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Efficient Lightning Protection of Modern Wind Turbines; How Long will a Blade get before the Effect of the Single Tip Receptor is no Longer Felt at the Bottom of the Blade

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Abstract—*Due to higher generated power and better wind conditions, wind turbines are getting taller and the blade length are increased bringing them closer to lightning. Modern wind turbines are predominantly protected by the single tip receptor method due to weight related matters. However, strikes attaching inboard of the blade are highly reported. Indicating that the single tip receptor might not give adequate protection to inboard of longer blades. It will be very risky to assume that a single receptor at the blade tip can protect an infinite blade length. It is therefore necessary to investigate the distance from the blade tip at which the single tip receptor is no longer effective. This paper investigates how long a blade becomes before the effect of the tip receptor is no longer felt at the bottom of the blade. The maximum electric field strength on a 100 m blade surface is evaluated using COMSOL Multiphysics software. Results show a sharp drop in value at 89 m from the blade tip. This indicate that blades longer that 90 m might be at high risk of lightning attaching inboard the blade when protected with a single tipreceptor. The point of initiation of upward leader coincided with experimental data.*

Index Blade length, FEM, lightning protection, receptor, wind turbine.

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I. INTRODUCTION

At higher altitudes, wind becomes more persistent, steadier and of higher velocity. Wind turbines are commonly placed on high ground because power available in wind increases as the cube of velocity.

Due to higher generated power and better wind conditions, wind turbines are getting taller, the swept area and the blade length are increased, and they are also moving offshore bringing them closer to lightning. They have become very high that the tips of the rotating blades now reach altitudes as in rocket triggered lightning [1]. Presently, the largest wind turbine in the world, has 8 MWrated capacity,164 m rotor diameter, 80 m blade length and a total height of 220 m [2]. It signifies a quantum leap forward in rotor size and energy capture with a swept area of 21,124 m^2.

As far as wind power generation is concerned, the size of the wind turbine blade is very pertinent to the capacity generated. Over the last 3 decades, blades have grown in length and continue to harvest more energy. There is a relationship between generated power and blade length, for instance, V100 model of vestas wind turbine can generate 2.0 MW power with 49 m blade length, V136 model of vestas wind turbine can generate

3.45 MW power with 66.7 m blade length and V164 model of vestas wind turbine can generate 8.0 MW power with 80 m blade length [2]. 80 m long blade is shown in Figure1 below. As wind turbine size and blade length continue to increase, they become more vulnerable with increasing probability of lightning strike.

Figure 1.V164-80m long wind turbine blade [2]

When hit by lightning, the blades are at the highest risk of lightning attachment with the tip more exposed than other parts [3]. According to field studies [4, 5], they experience a substantial amount of lightning strikes in their life-time. Blade damages are quite severe, replacement cost is high compared to other components [6].

Modern wind turbines are normally fitted with lightning protection systems (LPS) [7, 8], which are positioned for efficient protection but laboratory experiments [9] and field observations [10] have shown that it is also possible for lightning attachment on the blade surface and inboard the blade tip instead of the receptor, with the risk of substantial damages [6, 11-13].

Recently, multiple discharge in the turbine associated with nearby cloud to ground lightning [14] and also strikes attaching inboard on the blade due to dart leader[15] are also mentioned as causes of continued blade failures.

Existing lightning protection systems are designed using the Electro Geometric Model (EGM) methods which relate the striking distance to the prospective peak stroke current, but recently invalidated and according to IEC 61400-24, the EGM are no longer appropriate for large wind turbine blades [16, 17]. In other words, air terminals are used in accordance with the EGM but blade failures are still highly recorded. Standards requires that lightning protection systems should intercept and conduct the majority of strikes to ground without damage to the wind turbine [18]; however, according to a German study, lightning strikes accounted for 80% of wind turbine insurance claims [19], and even caused some power company to shut down and dismantle.

The receptor method of protection though effective [11], also failed in so many instances [20, 21]. However, due to weight related matters, modern wind turbines are predominantly protected with the tip receptor method. More also, multiple receptors on the blade has been a focus of research but the single tip receptor method has remained the preferred choice. Therefore, only the single tip receptor method is considered in this paper.

