PO.ID 004

Lightning protection zoning and risk exposure assessment of wind turbines

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Abstract

The lightning protection standards describe how wind turbine blades should be protected to LPL1 (200kA strike) from the tip and down to radius 20m, whereas only a few evidences of such exposure has been presented. Both numerical simulations as well as extensive field data provide evidence that the direct strike exposure is focused on the tip of the blade, and that the peak current of strokes expected inboard are of limited amplitude. This has led to the Lightning Zoning Concept for blades, as well as a revised approach of the Exposure Risk assessment which is treated in the present paper.

In 2010 a zoning concept for lightning protection of wind turbine blades was published, refined slightly in 2012. The Zoning concept was developed to present an engineering tool for assessing which lightning strikes that attaches to the different regions of the blade. In the present paper, this Zoning concept is revised based on more recent analysis and field investigations, and defines regions of the blade that would be exposed to certain peak currents.

Attachment process

Direct lightning attachment to any structure can be triggered by processes initially formed at the cloud, or by the development of an upward leader at the grounded structure. These important processes are the basis for deciding where the lightning will strike the turbines, downward strikes may attach several different places depending on the origin of the DW leader and the charge distribution along the leader, whereas upward strikes tends to be triggered at the extreme points (blade tips).

Empirical Ratio of Upward and Downward strikes

Comparing different lightning incidences to structures of various heights, it is found that for structures below 100m of effective height almost all strikes appear to be downward initiated, whereas structures with a height of more than 500m tend to trigger only upward strikes.

In 1987, Eriksson published a research on lightning attachments to structures in different countries with heights ranging from 20m to 540m, and derived an empirical relationship between the total number of strikes to a certain structure (including both upward and downward initiated strikes) and the ground flash density [8].

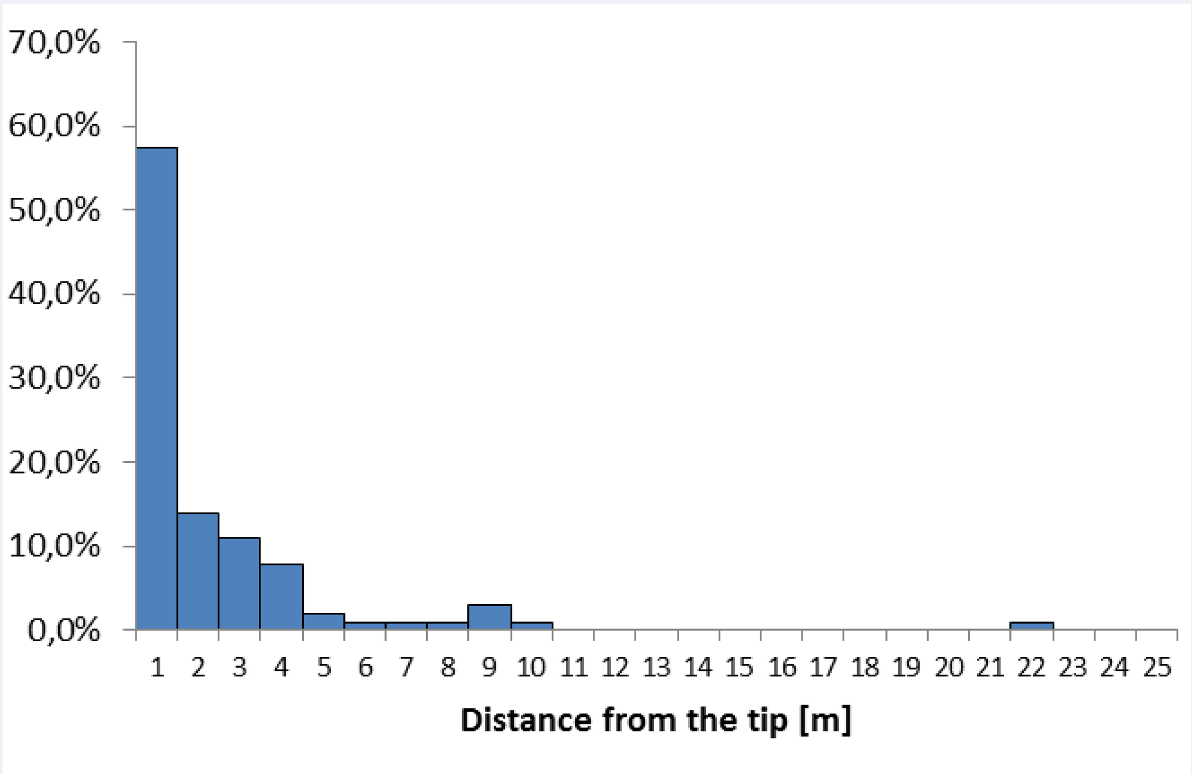
$$N = 24 \cdot 10^{-6} \cdot H_S^{2.05} \cdot N_g$$

In the equation Hs [m] is the structure height and Ng [1/yr•km²] is the annual ground flash density for the site in question. The relationship is believed valid for objects of height taller than 60m.

