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Fair Weather Induced Charges and Currents on Tall Wind Turbines and Experiments with Kites

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***Abstract*—Earth's atmospheric potential rapidly increases up to few tens of kilovolts below 200 m altitude. This potential drop will induce charge to tall objects at ground by virtue of electrostatic induction. In this work we investigate the induced electric charges in fair weather to a 1.5 MW and 5 MW wind turbines. The effect of rotation is included and the current calculated result in currents of few micro-amps. The production of point discharge and corona is investigated and some experiments are conducted by means of instrumented kites.**

Keywords-wind turbines;atmospheric potential;electrostatic induction; kites; point discharge; corona

I. INTRODUCTION

Earth's global electric circuit is characterized by an atmospheric potential between ground and the ionosphere of few hundreds of kV (typically ~250 kV) e.g. [1]. The atmospheric conductivity has a scale height of about 6 km and thus, the potential varies with the same rate. At low altitudes, the voltage drop at~1 km is already 100 kV whereas about ~50 kV at 200 m above the ground (see [2]).

The effect of the atmospheric potential gradient will result in electrostatic induced charge on grounded objects. In [3], by means of ascending and descending tethered balloons, currents were measured under fair weather and thunderstorms. Currents were the order of tens of micro-amps depending on the altitude of the balloon and the wind speed. Recently, the UPC group (authors) started to experience with measuring induced currents and voltages in conductive tethered kites [4]. As in balloons and kites flying at altitudes of more than few hundred meters, currents can be associated to the establishment of the induced charge and to point discharge.

Wind turbines are electrically conductive tall structures (>100 m) with a significant part of their length rotating. Modern multi-megawatt wind turbines can be as high as 200 m (e.g. 5 MW wind turbine). In these structures, as in any others, the effect of the atmospheric potential will result in an induced charge by virtue of electrostatic induction but the rotation will cause the establishment of current.

Recently [5] discovered repetitive electrical discharges produced by rotating wind turbines under electrified clouds. In that work the authors used a Lightning Mapping Array (LMA) network with sensors at several kilometers. The same findings have been found by [6] and extended to low electric field conditions.

In this paper, we calculate the induced charges and currents on rotating wind turbines under fair weather conditions and evaluate the occurrence of point discharge and corona. In addition, we present experimental results of current measurements using kites flying at altitudes similar to wind turbine heights.

II. FAIR WEATHER ELECTROSTATIC INDUCED CHARGE AND CURRENTS

The induced charge to a tall grounded structure is evaluated here by means of the method-of-moments [5]. The wind turbine geometry is simplified by a conductive thin wire of radius 1cm (Fig. 1).

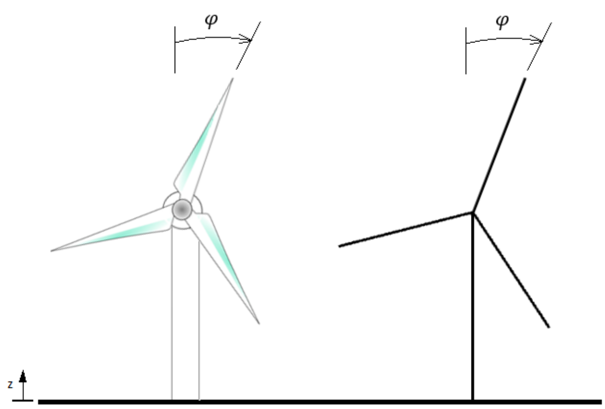

Figure 1. Left: wind turbine with a rotor blade at positionφ. Right: simplified geometry where the turbine is represented by conductive wires. The position of the rotor blade is φ.

H_T corresponds to the height of the tower whereas H_B corresponds to a single blade length. In the method-of-moments the simplified wind turbine geometry is segmented with a n-number of segments. The induced charge density (ρ) at any segment can be approximated by:

$$\rho = k(\Phi_z - \Phi_{(z=0)}) \quad (1)$$

Where Φ_z is the atmospheric potential at level z, $\Phi_{(z=0)}$ is the ground potential ($\Phi_{(z=0)} = 0$ V) and k is a factor (or segment capacitance) to be determined by the method-of-moments. As boundary conditions, the atmospheric potential up to 500 m is adopted from [2] and plotted in Fig. 2.

