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EMTP-RV Analysis of Lightning Surges on Wind Turbines

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Abstract. This paper is concerned with lightning surge propagation on wind turbines. As wind power generation undergoes rapid growth, lightning incidents involving wind turbines have come to be regarded as a serious problem. Nevertheless, no known studies exist yet in Portugal regarding lightning protection of wind turbines. Hence, we present a case study, based on a wind turbine with an interconnecting transformer, for the analysis of lightning surges. Computer simulations obtained by using the EMTP-RV code are presented. Conclusions are duly drawn.

Key words

Lightning surge, transient analysis, wind turbine.

1. Introduction

The need to control climate changes and the increase in fossil-fuel costs stimulate the ever-growing use of renewable energies worldwide. Concerning renewable energies, wind power is a priority for Portugal's energy strategy.

In Portugal, the wind power goal foreseen for 2010 was established by the government as 3750 MW and that will constitute some 25% of the total installed capacity by 2010 [1]. This value has recently been raised to 5100 MW, by the most recent governmental goals for the wind sector. Hence, Portugal has one of the most ambitious goals in terms of wind power, and in 2006 was the second country in Europe with the highest wind power growth.

As wind power generation undergoes rapid growth, lightning incidents involving wind turbines have come to be regarded as a serious problem [2]. Lightning protection of wind turbines presents problems that are not normally seen with other structures. These problems are a result of the following [3]:

- wind turbines are tall structures of up to more than 150 m in height;
- wind turbines are frequently placed at locations very exposed to lightning strokes;
- the most exposed wind turbine components such as blades and nacelle cover are often made of composite materials incapable of sustaining direct lightning stroke or of conducting lightning current;
- the blades and nacelle are rotating;
- the lightning current has to be conducted through the wind turbine structure to the ground, whereby significant parts of the lightning current will pass through or near to practically all wind turbine components;
- wind turbines in wind farms are electrically interconnected and often placed at locations with poor earthing conditions.

Modern wind turbines are characterized not only by greater heights but also by the presence of ever-increasing control and processing electronics. Consequently, the design of the lightning protection of modern wind turbines will be a challenging problem [4]. The future development of wind power generation and the construction of more wind farms will necessitate intensified discussion of lightning protection and the insulation design of such facilities [5].

Nevertheless, no known studies exist yet in Portugal regarding lightning protection of wind turbines. Also, surge propagation during lightning strikes at wind farms is still far from being clearly understood. Thus, much work remains to be done in this area.

Direct and indirect lightning strokes can produce damages of electrical and electronic systems, as well as of mechanical components such as blades and bearings [6]. Damages statistics of wind turbine components has been analyzed in the literature [7], as well as the risk analysis [8].

Concerning mechanical components, blades and bearings are the most involved parts. In particular, lightning-damages produced at bearings positioned at the mechanical interface between rotating parts of the wind turbine, can result in high costs of maintenance, considering the difficulties involved in the replacement of such components [9]. Apart from serious damage to blades and bearings, breakdown of low-voltage and control circuits have frequently occurred in many wind farms throughout the world.

According to IEC TR61400-24 [3], the most frequent failures, more than 50%, in wind turbine equipment are those occurring in low-voltage, control and communication circuits. Indeed, many dielectric breakdowns of low-voltage circuits and burnout accidents of surge arresters in wind turbines are reported. Such frequent problems in the low-voltage circuits may cause a deterioration of the utilization rate and consequently cause increases in the cost of power generation [2]. The events on low-voltage circuits are not triggered by only direct lightning strikes but also induced lightning and back-flow surges propagating around wind farms just after lightning strikes on other wind power generators [10].

Usually, converter units and boost transformers are installed very close to wind turbines or inside windmill towers. In addition, lightning arresters are often installed on the high-voltage side (power grid side) and grounded jointly with the low-voltage side in order to decrease the grounding resistance and to protect against winter lightning. Therefore, when the grounding potential rises around transformers due to a lightning stroke, lightning arresters may operate in the opposite direction from ground to line, causing a lightning surge that flows toward the distribution line. In actual lightning accidents at wind farms, insulation breakdown often occurs not only in lightning-stricken windmills but also in adjacent windmills or even relatively distant ones [5]. Such reverse surges flowing from the low-voltage side to the high-voltage side should be studied in the case of lightning strikes on windmill towers and wind farms.

