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A simulation approach on rotor blade electrostatic charging and its effect on the lightning overvoltages in wind parks

Y. Méndez Hernández [a,b,*], T.E. Tsovilis [c], F. Asimakopoulou [c], Z. Politis [c], W. Barton [d], M. Martínez Lozano [e]

[a] Engineering Department, Universidad Simón Bolívar, Caracas, Venezuela
[b] R&D Department, Murayh Company, Munich, Germany
[c] R&D Department, Raycap SA, Athens, Greece
[d] Electric Power Systems: Wind Power, General Electric Company, Salzbergen, Germany
[e] Engineering Department, Universidad De La Salle Bajío, León, Mexico

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ABSTRACT

This study is an attempt to present a theoretical approach of the hypothesis of electrostatic charging of rotor blades during storms and its effects on the lightning protection and overvoltage protection systems during lightning strokes.

Overvoltage and overcurrent in form of surges may be the result of electromagnetic traveling waves caused by lightning strokes, especially if the grounding (earthing) system of the wind turbines (WTs) is galvanically connected between each other in order to ensure a common earth potential in the wind park (WP).

These effects may impose additional electrical issues to the low and medium voltage electrical installation including the surge protection devices.

1. Introduction

The hypothesis of the triboelectric effect or electrostatic charging caused by the friction between the isolating material of the rotor blades (glass fiber, balsa wood, gluing material, etc.) and the air, especially during storms is the main focus of this study.

Moreover, induced or transferred charge during normal operation and storms is a motivation to further explore this interaction. A simulation approach in electrostatic charging of rotor blades and its effect on the earth potential in Megawatt-class wind parks is proposed in this publication, as a first attempt to address this topic.

Before the occurrence of a lightning strike an increase in the value of the electric field is measured [1]. These observations extended to wind turbines and wind parks support the hypothesis that, during storms, an electrostatic charging may take place on the rotor blades and other components manufactured by composite materials, such as, the nacelle.

Fig. 1 shows an example of a continuous electric arc or discharge caused by electrostatic charging on a rotor blade root of a wind turbine [2]; the image was taken during a stormy day and is part of a video that lasts several tens of seconds. Rotor blades are mainly manufactured by non-conductive composite materials, with non-orthotropic dielectric properties and large dimensions (several meters of length) and weight (several tons), and therefore the probability of electrostatic charging is not negligible.

With regards to the dimensions of modern Megawatt-class wind turbines, unexpected effects in form of overvoltage and overcurrent may be the result of electromagnetic traveling waves caused by lightning strikes; especially if the earthing (grounding) systems of the wind turbines (WTs) are connected to each other in order to ensure a common earth potential in the wind park (WP) [3]. These effects combined with electrostatic charging of rotor blades may impose additional requirements on the reliable operation of the wind turbine's electrical system (low and medium voltage).

The simulation of electromagnetic transients combined with the one of electrostatic charging, such as lightning disturbances in wind parks, shall include specific models to represent each component within the wind turbine (WT) or wind generator (WG); this representation differs from other studies, such as stability and power flow calculations, on the high frequency point of view.

* Corresponding author at: Universidad Simón Bolívar, High Voltage Lab, Sartenejas, Venezuela. Tel.: +58 2129014131.
E-mail addresses: ymendezh@usb.ve, ymendezh@murayh.com (Y.M. Hernández).

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Fig. 1. Electric discharges on a rotor blade root [2].

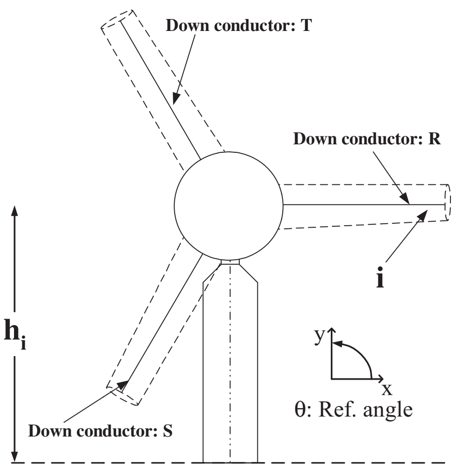

Fig. 2. Schematic diagram of the wind turbine incorporating symbols used in the calculations.

