Effects of Wind Turbine Grounding System Interconnection on Electromagnetic Transients Caused by Lightning

Efectos de la Interconexión del Sistema de Puesta a Tierra de Aerogeneradores sobre Transitorios Electromagnéticos Causados por Descargas Atmosféricas

Y. Méndez[1], J.C. Rodríguez[2], J. Ramírez[3]

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ABSTRACT

The latest edition of the norm IEC-61400-24 recommends that the wind turbine's grounding system should be interconnected to the other wind turbine's grounding system erected in the wind park; this is in order to reduce abnormal earth potential distribution and mitigate dangerous overvoltages. Based on this statement, an analysis of the effects on transient current and voltage during lightning attachment is conducted.

A comparison between a stand-alone wind turbine (without grounding system interconnection) and a set of interconnected wind turbines (with grounding system interconnection) is presented and analyzed. Overvoltage and overcurrent in form of surges may be the result of electromagnetic traveling waves caused by lightning; these effects may impose additional requirements for the reliable operation of the low voltage and medium voltage grid against surges caused by lightning strikes.

Keywords: Overvoltage, wind parks, rotor blades, lightning.

RESUMEN

La edición más reciente de la norma IEC-61400-24 recomienda que el sistema de puesta a tierra de los aerogeneradores sea conectado galvánicamente a los sistemas de puesta a tierra de los otros aerogeneradores en el parque eólico; esto con el fin de reducir una distribución anormal de potencial de tierra y mitigar sobretensiones. Basado en este argumento; se realiza un análisis de transitorios, en forma de voltaje y corriente, causado por descargas atmosféricas con el fin de explorar el efecto de la interconexión vs. un aerogenerador sin sistema de puesta a tierra interconectado.

Palabras clave: Sobretensiones, parques eólicos, aerogeneradores, palas, descargas atmosféricas.

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Introduction

Modern multi-megawatt wind turbines may experience unexpected effects in form of overvoltage and overcurrent 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).

A simulation approach in the effects of the interconnection of the wind turbines' grounding system on the wind park's electrical installation is explored in this study, as a first attempt to address this topic.

Wind Turbine 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 Figure 1.

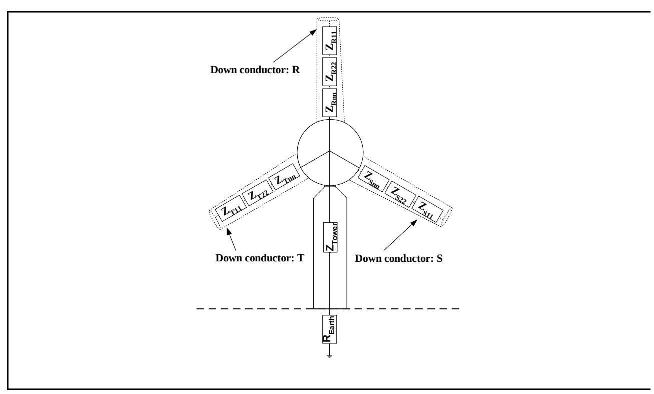

Figure 1. Model of the wind turbine.

[1] Dr.-Ing. MBA, Universidad Simón Bolívar, Venezuela. E-mail: yarumendez@usb.ve
[2] MSc., Universidad Simón Bolívar, Venezuela. E-mail: jramirez@usb.ve
[2] MSc., Universidad Simón Bolívar, Venezuela. E-mail: jrodrig@usb.ve

The other components, such as rotor blade bearings, azimuth bearings, steel tower, earthing system, low (LV) and medium (MV) voltage distribution cables, distribution transformer and LV and MV MOVs were also modeled and widely described in the references.

The topology of the wind turbine chosen for this study, which consists of a double-fed induction machine (DFIG) connected to the grid on the stator side and to an electronic converter on the rotor side is depicted on Figure 2. This topology is often implemented in wind turbines due to technical and commercial benefits.