The single receptor at the blade tip though the preferred method due to reasons mentioned above, it is very risky to assume that a single receptor at the blade tip can protect an infinite blade length. It is therefore necessary to investigate the distance from the blade tip at which the single tip receptor is no longer effective.

Some progress has been made with wind turbine lightning protection [12, 16, 22-24] on the performance of the receptor [24][3]23], however, the performance of the receptor considering the length of the blade has not been considered in literature and are not suggested in the current lightning protection standards. The effect of blade length on the performance of the receptor is very important to enable improvement on the protection systems.

This paper investigates how long a blade becomes before the effect of the tip receptor is no longer felt at the bottom of the blade.

The extended vertical tri-pole cloud charge model developed in [25] is used to create an ambient field representing uniform electric field due to cloud charge distribution at 200 m above ground. The field is applied on the wind turbine and the maximum electric field strength is obtained at any point. The same concept of evaluation methodology that have been published in [25-29] are utilized. The simulation is done using COMSOL Multiphysics software. It is considered that the magnitude of the electric field strength distribution determines the point of upward leader inception. By comparing the electric field strength as the position from the blade tip is changed, the performance of the receptor against the length of the blade is evaluated. The rest of the paper is organized as follows: Section 2 deals with Analysis Model Setup, while Section 3 contains results and discussion, Section 4 finally concludes the paper.

II. ANALYSIS MODEL SETUP

The wind turbine model used in this paper is a horizontal axis wind turbine with three blades and each blade is 100 m long shown in Figure 2. In the simulation, the blade is made of fibred glass with a relative permittivity: 4.2, Conductivity:1.0×10^{-14} S/m. The nacelle and tower are conductive and are set to ground potential.The receptor is integrated into the model design, placed 1.5 m from the blade tip, grounded through the down conductor so as to take the lightning current to ground. It is 10 mm in diameter and is made of copper (conductivity: 6.0×10^{-7}S/m). The model of a single receptor used on one of the blades in the vertical positionwhich is used in the analysis is shown in Figure 3.

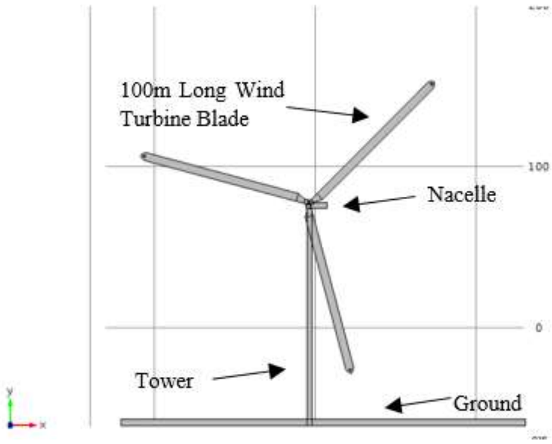

Figure 2. Wind Turbine Mode

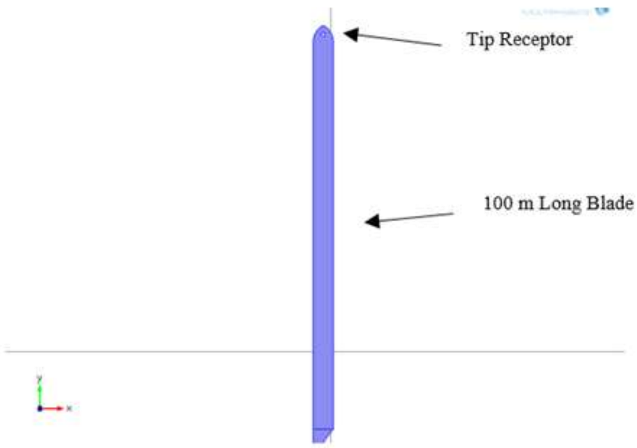

Figure 3. 100 m long blade model in the vertical position used for analysis

The focus is on evaluating the efficiency of the receptor as the blade length increases. This is achieved by obtaining the maximum electric field strength required for the initiation of upward leader due to thunder cloud charge. The peak current I_{peak} applied is 30 kA chosen because it represents the general situation of lightning strikes [30].

