ANALYSIS OF WIND TURBINE GROUNDING SYSTEMS

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Abstract

In this paper, the response of windturbine grounding systems is calculated under fault conditions or when they are hit by lightning. The objective is their effective design in terms of dispersion of imposed currents and minimization of raised potentials. Locally raised potentials are calculated in terms of steady state GPR. Transferred potentials to neighboring windturbines are also computed. Measures taken to reduce potentials are presented and commented. For the purposes of this paper the well-known software packages EMTP (Electro Magnetic Transients Program) and CYMGRD (CYMe's GRounDing) have been used.

Index terms: *wind turbines, windfarms, grounding, lightning strikes, EMTP-modeling, effective length.*

1. INTRODUCTION

Windturbine grounding system has to be effectively designed in order to prevent excessive overvoltages and potential gradients that may cause damage to equipment or threaten human life. Fault or lightning currents to any windturbine in a windfarm installation, may damage equipment directly or indirectly as transferred potentials may exceed allowed values at windturbines in the neighborhood of the fault.

Windfarms are usually situated in rocky and mountainous areas where the wind potential is high[1],[2]. In these areas soil resistivity also has high values. For this reason difficulties arise when designing grounding systems of windturbines in terms of reduction of touch and step potentials and minimization of grounding system resistance.

The area that the grounding system takes is often limited by topographical factors. For this reason practical problems arise, as the area which is practically available is smaller than the one required for correct dimensioning of the grounding arrangement. Installation costs also increase for ground rods installation in highly resistive soil. (Use of special equipment).

In case of extended grounding systems i.e. when windturbine grounds are interconnected, the effect of "effective length" of interconnection conductors is analyzed and investigated. Its effect on lightning surge analysis is very important as it weakens the effect of adding more material in order to reduce grounding resistance.

For the purposes of this paper, existing software packages as CYMGRD[3], and EMTP[4], suitable for grounding system analysis, have been used in order to calculate grounding resistance and touch and step potential values. Analysis using the software program CYMGRD is based on finite element method, and division of the grounding system into elementary segments. EMTP is mostly used in computation of the transient response of grounding arrangement. By extending its capabilities for transmission lines calculations [5] it has been effectively used for grounding systems analysis.

Particular methods followed in order to reduce maximum voltages observed are presented. Alternative grounding system design techniques are also presented and discussed. Various methods to minimize touch and step voltages are examined for their effectiveness.

According to current international Standards the following definitions apply [6]:

- *Ground Potential Rise (GPR)*: The maximum voltage that a station grounding rid may attain relative to a distant grounding point assumed to be at the potential of remote earth.
- *Touch Voltage* is the potential difference between the ground potential rise (GPR) and the surface potential at the point where a person is standing, while at the same time having his hands in contact with a grounded structure.
- *Step Voltage* is the difference in surface potential experienced by a person bridging a distance of 1 m with his feet without contacting any other grounded object.

2. SAFETY CRITERIA

Safety criteria that have to be met are set according to International Standards. There is a difference in regulations that apply in case of short circuit analysis [6] and in case of analysis of lighting response [7]. More particularly it is:

2.a Lightning strikes

Grounding resistance of WT arrangement or WT connected to the local transformer grounding system is required to be below or equal to 10 Ohms. This is the only requirement being suitable for lightning protection. A resistance of 10Ω or less (before it is connected to any other system) is stated in international standards/recommendations. When the system is concentrated, or when it takes a small area, raised

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potentials are equal to those produced by an AC current of the same magnitude.

2.b Short circuit

In case of short circuit the step voltage safety limits are determined using IEEE Guide [6]. For calculations of grounding arrangements in this paper the following parameters values are taken:

Soil resistivity = 400 Ωm / 600 Ωm.

Human Weight = 50 kg

Shock Duration =0.02 sec - 0.10 sec

Table 1: Maximum Allowable Step Voltage

Soil Resistivity / Shock Duration	ρ_s=400 Ωm	ρ_s=600 Ωm
0.02 sec	3885 V	5273 V
0.03 sec	3172 V	4305 V
0.10 sec	1737 V	2358 V

Touch potentials safety limits are used to determine the area where a man in contact with the grounded structure can safely stand. Practically, it is very rare for a working person close to a WT grounding to experience high touch voltages because the area surrounding WT tower is usually safe. It is also suggested to place a fence surrounding the safe area.

3. FUNDAMENTAL DESIGN OF WT GROUNDING

The grounding of a single wind turbine is normally achieved by placing a ring electrode around the foundation and bonding it through the foundation to the turbine tower.