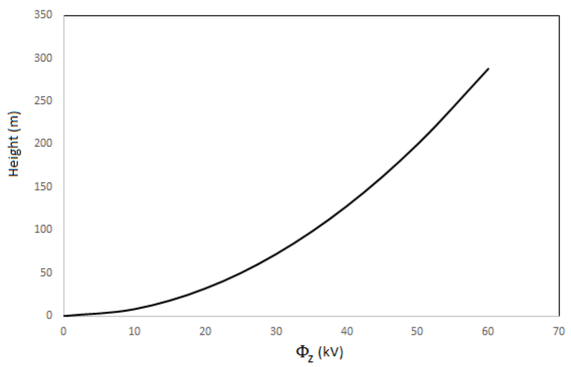

Figure 2. Atmospheric potential for the first 300 m adopted from [2].

The atmospheric potential in Fig. 2 is assumed to be for flat terrain and sea level to be as height reference (z = 0 m).

The electrostatic induced charge is calculated for the geometry in Fig. 1 (simplified geometry) considering technical data of a 1.5 MW wind turbine (H_T= 65 m and H_B = 31 m) and a 5 MW wind turbine (H_T= 140 m and H_B= 31 m). For each case, the charge is computed for several rotor blade angles ranging from 0º to 180 º. The tower height and the blade length were divided into several discrete segments of lengths 3 centimeters. The results are presented in Fig. 3 and Fig. 4.

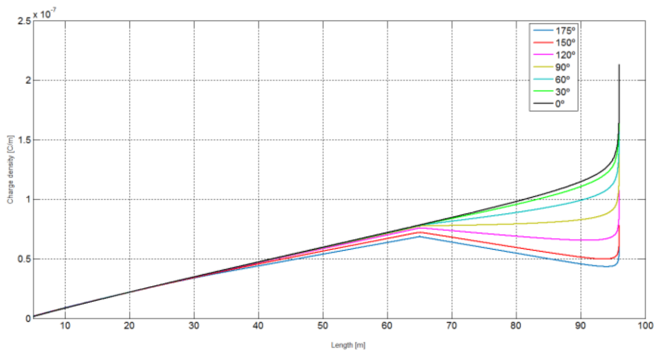

Figure 3. Charge density along the wind turbine at different rotor blade positions (φ) for the considered wind turbine of 1.5 MW (H_T = 65 m and H_B = 31 m).

When the blade is located at φ=0º (vertical position), the maximum value of charge density is induced over the blade and decreases when the blade position change from φ=0º to φ=175°, behavior that we expected because the charge density is a function of the atmospheric potential distribution (Fig. 2). On the other hand, the maximum charge density was computed on the thin wire end.

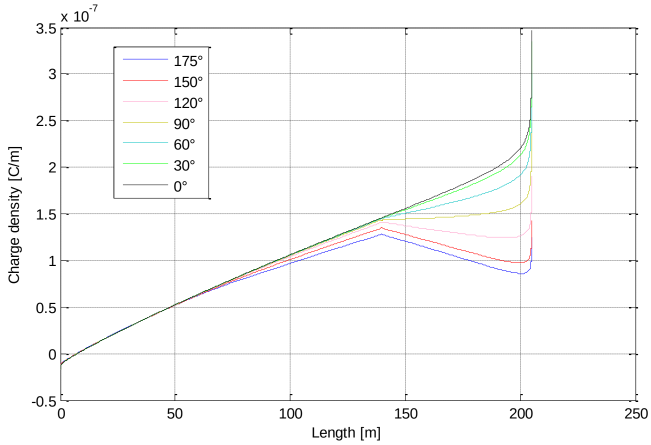

Figure 4. Charge density along the wind turbine at different rotor blade positions for the considered wind turbine of 5 MW (H_T = 140 m and H_B = 64.5 m).

The rotating speeds (maximum) are considered to be 20 rpm for a 1.5 MW turbine and 14.5 rpm for a 5 MW wind turbines. The currents can be calculated as:

$$i_B = \frac{dQ}{d\varphi}\omega \quad (2)$$

Where ω the rotation speed of the turbine is in rad s^{-1} and Q is the total blade's induced charge at a given blade angle φ.

$$Q(\varphi) = \int_{Ro}^{R_L} \rho(\varphi, R)\, dR \quad (3)$$

Where Ro is the root of the blade and R_L is the length of the blade and R is the radius between Ro and R_L.