Eleven different distances from the blade tip (Figure 4(b)) are applied on the 100 m long wind turbine blade to investigate the effect of blade length on the performance of the receptor. In the configurations, the effect is studied considering various distances from the blade tip. These distances are 0 m, 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 70 m, 80 m, 90 m and 100 m from the blade tip respectively. The blade in the vertical position in Figure 2 is referred to in this paper as blade A and only the results for blade A are provided. Also, values are obtained from various distances from the blade tip.Figure 4(a) is 100 m long blade model showing the blade tip, receptor and blade bottom. While 4(b) is 100 m long blade model showing distances from blade tip used for analysis

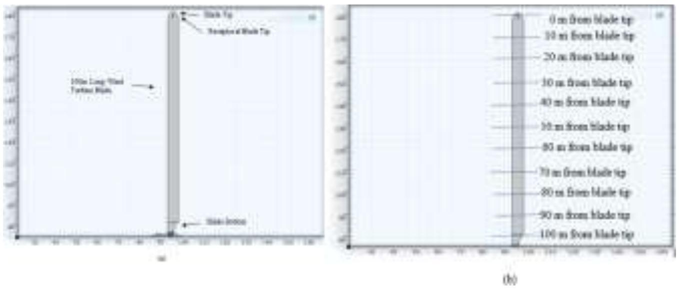

Figure 4(a) 100 m long blade model showing the blade tip, receptor and blade bottom. (b) 100 m long blade model showing distances from blade tip used for analysis.

Electrostatics equations can be used to calculate the electric field due to thunder cloud charge and the governing equations are solved with FEA software COMSOL Multiphysics and the computational domain is shown in Figure. 2.

III. RESULTS AND DISCUSSION

The wind turbine is protected by activating the receptors, field enhancement is seen as shown below in Figure 5. Details of activities around an activated receptor such as upward positive polarity for streamer activities, the negative polarity going to ground through ground wire, positive polarity on the blade surface and the produced corona charge which lowers the electric field on the tip inhibiting the occurrence of a streamer are shown in [25].

Figure 5 shows the maximum electric field distribution as the distance from the blade tip are varied.These distances are 0 m, 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 70 m, 80 m, 90 m and 100 m from the blade tip respectively. In the simulation, the investigation begins with 0 m from the blade tip. This position is also referred to as the blade tip itself. The simulation is conducted at this point and the values obtained after which the position is moved to 10 m from the blade tip and the process is repeated. This is done until 100 m from the blade tip is reached.

If lightning attaches to the receptor, it will be conducted to ground through ground wire without causing damage to the turbine. This is the intent of the lightning protection designer. But, when lightning attaches to the blade surface instead of the receptor, the blade and sometimes the entire wind turbine can be destroyed. The positions with higher electric field strength are considered to have higher possibility of inception of upward leader in this paper. Also shown in the figure is the field enhancement due to the receptor.For an efficient lightning protection, it is desirable that the value of electric field at the blade surface be kept to a minimum as a result of the presence of the receptor, whereas, most importantly, it should be maximum on the receptor so that leader will incept from it first.