Scale models of electrical systems have been a popular tool, especially in the past, to predict power system transients after different types of perturbations [11]. For instance, a 3/100-scale model of an actual wind turbine generation system that has blades with a length of 25 m and a tower that is 50 m high was considered in [12,13] for experimental and analytical studies of lightning overvoltages. However, in recent years, scale models have been progressively replaced by sophisticated numerical codes, capable of describing the transient behavior of power systems in an accurate way, such as the EMTP-RV, which designates the latest version of the Electro-Magnetic Transients Program and RV stands for Restructured Version [14].

In this paper, we present a case study, based on a wind turbine with an interconnecting transformer, for the analysis of lightning surges. Computer simulations obtained by using the EMTP-RV code are presented, and conclusions are duly drawn.

2. Wind Turbine Description

The wind turbine considered has 2 MW of rated power. Rotor blades are manufactured using the so-called sandwich method. Glass fibre mats placed in the mould are vacuum-impregnated with resin via a pump and a hose system. The rotor diameter is about 82 m. The rotor hub and annular generator are directly connected to each other as a fixed unit without gears. The rotor unit is mounted on a fixed axle. The drive system has only two slow-moving roller bearings due to the low speed of the direct drive. The annular generator is a low-speed synchronous generator with no direct grid coupling. Hence, the output voltage and frequency vary with the speed, implying the need for a converter via a DC link in order to make a connection to the electric grid. The hub height varies between 70 to 138 m. The tubular steel turbine is manufactured in several individual turbine sections connected using stress reducing L-flanges.

The LV/HV transformer is placed at the bottom of the turbine. It has 2500 kVA of rated power and has a special design to fit the reduced dimensions and working conditions of the turbine. In Figure 1 a wind turbine is represented.

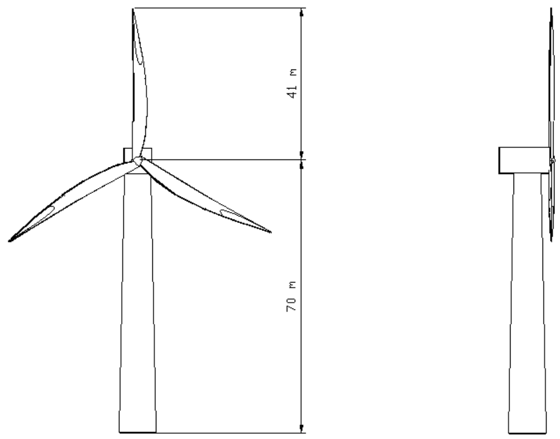

Fig. 1. Dimensions of the wind turbine.

The following assumptions are made for the wind turbine model:

- The gearbox, wind power generator, rectifier, and inverter (power conditioner) are treated as a unit, specifically, as a 690 V synchronous generator that is sufficiently stable at 50 Hz;
- A 690 V / 20 kV boost transformer (Y–Δ connection) is placed inside the wind turbine or installed rather close to the turbine. In addition, joint grounding of the primary and secondary side is assumed;
- In the transformer model, only electromagnetic transfer is considered, and static transfer is ignored. This is because we assume surges with relatively long periods exceeding 100 μs;
- No lightning arresters to protect control circuits are connected to the primary side (low-voltage side) or secondary side (high-voltage side, power grid side) of the boost transformer;

- Interconnection to the power grid is through a 20/60 kV transformer;
- The grounding resistance considered for the electrode in the absence of lightning currents is 5 Ω.

In addition, we assume a standard lightning waveform with wave front duration of 1.2 μs, wave-tail duration of 50 μs, and a peak value of 10 kA. This is because in [15] 80% of lightning strokes have at least 10 kA of peak value.

3. EMTP Models

The EMTP has been used to study transients in large scale power systems or in arbitrary electrical networks. In this paper the most recent version, the EMTP-RV, is applied. The complete software is also named EMTP/EMTPWorks, where EMTP designates the computational engine. The following explains briefly the most important models used in this paper.

A. Lightning Current Source

The ICIGRE device was chosen to simulate the current lightning source. This device is used for accurate calculations of the lightning performance of equipment. A complete description of this model and the reasoning behind the provided analytical representation of the current shape can be found in [16].

B. Wind Turbine Structure

To model the structure of a wind turbine, the Constant Parameter (CP) line is used. The CP is classified as a frequency independent transmission line model. Its main advantage is computational speed. It is less precise than frequency dependent line and cable models, but it can be successfully used in analysis of problems with limited frequency dispersion. The CP line parameters are calculated at a given frequency and that is why it is labeled as a frequency independent line.

