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Experimental evaluation of air-termination systems for wind turbine blades

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ABSTRACT

In this paper, air-termination systems for wind turbine blades reported in IEC-61400-24 standard are evaluated experimentally. These systems are such as receptor, metallic mesh and metallic conductor on the blade edges. In addition to these systems, metallic cap on the blade tip is investigated. The lightning attachment manner to the wind turbine blade is studied under positive and negative impulse voltages and for polluted and unpolluted blade surfaces. As the blades are rotating, the experiments are conducted considering five positions with different angels. The protection evaluation is done using 2 m blade tip section that is a part of 19.1 m actual blade length of 600 kW wind turbine. According to the comparison between the above systems, a proposed air-termination system is developed and experimentally examined. The results show that the proposed system attains higher lightning protection efficiency. The tests are carried out using a designed blade tip section with applying standard lightning impulse voltages.
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1. Introduction

Recently, wind farms are rapidly growing worldwide and are becoming very important sources of electric energy. With the gradual increase of wind turbines number and size, the risk that the turbine could be hit by a lightning also increases. Lightning damages to wind turbine blades are quite serious since the cost for replacement is remarkably high and long repair time is required. Where, the cost of the rotor (3 blades) accounts for 15–20% of the total wind turbine costs [1]. On the other hand, when blades are polluted or become wet by rain or heavy fog, they become conducting which results in lightning current channels through wind turbine blades. These increase the risk of lightning damage to the wind turbine blades. Therefore, reliable protection system should be used with the blades.

Although, the current air-termination systems of wind turbine blades, based on air-termination system, are designed to withstand about 98% of lightning strikes, there still local damage can occur [2,3]. This percentage depends mainly on some important factors such as the composite materials used for blade design (e.g. glass fiber reinforced plastic (GFRP), carbon fiber composite (CFC)), the applied air-termination systems, and the length of the protected blade [2]. Considering CFC, this material has light weight and stiffness compared to GFRP but it is very expensive. Furthermore, the large current density at the arc root, combined with the high resistivity of the materials result in the dissipation of a considerable amount of energy. The release of this energy causes the material to delaminate. Also, in some cases, evaporation of resin and fibers can occur [4]. Therefore, many studies have been carried out on the GFRP blades as reported in [2–9]

Evaluation of air-termination system of GFRP blades, which is based on spraying a molten metallic surface on the outer blade shell has been carried out [5]. The main drawbacks of this system are the cost of the spraying process and the weight issues considering the size of the modern wind turbine blades, since thicknesses of 0.1–0.2 mm are usually required [4]. The other researchers as in [2,3,6–9] evaluated GFRP blade model considering only two lightning protection systems such as a receptor and metallic cap. They have shown that, the metallic cap system has a higher protection performance than the receptor system. However, this evaluation has been limited to two protection methods.

This paper is directed to wide investigation of different air-termination systems applied on GFRP blade in order to discover the best one. The evaluated protection systems are based on the recommended ones reported in [8,10]. The same concept of evaluation methodology and experimental setup that have been published as in [3,6–9] are utilized in order to provide evidence of the efficiency of the proposed protection system. The experiments were carried out considering positive and negative impulse voltages under different conditions of blade pollution. Different blade positions during its rotation were concerned in order to emulate real situation of lightning hit blades. From the lightning protection point of

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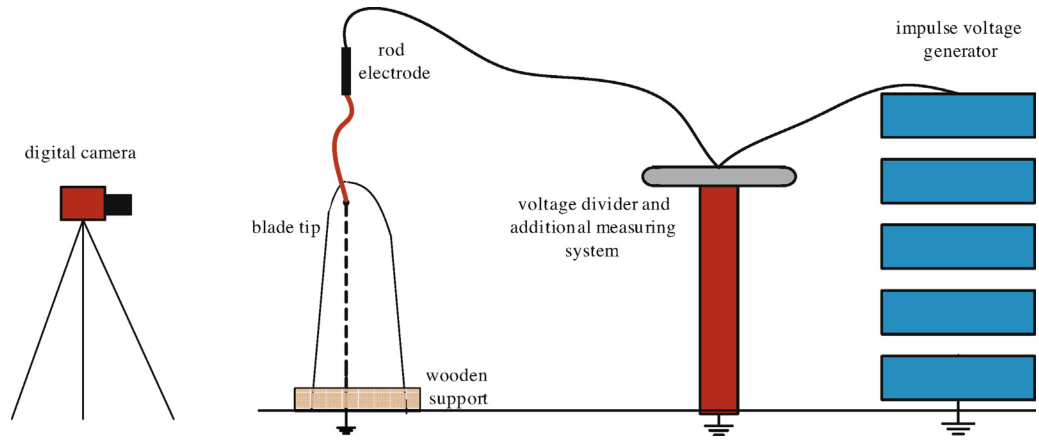

Fig. 1. Experimental test system.

view, the best protection system is selected. Finally, the enhancement of this system is proposed to increase the lightning protection efficiency.