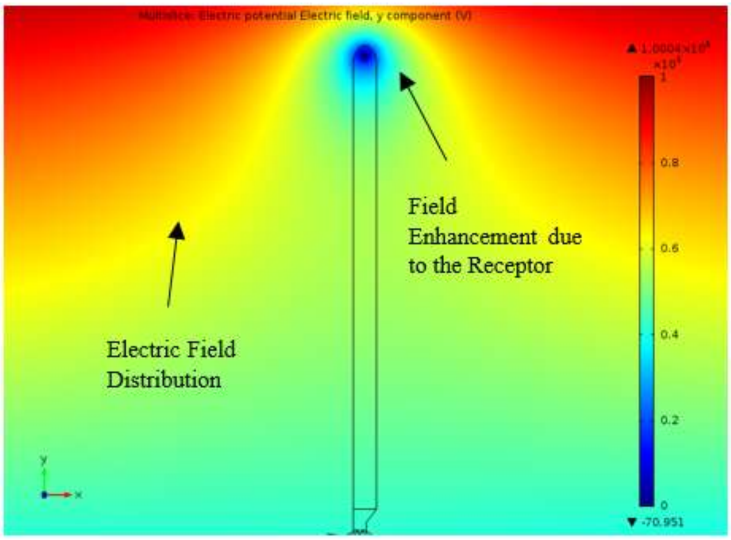

Figure 5. Simulation model showing electric field distribution

The results of maximum electric field strength distributions for various configurations obtained are shown in table 1 and plotted in Figure 6.

Table 1 Electric Field distribution (kV/m) on various distances from the blade tip

Distance from Blade Tip (m)	Electric Field Distribution (KV/m)
100	3.36
90	3.71
80	5.00
70	5.39
60	5.47
50	5.38
40	5.22
30	5.00
20	4.74
10	3.49
0	3.23

Shown in Figure 6 above is the electric field distribution versus the blade length. The value of the electric field distributed at the blade tip is higher and as such, the blade tip is the most vulnerable part for lightning attachment. However, as shown on the plot, the values at 100 m to 80 m is lower than it should be, this is because of the negative polarity [25] going to ground through ground wire (Blue color in figure 5) which is superimposed on the positive polarity (Red and light blue color). The positive polarity is for streamer activities. The negative polarity is usually confined to the ground wire and not on the surface of the blade in practical situation. The values (Initially at 5,39 kV/m) decrease progressively toward the bottom of the blade. This implies that the efficacy of the receptor decreases with blade length. A sharp drop in value was observed at 89 m (Value at 3.29 kV/m) from the blade tip in Figure 6 and dropping finally to (3. 23 kV/m) at the blade bottom. This point is very pertinent to this study as it shows the point where the influence of the receptor is no longer felt on the blade. This indicate that blades longer that 90 m might be at high risk of lightning attaching inboard the blade when protected with a single tip receptor.

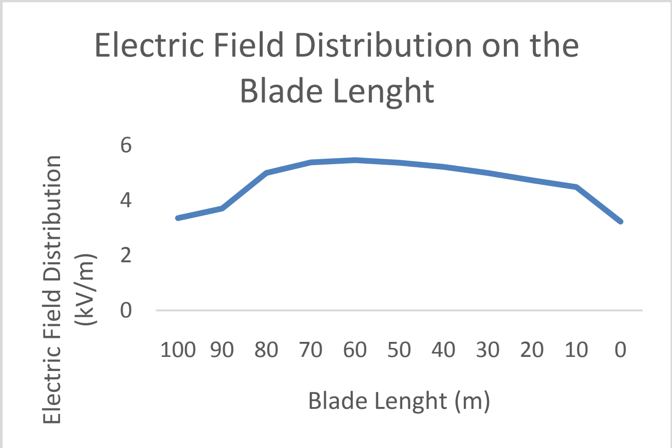

Figure 6. Electric field distribution versus the blade length.

The model used in this analysis was validated experimentally in [25, 27-29]. It is presently difficult to carry out experiment on a 100 m long blade. The value of the maximum electric field strength on the model agrees favorably well with the experimental result and lightning attachment manner indicating that an upward leader will likely be initiated from the blade tip.

IV. CONCLUSION

The effects of blade length on the performance of the receptor have been investigated. The maximum electric field strength on a 100 m blade surface of a modern wind turbine has been evaluated using COMSOL Multiphysics software. The extended vertical tri-pole model has been applied to a full scale wind turbine to study the variations in maximum electric field strength required for the initiation of upward leader. By comparing the electric field strength as the distance from the blade tip is changed the receptor performance has been evaluated. The point of initiation of upward leader coincided with experimental data. Result shows that the efficacy of the receptor decreases with blade length. A sharp drop in value was observed at 89 m from the blade tip. This indicate that blades longer that 90 m might be at high risk of lightning attaching inboard the blade when protected with a single tip receptor.

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