Later Eriksson and Meal (1984) fitted the data with an equation defining the percentage of upward strikes relative to all strikes, valid for structure heights ranging from Hs=78m – 518m where the percentage of upward strikes according to the equation is 0% and 100% respectively [8].

$$P_u = 52.8 \cdot \ln(H_S) - 230$$

Applying these equations on turbine sites, suddenly prove that the the total number of strikes to the turbines are greatly underestimated, since upward strikes increase rapidly with height. This is a main driver for focusing on the zoning concept, that large down ward strikes seek towards the tp, and upward strikes (being more and more common for tall structures) are only incepted at the tip.



Location of the lightning damage (in percentage) in damaged blades with mixed fiberglass and carbon fibre structure

Probability and Risk

One of the issues which needs to be considered when designing blade LPS, is the probability of having strikes of different amplitudes. This means that even if a strike of a certain type may cause very severe damage, it might be that the probability of having such a strike is insignificant. Evaluating the risk may therefore lead to the decision that the installed LPS doesn't need to intercept such a strike. To assess these circumstances, the probability density functions as presented in the IEC 62305-1 [2] are discussed.

Eventually the entire discussion of upward and downward lightning interacting with wind turbines, a literature review of recorded lightning incidences world wide, and numerical modelling of the physical characteristics of lightning attachments led to the revised Zoning concept.

Revised Zoning Concept

After the first suggestion of the Zoning Concept, lightning protection systems on blades exceeding 80m lengths have been designed. By conducting the detailed attachment point distribution analysis on such longer blades, it was found that smaller amplitude strikes may attach further inboard on the blades.

The process involved the use of numerical models of downward leader propagation and the following inception of upward leaders from the structures proposed by Becerra [7], to determine which parts of the wind turbine are exposed to direct attachment of different amplitudes. The equations outlined in the papers by the Uppsala lightning research team has been implemented in Comsol and Matlab, to enable import of a 3D turbine geometry and analyzing the exposure [5].

The principle using inclined leaders with prospective peak currents of 3-20kA has been applied on a generic turbine structure with 60m blades. On Fig. 4, the percentages of strikes attaching at each blade radius (averaged over all three blades for different rotor angles) is plotted for different prospective peak currents. Note that the peak of the scale is set to 3%, meaning that the actual fraction of strikes attaching to the tip region for strikes of higher amplitudes cannot be seen. The results indicate clearly that for higher current amplitudes, the attachment tends to move towards the blade tip.

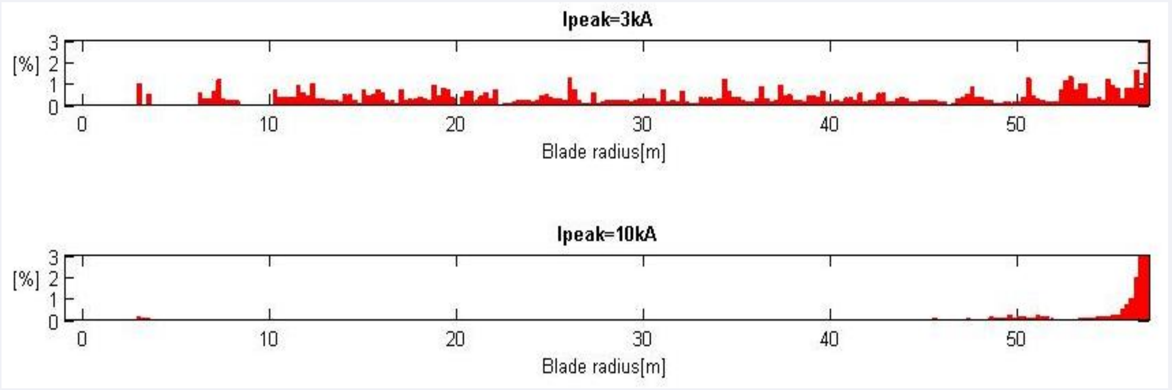


Figure 4. Attachment to the blade vs. the blade radius (60m blades). Comparison between the attachment simulation results for different Ipeak=3, 10kA. For current larger than 10kA attachment is most likely within 5m from the tip (between 70-90% of the attachments), while currents around 3kA can attach along the entire length of the blade.

