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An experimental field study of the grounding system response of tall wind turbines to impulse surges

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ABSTRACT

In this work, an experimental investigation of the grounding system behavior of tall wind turbines in both time and frequency domains is presented. Two scenarios were considered: in the first one, measurements were carried out on the grounding system embedded in the wind turbine foundation, before assembly of the wind turbine itself; in the second one, the complete wind turbine (tower, nacelle and blades) was included. The study also presents an enhanced signal processing technique for noise cancelation in a harsh electromagnetic environment. In the analysis, the frequency dependence of the grounding impedance was evaluated and a numerical simulation in steady state was performed. The simulation model leads to a satisfactory representation of the studied system. Preliminary results show that the evaluated grounding impedance is not significantly affected by the presence of the complete wind turbine at the evaluated frequencies.

1. Introduction

Grounding systems are one of the main resources capable of keeping the physical integrity of an installation in the event of a ground fault. Suitable grounding schemes are also important for the population's safety. Generally, electrical installations are constantly subjected to the occurrence of high currents related to short circuit faults and especially to the occurrence of lightning. The proper design and evaluation of a grounding system is therefore relevant to achieve efficiency of the involved protection system with consequent personal safety, particularly in transmission networks and in the protection of devices subjected to high risk of failure caused by lightning strikes, as is the case for wind turbines (WT). To reach this aim, a methodology as accurate as possible must be used.

Upward flashes are of great interest for lightning protection of tall structures. Indeed, they constitute a major threat for wind turbines that are characterized by very long blades and tall masts [1,2]. The use of renewable energies is a global trend and the current pace of development of the associated new technologies is expected to continue. Particularly, in the case of wind farms, where the wind turbines are extremely susceptible to failures due to lightning strikes, the protection of the involved system is a must. The reliability of wind parks in the mountains is of great concern due, on the one hand, to the high risk of failures due to lightning strikes [3] and, on the other hand, to the high maintenance and repair costs stemming from their remote location. Research on lightning protection of wind turbines is mainly focused on the protection of the blades, whereas proper grounding also plays an important role in the performance of the WT and its equipment during a lightning strike [4–7]. The evaluation of these devices can be a valuable practice contributing to a better protection against lightning [8].

Experimental field measurements associated with signal processing techniques and computer simulation are important practices providing a better understanding about the performance of wind turbines struck by lightning and the grounding systems behavior, contributing to improve the reliability of the power electric system (PES).

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Fig. 1. Mont-Crosin wind park overview.

Fig. 3. Grounding system of WT6.

As recommended by the standards [9], the steady state grounding resistance of the wind turbine should be less than 10 Ω. However, sometimes this requirement is not achieved, mainly due to the soil characteristics in the wind farm area. According to Ref. [7], based on more than 450 measurements, only 30% of the considered WTs satisfied this recommendation (grounding resistance less than 10 Ω); and only 3% of the WTs grounding resistance were less than 1 Ω. Furthermore, not only the steady state analysis, but also the transient evaluation of the grounding system provides important information to a complete and proper characterization of the wind turbine behavior [10–12].

In this context, the goal of this paper is to present a study based on the wind turbine grounding measurements performed at the Mont-Crosin wind park in Switzerland. Experiments were carried out when only the construction of the wind turbine foundation had been completed and then after the installation of the rest of the wind turbine was finished, namely the tower, nacelle and blades. Preliminary experimental results have been presented in Ref. [6]. In the present study, new sets of experimental results were used, including significant improvements in the signal processing technique. In addition, numerical simulations to evaluate the performance of the grounding static resistance are presented.

This work is structured as follows: Initially in Section 2, the main features related to the Mont-Crosin wind park are introduced. In Section 3, some aspects regarding the grounding system measurements are presented. Section 4 is dedicated to discussing the signal processing technique used in this work. Afterwards, the evaluation of the experimental measurements both, in the time and frequency domains, is reported in Section 5. The numerical simulations in steady state are the focus of Section 6. Finally, the conclusions of the study are reported in Section 7.

2. Mont-Crosin wind park overview

The Mont-Crosin wind park is located in the Jura Mountains and is composed of 16 WTs with nominal power ranging from 850 kW to 2 MW, with an overall installed capacity of 29.2 MW and annual energy production above 40 GWh. Fig. 1 shows an aerial view of the wind park.

Even considering that Mont-Crosin is not located in an area of high keraunic level, about 2–3 flashes per km^2 per year, in the past years a number of lightning flashes have hit several wind turbines causing severe damage. Fig. 2 illustrates some of the damages in the blades caused by lightning in two units present in the park.

Recently, during the repowering process, four new 2 MW units replaced the old ones (WT5, WT6, WT7 and WT8) and the opportunity was taken to begin a study on the behavior of the grounding system. The tower height of the considered WTs is 95 m, with a base diameter of 7.5 m, a rotor diameter of 90 m and total height of 140 m.

The grounding of the new wind turbines consists of a copper wire ring of 18 m diameter at the base, interconnected with several circular copper and aluminum conductors at different depths (6 m diameter for the top ring) and linked to steel reinforced bars. This structure, also called concentrated grounding, is filled with concrete and is encased in the tower foundation. Fig. 3 shows the referred grounding system including the aluminum, steel and cooper conductors before its encapsulation in concrete.

The interconnection among the grounding grid components should be based on the requirements of the used conductors, namely: electrical conductivity, corrosion resistance, current carrying capacity and mechanical strength. The connections must maintain a temperature rise below that of the conductor in order

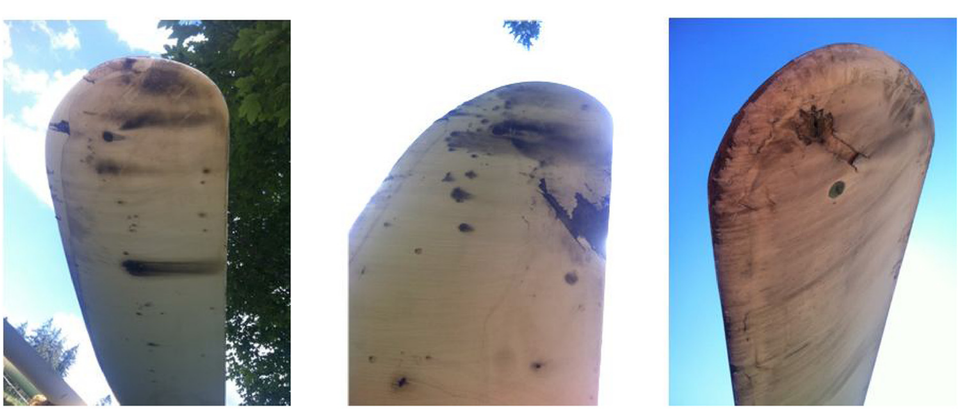

Fig. 2. Damages in wind turbine 6 (WT6) and wind turbine 8 (WT8) caused by lightning.