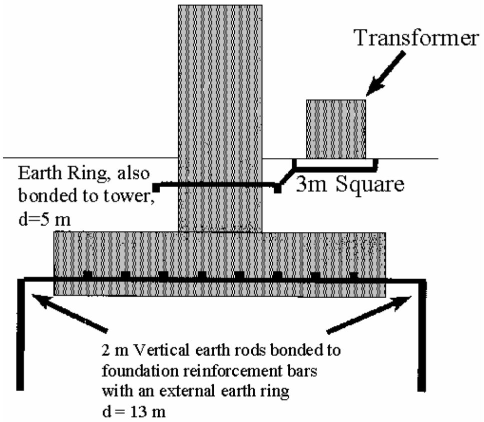


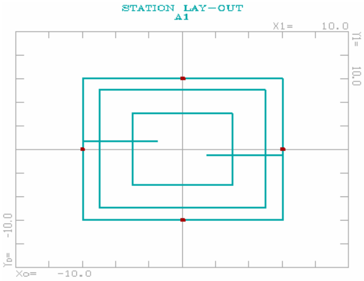
Figure 1

The foundation reinforcement bar is also connected directly or via the turbine tower to the ring electrode and will be effective in acting as a ground electrode since the surrounding concrete can be considered to have a resistivity equal to that of the surrounding soil. However, in relevant calculations it is normally ignored to provide a worst case analysis of the grounding system. Vertical rods or strip electrodes (horizontal electrodes) are often used in conjunction with this ring electrode to achieve a certain value of ground resistance. Furthermore, ring electrodes of gradually increasing depth and diameter may be added in order to reduce touch and step voltages at the edges of the system.

Dimensions shown in figure 1 are common for windturbines in the range of 600kW as for practical reasons grounding system dimensions depend closely on the WT foundation dimensions.

4. INDIVIDUAL WIND TURBINE GROUNDING

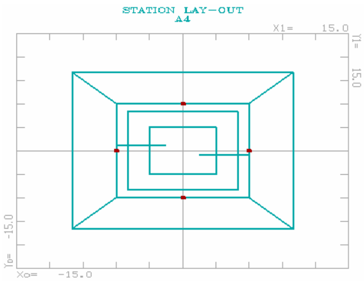
Grounding resistance of WT arrangements as shown in fig.1 have been calculated. These arrangements correspond to actual wind turbines installed in Greece.



Case 1
ρ_{soil}=400 Ω-m
R=13.0538

Case 2
ρ_{soil}=600 Ω-m
R=19.5806

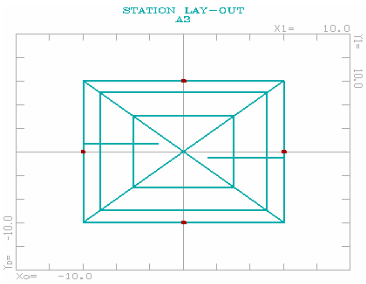
Figure 2.a



Case 1
ρ_{soil}=400 Ω-m
R=8.8966

Case 2
ρ_{soil}=600 Ω-m
R=13.3449

Figure 2.b



Case 1
ρ_{soil}=400 Ω-m
R=12.8046

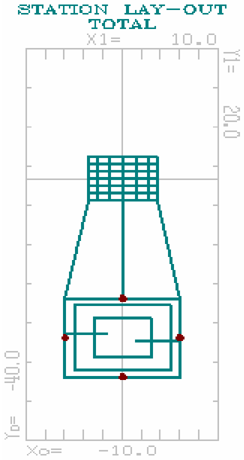
Case 2
ρ_{soil}=600 Ω-m
R=19.2068

Figure 2.c

It can be observed that the area taken by the grounding system following an inverse square law mainly reduces grounding resistance. Furthermore, increasing the depth there is no important decrease in grounding resistance.

The WT grounding arrangement is usually connected to the local transformer grounding. This makes use of the existing path for the connection between the WT tower and the transformer, lowering the total grounding resistance. This is shown in figure 3.a where local transformer grounding has been connected to WT grounding using three conductors. In order to reduce grounding resistance, a large grounding arrangement has to be installed as shown in fig.3.b.

Step potentials along the y-axis are plotted in fig.4.a for the arrangement of fig.3.a and in fig.4.b for the arrangement of fig.3.b. A serious decrease can be observed at fig.4.b and safety criteria (horizontal lines) given from Table 1are met in most of the points close to WT.



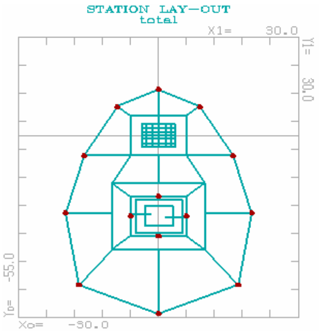
Case 1

ρ_{soil}=400 Ω-m R=8.6485

Case 2

ρ_{soil}=600 Ω-m R=12.9726

Figure 3.a



Case 1

ρ_{soil}=400 Ω-m R=3.9851

Case 2

ρ_{soil}=600 Ω-m R=5.9776

Figure 3.b

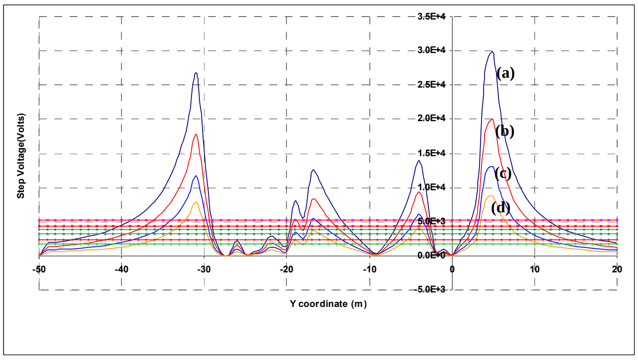


Figure 4.a: Step Voltage along the y-axis for injection of i) (a),(c) 16 kA or ii) (b),(d) 7 kA