Here we only analyze the induced charge at positions ranging from φ=0º to φ=175º (Fig. 3 and 4) and the resulted currents are presented in Fig. 5.

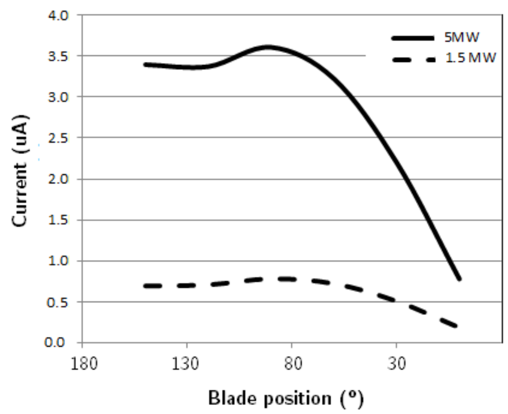

Figure 5. Blade currents for 1.5 MW and 5 MW wind turbines due to rotation in fair weather. Only electrostatic induction is considered.

III. EVALUATION OF POINT DISCHARGE AND CORONA

Point discharge occurs when the local electric field at the tip is high enough, free electrons can be accelerated having enough kinetic energy to ionize neutral air molecules by inelastic collisions. Point discharge is not luminous and energetic as corona. According to the American Meteorological Society - AMS definition, corona discharge is in between a point discharge and a spark discharge. It must be distinguished the following types of coronas: glow corona and streamer corona. Glow corona is a streamer-free corona whereas a streamer corona is a flash of streamers [7]. The onset electric field for corona discharges is commonly determined by Peek's formula e.g. [8] which typically requires electric fields of the order of 3 MV/m. However, coronas has been observed to occur at lower electric fields as suggested by the AMS e.g.: ~100 kV/m.

Figures 6 and 7 plot the electric fields for the 1.5 MW and 5 MW wind turbines, respectively. The figures show the turbines with vertical blade position (φ=0º). The electric field was calculated from the charge density distribution at 10 cm from the segments of the simplified win turbine model.

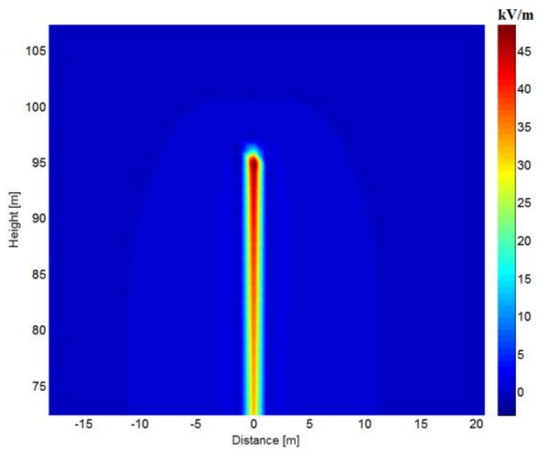

Figure 6. Electric field for a 1.5 MW wind turbine calculated at 10 cm form the segments of the simplified turbine model and excluding the two lowest blades.

The results suggests that the modeled 1.5 MW turbine wind turbine the production of point discharge current will be much lower than the 5 MW. The 5 MW turbine is close to electric field levels of 100 kV/m in which corona might occur (according to AMS). With result suggests that a tall wind turbine or one affected by the terrain (not in a flat ground close to sea level) corona discharges can appear even in fair weather or with a very low effect of close electrification. That might be the case presented in [6] where corona discharges emitted by wind turbines were detected even with electrostatic field levels of 100 V/m at ground.

