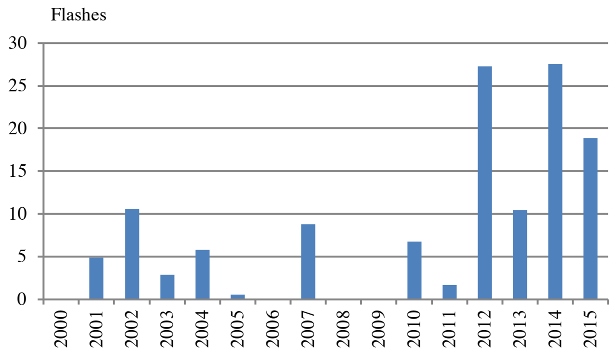
where N_{total} is the total number of flashes registered by a lightning location system within a given cluster,
N_{up} is the number of upward flashes from an object or a group of objects within this cluster.

For all the wind turbines in operation within a given time period defined in Tables 1-3, the wind turbines were grouped into clusters using the methodology described in Section 2.2. An example for the year 2017 is shown in Fig. 1d, for 16 wind turbines currently in operation, grouped into two clusters. Within the first cluster, there are 12 wind turbines; the second cluster regroups the 4 remaining wind turbines. The surfaces of these clusters are 14.4 and 6.9 km^2, respectively.

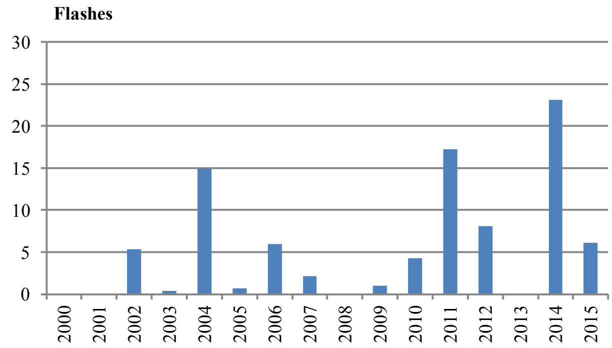
For the analysis of the lightning incidence to these wind turbines, data extracted from the EUCLID database and covering the area shown in Fig. 1 were used.

The number of upward flashes within these clusters was estimated for the period 2000-2015 according to Equation (2). The obtained values are shown in Fig. 2. From the comparison of Tables 1-2 and Fig. 2, it can be seen that the installation of new wind turbines and replacements of the old wind turbines in Cluster 1 resulted in a significant increase in terms of upward lightning flashes within these areas. The same observation can be applied to the Cluster 2 shown in Fig. 2b. It is worth noting that the observed increase can also be due, at least in part, to yearly meteorological variations.

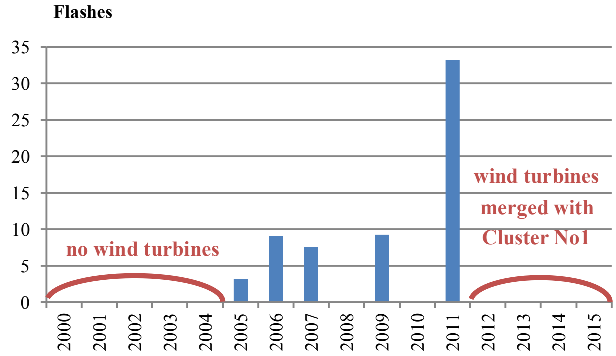
The obtained values could be only half of the real number of upward flashes since about 50% of upward flashes to tall structures are considered to consist of initial continuous current (ICC) only [4] without any high-amplitude impulses and are therefore not registered by a lightning location system.



a) Cluster 1



b) Cluster 2



c) Cluster 3

Fig. 2. Number of upward flashes estimated from EUCLID data within the areas of clusters 1, 2 and 3.

4. METHODOLOGY FOR THE PREDICTION OF LIGHTNING INCIDENCE BEFORE CONSTRUCTION

We saw in Figure 2 that the installation of additional wind turbines leads to an increase in the number of flashes per km^2 in the clusters. The increase is linked to a number of parameters, including the change in the total number of wind turbines, the effective heights of the new turbines, and the relative arrangement of the turbines. Knowledge of the relation between these parameters and the ground flash density in the clusters would allow the prediction of the lightning incidence before new turbines are installed.

The number of wind turbines at the Mont Crosin Wind Park was increased in 2010, then in 2013 and recently towards the end of 2016. The change in 2016 is too recent for conclusions to be drawn on its effect on lightning incidence observations. In a few years, however, we will be able to use data on the changes in lightning incidence to attempt to find an empirical relation between the mentioned paramerters and the ground flash density. These could be used to estimate the expected increase in the lightning incidence due to planned installations of new wind turbines.

5. CONCLUSIONS

Mont Crosin offers a unique area of study of lightning incidence to the wind turbines. Available remote observations of lightning since 2000 allow investigating temporal variations of lightning incidence to the wind turbines during the construction and repowering of this wind turbine park in 2010, 2013 and 2016. In the full version of this paper, we will present more detailed analysis of this area, including the analysis of upward flashes initiated from the antenna on the Chasseral Mountain and application to other tall structures and wind turbines.

6. ACKNOWLEDGEMENTS

Financial support from the Swiss National Science Foundation (Projects No. 200021_147058 and IZLRZ2-163907/1) and from the Russian Ministry of Education and Science (Project No. RFMEFI58416X0019) is acknowledged. We thank EUCLID and BKW for providing the data for the analysis.

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