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Puncture position on wind turbine blades and arc path evolution under lightning strikes

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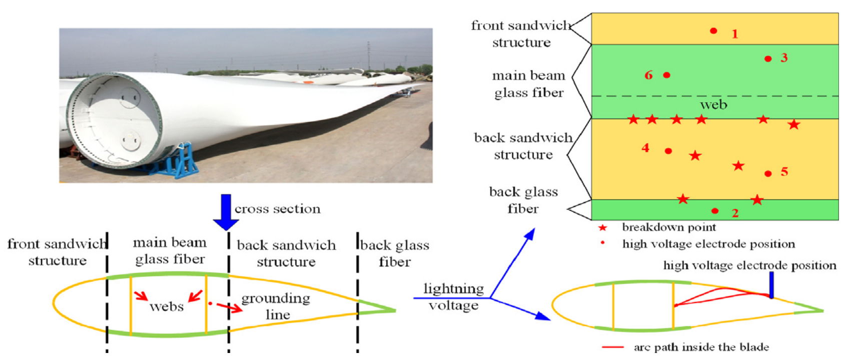
HIGHLIGHTS

- The wind turbine blades usually get breakdown on the back sandwich or the thin glass fiber.
- Long arc paths may exist if the blade width is large enough.
- Lightning induced arc is characterized as a short surface path on the top blade.
- Water moisture of the blade surface increases the risk of lightning strikes.

GRAPHICAL ABSTRACT



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ABSTRACT

Wind turbine blades are easy to get lightning strikes, which is calling more and more attention in recent years. Impulse voltage was applied on different blade structures and materials to study the puncture position distribution and the arc path inside the blade chamber. The experimental results reflected that most puncture points were located in the sandwich structure and thinner glass fiber cover. There was no obvious connection between puncture position, voltage polarities, and voltage peak values as to the experiment in this paper. However, the surface moisture and the experimental electrode position had significant influence for the puncture position. Arc paths inside the blade chamber considering different puncture positions were also studied. It can be concluded from the experiments that the arc usually consisted of surface-arc part and the air-arc part, in which the length of each part varied with the puncture position, voltage peak values and polarities. The research findings revealed the weak areas on typical blade and as well as the possible arc paths inside the sealed chamber, which will offer guidance for the lightning protection design of blade materials and the whole structure.

1. Introduction

Renewable energy sources, especially wind energy, are widely applied because of the reduction of the usage of conventional fossil energies and its environment-friendly characteristic. However, with the development of wind farms, lightning strike on wind turbine calls more attention owing to its high structure.

Lightning protection of the wind turbine mainly relies on a receptor-grounding line system currently. The metal receptors installed on the top blade and the blade body (Fig. 1) are expected to intercept the downward lightning leader and then lightning current can be safely

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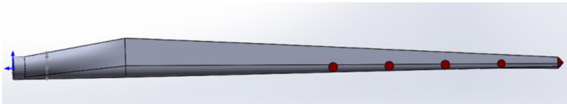

Fig. 1. Receptors on wind turbine blade.

leaded away by the grounding line connected to the receptors. In recent years, studies aiming to improve the lightning protection method for different wind turbine devices also have been conducted mainly by calculation method. Based on a physically reduced scale model and two calculated models of the main shaft wind turbine bearings, the bearings' electrical impedance was calculated to develop lightning protection method for wind turbine bearings [1]. EMTP-RV was used to calculated the lightning surges in wind turbines to build adequate lightning protection measures In Ref. [2] and Ref. [3]. Transient lightning overvoltage was calculated for designing and optimizing the arresters near step-up transformer inside wind turbine nacelle in Ref. [4]. All the above research provide essentially theoretical support for the lightning protection development of the wind turbine. However, much more work is still needed to be done for practical application.

Among all the lightning induced faults, blade damage always involves the highest repair cost, including materials, labor and downtime [1]. When the receptors fail to intercept lightning leader, lightning hits on the blade materials (90% on the top 5 m of the blade) [5] directly. The large impulse voltage will puncture into the sealed chamber of the blade. The huge thermal impact of the lightning induced arc will result in delamination, debonding, shell detachment and tip detachment [6]. For the problem of lightning strikes on blade, most worldwide researchers focus on verifying the reliability of receptor-grounding line system and optimize it to make it protect the wind turbine more effectively [7–13]. Several novel lightning protection methods have been proposed theoretically, and to some extent, some of them have been tested in the laboratory or by simulation method [12,13], but none of them have got wide application right now because of their potential influence on the aerodynamic characteristic.

Fig. 2. Blade structure.

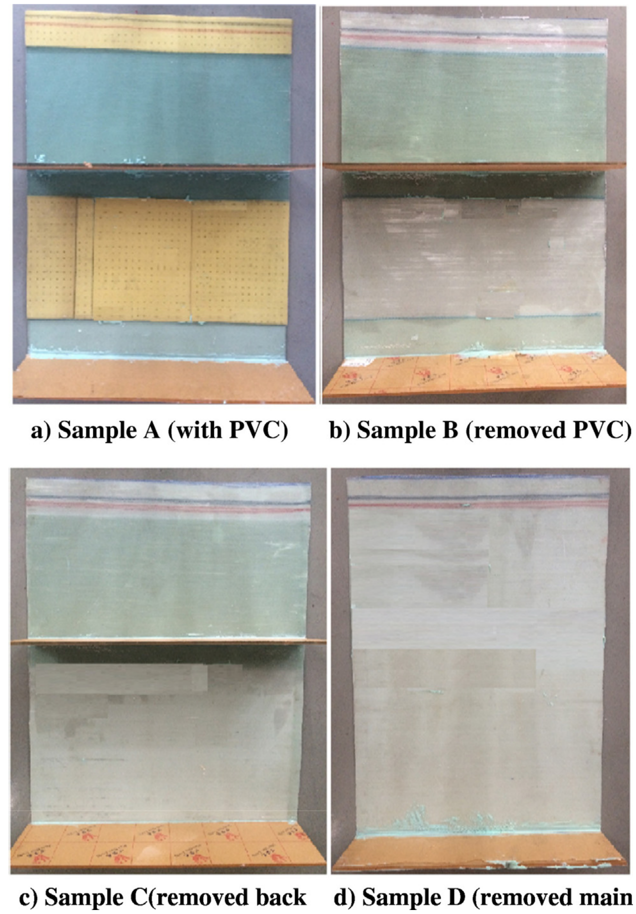

Fig. 3. Experimental samples.

Another aspect to keep the blade away from large destruction is to study the damage process, of which the outcomes can help design the blade structure to make the blade itself stronger to resist the lightning impact effect. Some preliminary current experiments have been done to simulate the thermal explosion effect of lightning induced arc [14–16]. In Ref. [17], lightning arc radius, heat flux distribution inside blade materials and damage depth of blade materials were analyzed by calculation method. However in all of above reports, the "lightning induced arc" is set to specific paths for study's convenience. But the evolution characteristics of arc path inside the blade chamber have not been studied deeply, which is essential basis of the research on the damage process of blade.

To study the damage process of the wind turbine blade under lightning strikes, impulse voltage experiments have been done to study the puncture position and typical arc paths inside blade. The findings are essential to study the impact force distribution on the whole blade under inside arc paths, which will offer guidance for the lightning protection design of blade materials and structure.

Table 1
Glass fiber layers of samples.

Position	Main beam	Back edge	Sandwich structure (cover)
Sample A	7	4	2
Sample B	5	3	2
Sample C	4	2	2
Sample D	2	2	2