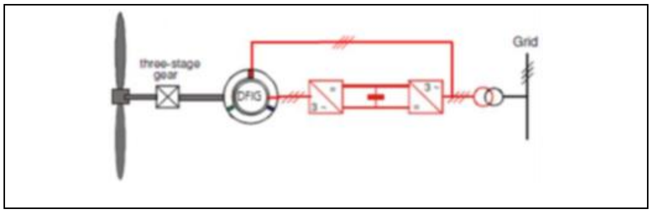

Figure 2. Topology of the wind turbine.

Focal point of this research work is the simulation model of the electronic converter is depicted in Figure 2. These parameters are optimized for the frequency range implemented in the study of transients.

It is worthwhile to mention, that the neutral conductor of the converter is floating; this practice is in order to reduce the common-mode in the normal operation of the power electronics of the converter.

The surge impedance model reflects the electromagnetic coupling between both AC sides and connected to the grid and generator's rotor low voltage side respectively. Figure 2 depicts the topology adopted for the electronic power converter.

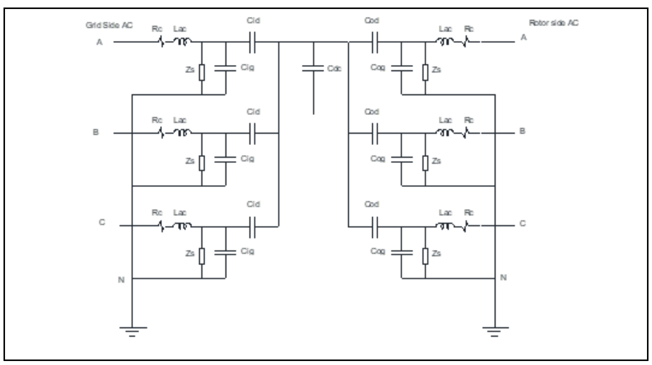

Figure 3. Topology of the Wind Turbine's Electronic Converter.

The model neglects the mutual capacitance between phases and considers the R_c (ohmic losses) and L_{ac} (coils) for connections in both converter's sides (including the harmonic filters).

A concentrated impedance in form of a shunt resistance Z_s and shunt capacitances to ground C_{ig} and C_{og} represents the commercial low voltage integrated circuits (ICs), such as IGBTs (see Table 1).

Table 1. Electronic Converter parameters.

R_c [Ohm]	L_{AC} [mH]	Z_s [Ohm]	C_{ig}/C_{og} [nF]	C_{id} [nF]	C_{DC} [µF]
0.10	200.00	250.00	0.10	1.00	2400.00

Study: Effects of the Grounding System Interconnection

A simulation study in order to explore the effects of the grounding system interconnection was conducted with the program EMTP. In the first case, a standalone wind turbine was struck by lightning; evenly, in the second simulation group composed by three wind turbines was explored. The simulation parameters are listed as follows:

- Lightning peak current: 200 kA.
- WT tower height: 140 m (35 m length/segment for a total of 4 segments).
- Rotor blade: length 56 m, manufactured in glass reinforced fiber composite (GRFC).
- Distance between wind turbines: 300 m.
- The wind park consists of three (3) WTs, the central wind turbines is struck by lightning.
- The sheath of the medium voltage cable and the grounding conductor of each WT are grounded.
- The total simulation time is 100 µs and the simulation time step (delta t) is 10 ns.
- A value for the soil resistivity of 200 Ohmm was chosen in order to simulate boggy soil.

The simulation results are disclosed from figure 4 to figure 8. Figure 4 depicts the transient plot at the primary side of the wind turbine's distribution transformer that was struck by lightning.