2. Experimental work

As aforementioned, lightning attachment manner to the wind turbine blade sample was experimentally investigated where the experiments were carried out at the high voltage laboratory, Minoufiya University, Egypt. In this section, the experimental setup and the procedure used for evaluating the experimental results are discussed as follow.

2.1. Experimental setup

As shown in Fig. 1, the test system setup includes:

- Impulse voltage generator (5 stages, 0.5 MV, and 25 kJ),
- Mixed *R–C* voltage divider with high voltage arm capacitance of 1500 pF, low voltage arm capacitance of 375 nF and series resistance of 50 Ω,
- Oscilloscope, 100 MHz,
- Blade tip section of 2 m length a part of 19.1 m actual blade was made of glass fibers reinforced polyester and used as a blade model including the lightning protection system. This blade tip section was designed based on the dimension of 600 kW wind turbine and design steps are as reported in [11],
- Digital camera with UV filter used to determine and show the discharge attachment point to the blade sample. The digital camera has a resolution of 16.2 MP and records 1080 p movies at 30 farms per second.

There were four considered configurations of blade air-termination systems equipped with the blade sample as shown in Fig. 2. The specifications of each system are summarized as follow:

(1) Receptor: A disk type receptor made of copper of 20 mm in diameter was inserted at 150 mm from blade tip as shown in Fig. 2a. The receptor was connected to the ground via down conductor of 6 mm^2 cross section area embedded in the blade.
(2) Metallic cap: In this system, 150 mm tip part of the blade was completely covered with copper foil (see Fig. 2b) and connected to the ground via down conductor of 6 mm^2 cross section area.
(3) Metallic mesh: In this system, a metallic mesh was glued on the blade surface from its top to the root using a thin film of silicone adhesive. The mesh configuration is shown in Fig. 2c. The metallic mesh was made of steel wires with total width of 15 mm.
(4) Metallic conductor on the blade edges: Conductor made of copper with cross section area of 6 mm^2 fixed on the blade edges as shown in Fig. 2d.

2.2. Experimental conditions

The protected blade tip was tested in selected five positions as the blade rotates in the real field. These positions are shown in Fig. 3. They are vertical, oblique 45°#1 (with the leading edge facing the electrode), oblique 45°#2 (with the trailing edge facing the electrode), horizontal#1 (with the trailing edge facing the electrode), and horizontal#2 (the blade surface facing the electrode). These positions are for static blade (not rotating) where the lightning attachment process is not affected by the rotation [12,13]. However, the rotation effect takes place after attachment. When the lightning

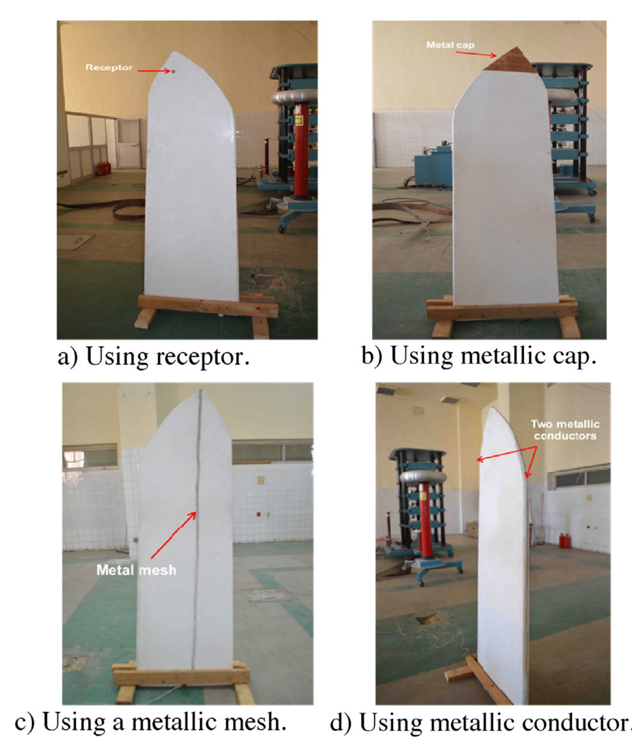

Fig. 2. Air-termination systems under test.

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