C. Ground Electrode

Precise modeling of the dynamic performance of grounding electrodes under lightning currents must include both the time-dependent nonlinear soil ionization and the frequency-dependent phenomena. These phenomena might have mutually opposing effects since the soil ionization effectively improves, while frequency-dependent inductive behavior impairs, the grounding performance. In this paper, we will use a circuit approach valid in the low-frequency domain, which leads to the well-known formulas for the grounding resistance [17].

4. Circuit and Results

It is assumed that the blade tip of a wind turbine is stroked by lightning (ICIGRE). The lightning current flows through the metallic wires (CP) placed into blades, nacelle and the turbine itself, towards the ground electrode (R1, L1, C1) and creating an overvoltage. Inside the wind turbine a 690 V RMS generator (AC1) produces electrical energy which is delivered to the main power transformer (DD_1) and to the adapter transformer (DY_1), which feeds electronic control equipment (RL1). Figure 2 represents the described circuit.

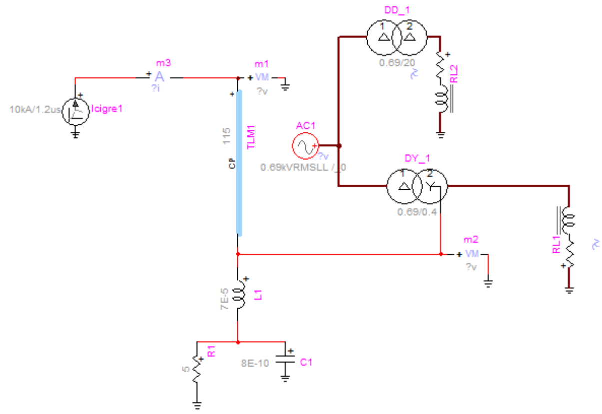

Fig. 2. EMTP-RV circuit.

Figure 3 presents the shape of the 1.2/50 lightning current with 10 kA of peak value using the source Icigre1 of EMTP-RV simulation.

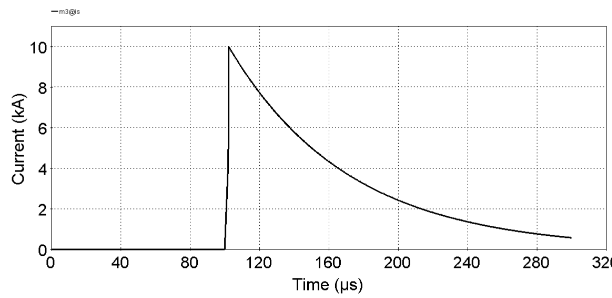

Fig. 3. Lightning current produced by source Icigre1.

Figure 4 presents the shape of the overvoltage that the turbine and blades have to support. The peak value of overvoltage reaches 1.2 MV.

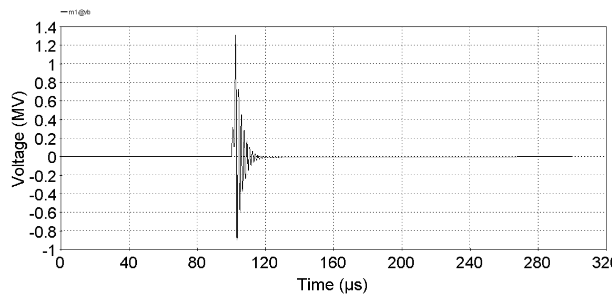

Fig. 4. Overvoltage at the wind turbine.

Figure 5 presents the shape of the overvoltages at the control electronic equipment.

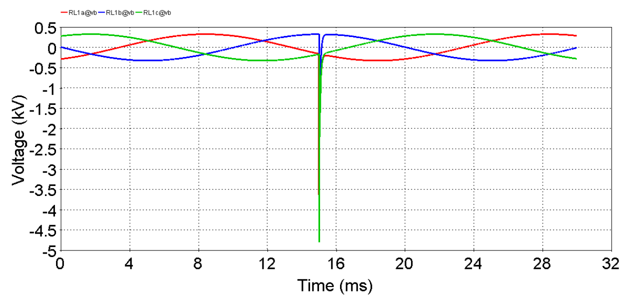

Fig. 5. Overvoltages at the electronic equipment.

The overvoltage produced by lightning reaches almost 5 kV, which is much more than this kind of equipment can support.

5. Conclusion

This paper is concerned with lightning surge propagation on wind turbines. The most recent national and international standards have been used in this work. Also, computer simulations have been obtained by using the latest version of EMTP-RV. As future work, we intend to use a more precise modeling of the grounding electrodes under lightning currents, including both the time-dependent nonlinear soil ionization and the frequency-dependent phenomena.

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