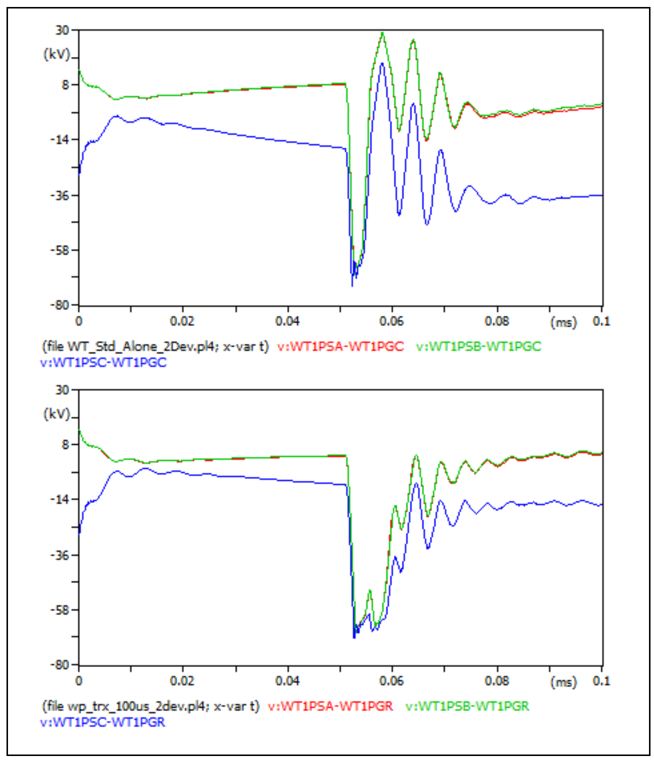

Figure 4. Transient voltage: wind turbine struck by lightning (transformer primary's side); without (top) and with (bottom) grounding system interconnection.

The interconnection of the other wind turbine's grounding systems increases the oscillations during the transient condition at the primary side of the wind turbine's transformer, this situation is mostly introduced by the grounding cables and travelling wave's transmission and reflections in the whole interconnected grounding system.

Concerning the magnitudes a slightly offset is introduced by the grounding system interconnection and the overvoaltes reach are attenuated within few cycles (see figure 4).

Figure 5 shows the transient plot at the secondary side of the wind turbine's distribution transformer that was struck by lightning; the interconnection of the other grounding systems increases the oscillations during the transient, probably due to travelling wave effects in the grounding system between the wind turbines and similar to the transformer primary side's response. It is advisable to design and install a proper overvoltage protection system.

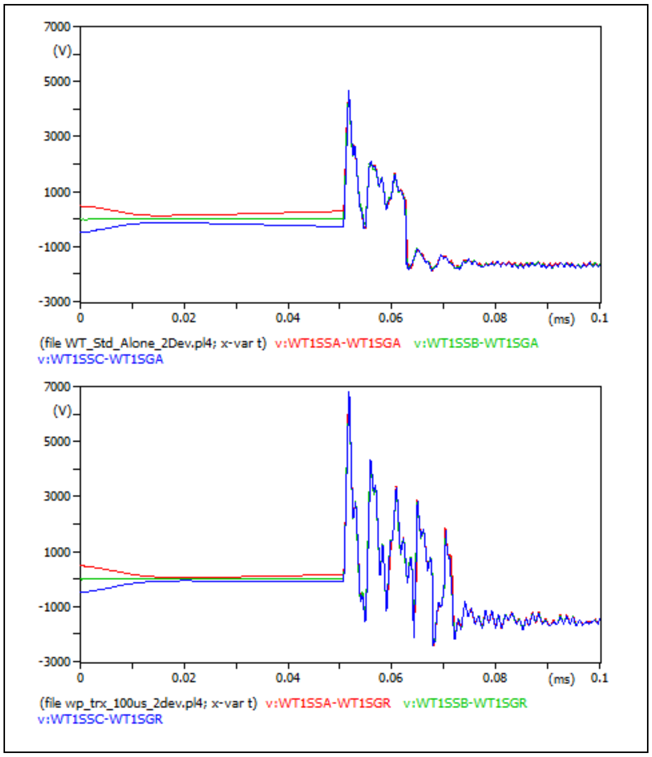

Figure 5. Transient voltage: wind turbine struck by lightning (transformer's secondary side); without (top) and with (bottom) grounding system interconnection.

Figure 6 shows the transient plot at the generator's stator. There are not remarkable differences in regards to overvoltages, when the grounding systems are interconnected; this probably observed due to the condition that the generator is located in the nacelle at 140 m height.