Realising that the 3kA or 5kA strikes may attach further inboard on the blade, changed the original Zoning concept in [6] where strikes only could attach at the blades outer 20m. The revised concept shown on Figure 3 includes a Zone 0A4 enabling direct strikes of 10kA for the entire blade length.

The consequence of extending the direct strike zone and using the Zoning Concept for blade LPS design, is then that the inboard sections should also be capable of withstanding direct strikes of 10kA. This may be achieved quite simply for blades with CFC in the shells, which can then be designed to accommodate the direct strikes, but for GFRP blades, the likely hood of a puncture through the root section must be addressed.

The revised zoning concept currently used is seen on Fig. 5.

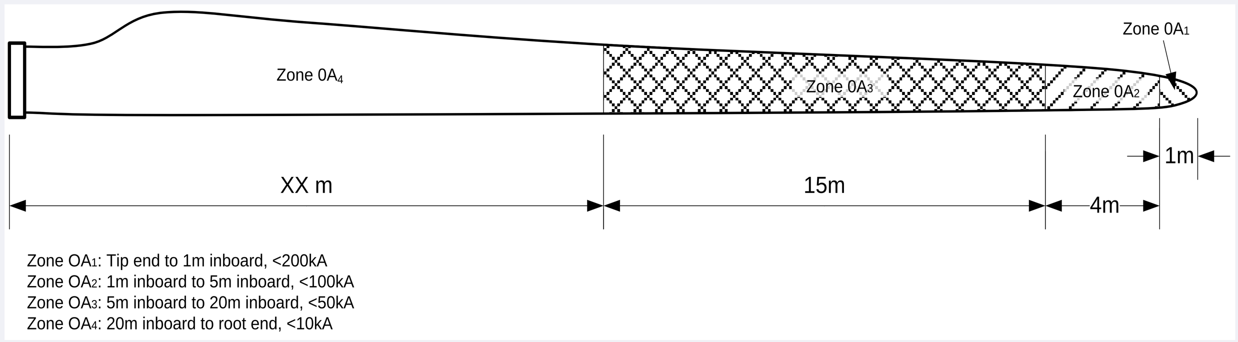


Figure 5. Zoning concept enabling direct attachment on the entire blade surface.

Revised Zoning Concept

The individual zones in the revised Zoning Concept is thereby defined in the following.

• Zone 0A1: The outermost 1m tip section exposed to the full threat - direct attachment with a maximum peak current corresponding to LPL1 in [2] - 200kA, 10/350us

• Zone 0A2: The section of the blade from 1m inboard the tip to 5m inboard the tip, exposed to direct attachment with current levels of only 100kA, 10/350us

• Zone 0A3: The section of the blade from 5m inboard the tip to 20m inboard the tip, exposed to direct attachment with current levels of only 50kA, 10/350us

• Zone 0A4: The section of the blade from 20m inboard the tip to the root end of the blade, exposed to direct attachment with current levels of only 10kA, 10/350us

The zoning concept does not dictate where to place receptors or air termination systems, it is only used to assess the possible strike amplitudes to different regions on the blade. Although it is not strictly formulated how to interpret the LPL1 requirements in the IEC 61400-24, it can be interpreted such that strikes with amplitudes between 3kA and 200kA must be safely intercepted and conducted towards ground, whereas damages are tolerated for strikes outside these extremities. In practice concerning the attachment process, it means that since strikes may occur to the inboard sections of the blade (even with a very low probability), the blade must be capable of handling it. Hence impulse current tests to inboard blade sections of 3-10kA has been conducted to provide evidence of only limited damages to the blade at such an exposure.

If the probabilities of having such small amplitude strikes to the blades are accounted for by considering the probability density functions described in the lightning protection standard [2], one can come to the conclusion that protection according to strikes of such low amplitudes is unnecessary, because they only occur very rarely.

Conclusions

The paper addresses a need for an engineering tool useful for LPS designers and still accounting for the slightly more complex lightning exposure experienced on large wind turbines.

The revised Zoning Concept provided along with the short guideline to achieve proper LPS designs for different blade types, will ensure that lightning engineers focus the attention towards the areas of the blades where lightning exposure is highest. During the design phase and for the final verification, the Zoning Concept is also used to assess the test parameters.

Following the publication and the ongoing revision of the IEC 61400-24, initiated March 2014, the revised zoning concept will be sought implemented in the upcoming version of the standard. By highlighting the special exposure on wind turbines relative to regular buildings the lightning protection system effectiveness will be improved, and most likely also result in a reduction of the cost of the overall LPS.

Finally having the methodology described in the international standard, makes the certification process easier for the certifying bodies.

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