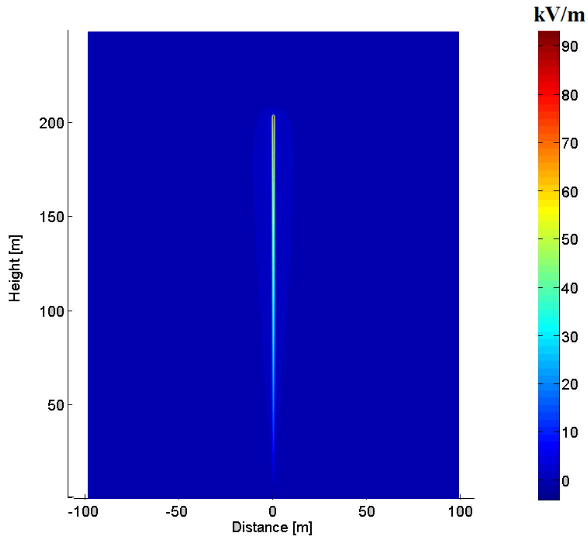

Figure 7. Electric field for a 5 MW wind turbine calculated at 10 cm form the segments of the simplified turbine model and excluding the two lowest blades.

IV. EXPERIMENTS WITH KITES

As pointed by Davis in [3] kites have been associated to atmospheric electricity and inspired lightning protection since the days of Franklin. In 2014 the UPC group started to experiment with kites using conductive tether [4]. Here we present recent experiments with the aim of measuring tether currents of a flying kite.

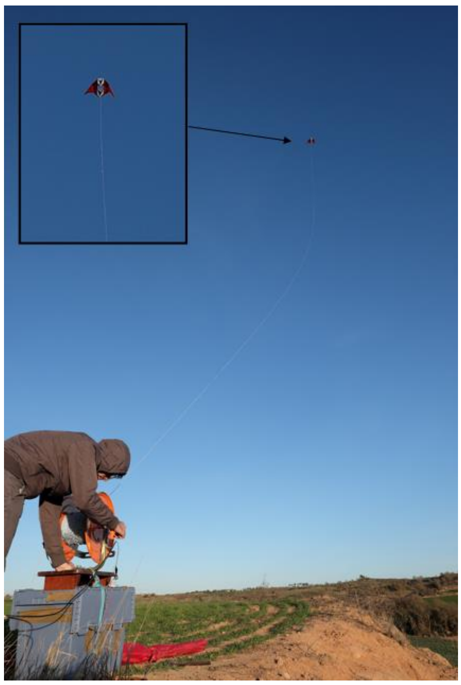

Figure 8. Picture during one flight experiment using a delta kite.

The current intensity that flows through the wire kite was measured with a picoammeter instrument. The measurement was developed when the kite reached 120 meters of the height. The range resolution of the instrument is from 2nA to 2 mA. At the same time a portable GPS tracker was attached to kite in order to obtain its position and elevation value.

An example of tether current measured at ground for a period of 1.5 minutes is depicted in Fig. 8. The measured current is at the range of micro-amps consistent with [3]. In the case of the kite, the deployment of tether does not mean flying at higher altitude. That is because the balance between the wind, kite's lift, kite's drag and tether drag.

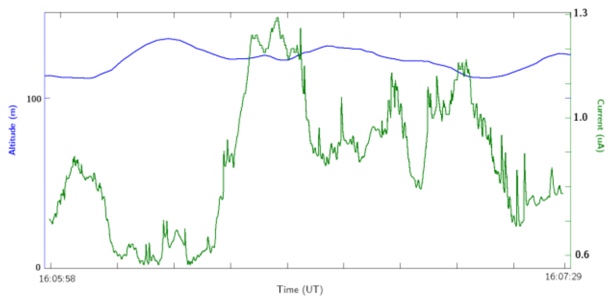

Figure 9. Kite altitude and tether current during 1.5 minutes period.

V. CONCLUSIONS

In this work we computed the induced charge to a 1.5 MW and 5 MW wind turbines. The results show that currents of the micro-amp range can circulate on wind turbine blades. These currents are very small and inoffensive. However, charge could be accumulated in the massive dielectric components and produce electrostatic discharges that can affect to instruments and personnel. The high electric fields at the blade tip suggest remarkable point discharge activity that in some cases can develop corona emissions. Some blade designs have CFRP laminates at the blade tip with, it is still not clear if the point discharge currents or corona for very long periods of time have some effect to the microstructure of the CFRP at that position.

At the last part of the paper, we showed our experience in measuring currents in a conductive tether of a kite. Our aim is to have measurements flying at wind turbines maximum altitude for some long periods. Despite the kite flight was development

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