Similarly, no harmful effects in form of overvoltages are observed at the generator stator as well. It is important to mention that the overvoltage protection system is installed at the generator's rotor output and electronic converter's input in order to mitigate any additional negative effects.

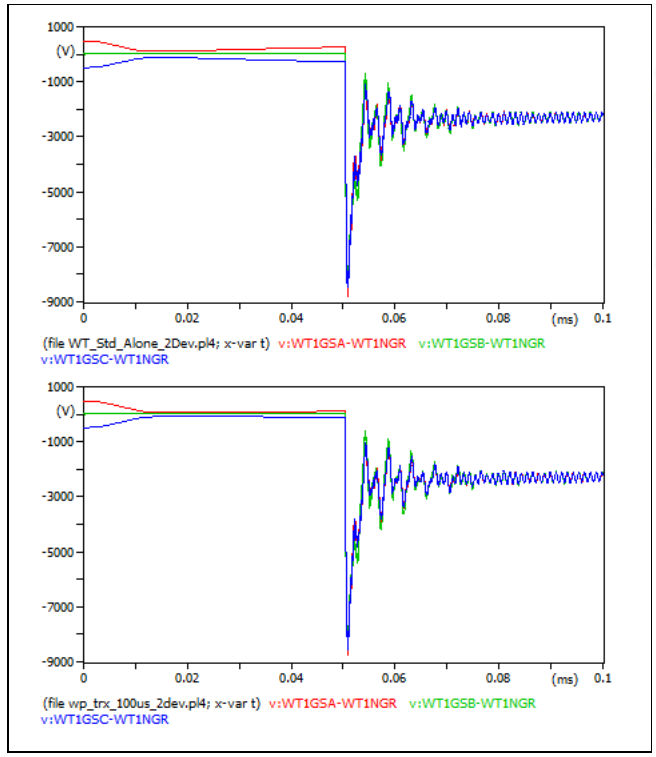

Figure 6. Transient voltage: wind turbine struck by lightning (low voltage double-fed generator stator); without (top) and with (bottom) grounding system interconnection.

The transient plot of the generator rotor, which is connected to the electronic converter, is depicted in figure 7.

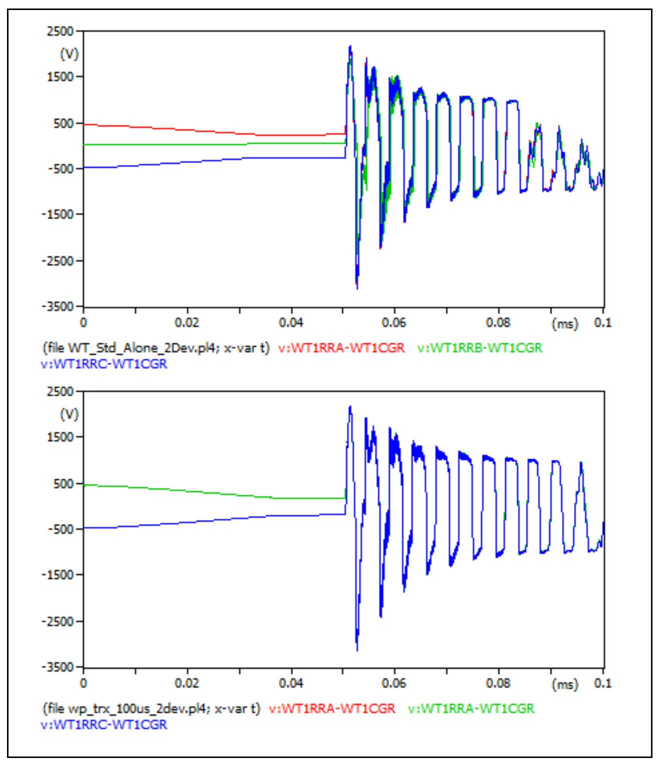

Figure 7. Transient voltage: wind turbine struck by lightning (low voltage double-fed generator rotor); without (top) and with (bottom) grounding system interconnection.