2. Approach and modeling

The components of the wind park were modeled in form of surge impedances with a propagation velocity of the travelling waves, where, i is the index of the down conductor of the corresponding rotor blade and h_i the height of the conductor above ground as showed in Fig. 2 [10].

The other components of the wind turbines, such as rotor blade bearings, azimuth bearings, steel tower, earthing system, low (LV) and medium (MV) voltage distribution cables, electronic converter, generator, distribution transformer and LV and MV MOVs were also modeled.

The time to front of the computed overvoltages across the wind park's electrical installation exhibits values lower than that of the incoming lightning current (10 μs). Due to electromagnetic wave reflections in the wind park under study the significant (dominant) frequency for the calculation of electrical parameters of system components should be considerably higher than 25 kHz or at least an order of magnitude higher. For this reason the guidelines for fast front transient calculation [21] suggest the use of a dominant frequency of 500 kHz for calculating transmission line electrical parameters in lightning surge analysis. In light of the above and based on several attempts of simulating the transient behavior of the wind park's complex system, the selection of 250 kHz as a dominant frequency can be considered, in this study, as an acceptable compromise between the electrostatic charging and the surge propagation modeling.

The topology of the wind turbine chosen for the calculations, which consists of a double-fed wounded-rotor induction machine or generator (DFIG) connected to the grid on the stator side and to an electronic converter on the rotor side, is depicted in Fig. 3.

2.1. Rotor blades, bearings and tower

The rotor blade lightning protection system (LPS) chosen for the model was the receptor-based lightning protection system explained in [3,6,7]. It was modeled by means of the following equation:

$$Z_{\text{Blade}} = 30 \times \ln\left(2\frac{\left(h_{\text{Blade}}^2 + r_{\text{Blade}}^2\right)}{r_{\text{Blade}}^2}\right)\ [\text{Ohm}] \qquad (1)$$

where h_{Blade} is an equivalent mean-height and r_{Blade} is an equivalent radius of the segment of the rotor blade being analyzed.

The parameters of assumed decoupled surge impedance model Z_{Blade} for the blades as an attempt to represent their electromagnetic response to fast transients based on the theory presented in [9,10,18].

For the calculation of the surge-impedance of the rotor blades an approximation was assumed with a reduced velocity of surges of 65% of light speed, as an attempt to model the capacitive-effect of the structural and skin material of the rotor blade (Glass fiber reinforced plastic—GFP). Carbon fiber reinforced—CFP materials, which are widely used in the wind turbine blade manufacturing, where not considered during this study and will be part of a future project.

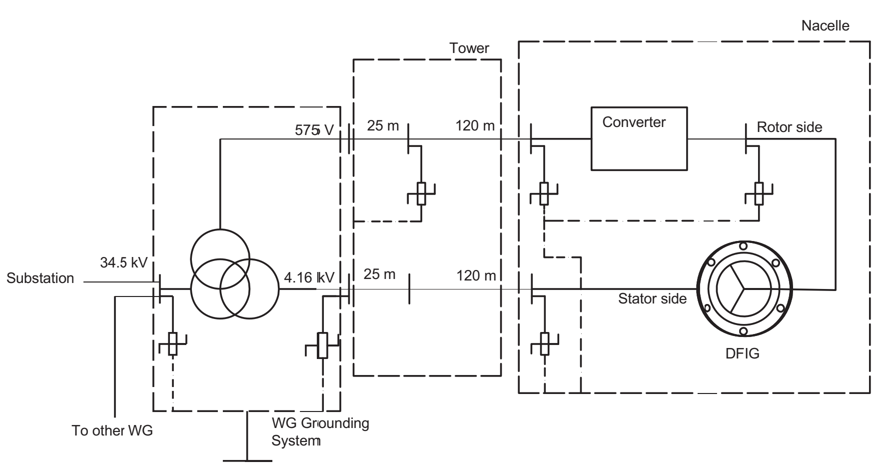

Fig. 3. Schematic representation including the DFIG and the AC/AC electronic converter connected at the grid side and the DFIG rotor side [4,5].