The generator rotor, which is connected to the electronic converter, is not showing remarkable differences in regards to overvoltages when the grounding systems are interconnected (see figure 7). No harmful effects in form of overvoltages are observed. It is important to mention that the overvoltage protection system is installed at the generator's rotor output and electronic converter's input in order to mitigate any additional negative effects.

The distribution of the transient current circulating across the yaw bearing, nacelle and upper segment of the tower is depicted in figure 8; in these regards, can be mentioned that a considerable amount of the lightning current flows across the nacelle and nacelle's grounding cables that are installed in the inner section of the wind turbine's tower. The segments can be used as grounding system; when the segment's surge impedance is lower that the grounding cables' surge impedance. In the case of these simulations and assumptions, it can be mentioned that the surge impedance of each segment imposes an elevated value to the high-frequency component (steep front) of the current.

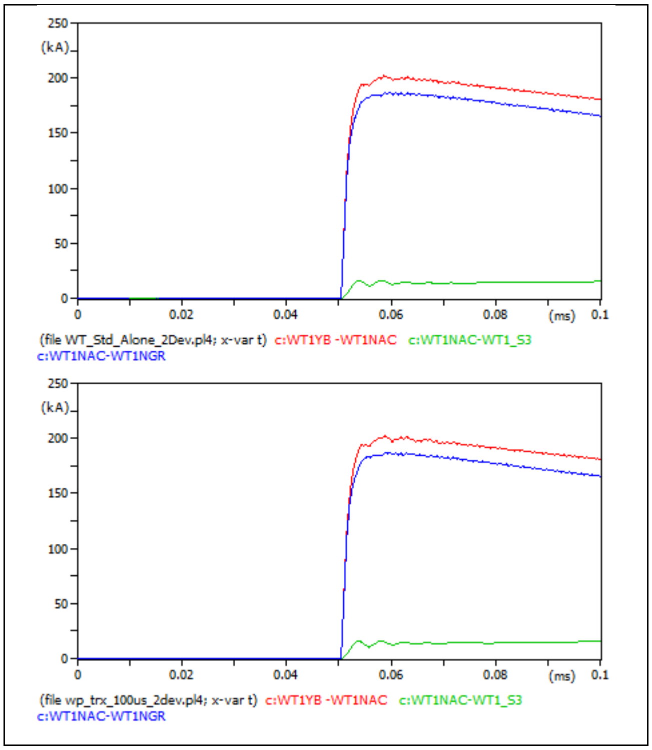

Figure 8. Transient current at the footing resistance of the wind turbine 1 transformer (Top: without grounding system interconnection; bottom: with grounding system interconnection).

Figure 9 shows the surge current across the footing resistance in both cases; as expected the peak value of the current is attenuated by the interconnection to the other grounding systems.

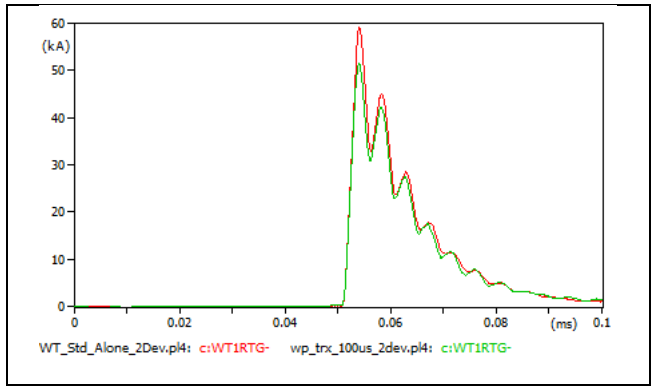

Figure 9. Transient current: wind turbine struck by lightning (footing resistance); without (top) and with (bottom) grounding system interconnection.

Conclusions

The surge suppression or overvoltage system evolves with these type of studies combined with additional experimental testing, certification and long-term field experience and applications.

The interconnection of the grounding system is an advisable practice in order to relief the transferred overvoltages at the distributions transformer of the wind turbines.

Further, a portion of the lightning current flows to the other wind turbine's grounding system. This situation could lead to some overvoltage effects on the other wind turbines of the wind park caused by earth potential rise.

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