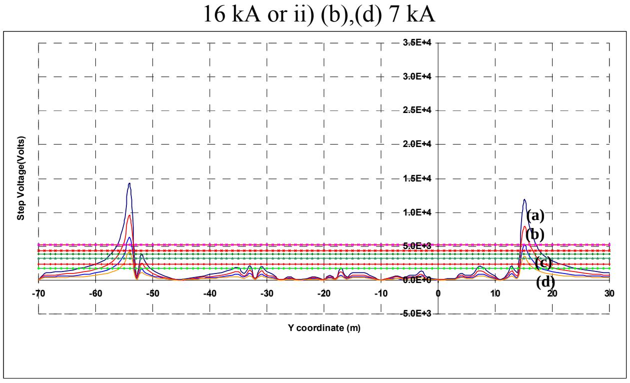


Figure 4.b: Step Voltage along the y-axis for injection of i) (a),(c) 16 kA or ii) (b),(d) 7 kA

In general, increasing the depth of the grounding installation lowers the produced values of raised touch and step potentials. Rings or closed type curves of gradually increased depth and diameter are used to eliminate raised potentials.

5. WINDFARM GROUNDING (–EFFECT OF INTERCONNECTIONS)

5.a. Fault Conditions – Low Frequency Response

The individual wind turbine grounds are in some cases connected by the metallic screen or armour of the main power cable running between the turbines. In this case power cable is considered as part of windfarm grounding system. This has the effect of reducing the overall site ground impedance to a low value, often 1-2Ω when a low frequency response is calculated or measured.

The following example of two connected WT arrangements shows how drastically grounding resistance and step voltages are reduced. Safety limits are met in almost all cases.

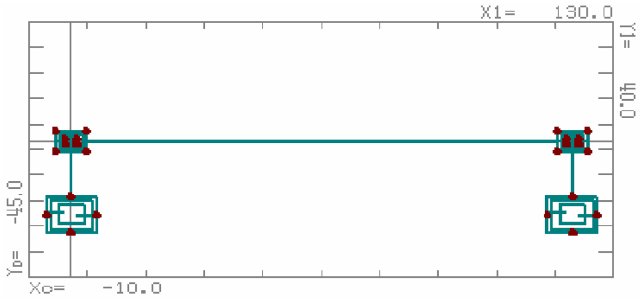


Figure 5.a

Grounding resistance values are:

When ρ_{soil}=400 Ω-m R=3.5758

When ρ_{soil}=600 Ω-m R=5.3636

Step voltages along the y-axis of WT are plotted in fig.5.b

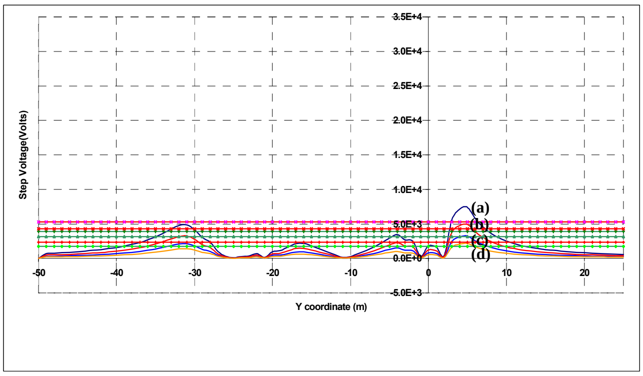


Figure 5.b: Step Voltage along the y-axis for injection of i) (a),(c) 16 kA or ii) (b),(d) 7 kA

Low frequency response of windfarm grounding system shows that it is beneficial to interconnect WT grounds. However when the windfarm is sited in an area of high soil resistivity or in mountainous area installation of an underground power cable is practically difficult. In similar cases in Greece overhead lines are used instead of power cable.

5.b. Lightning Strikes – High Frequency Response

A lighnting current that hits a single WT is dispersed in the earth, producing a max GPR as if windturbine grounding system was replaced by a resistance. This is explained by the fact that single WT grounding arrangemet is concentrated in a small area so its reactive component can be neglected even in high frequencies. When an extended grounding system is examined, as in the case of windfarm with interconnected WT grounding systems the reactive component is important at high frequencies. Consequently the overall impedance in case of lightning is much greater that the grounding impedance in case of short circuit.

The effect of interconnection electrodes determines the overall impedance that sees the impulse lightning current when it hits a WT. Their effective length value limits their contribution to the reduction of the impedance to an upper value. Effective length is the length value above which, no considerable reduction of the impedance of the electrode is observed, when increasing the length[8]. It is dependent on frequency and soil characteristics. An example of this fact is given in fig. 3.where the max. GPR produced by a 9kA 1.4/17μs impulse current strike and also by a sinusoidal 9kA*sinωt current source has been plotted using EMTP.

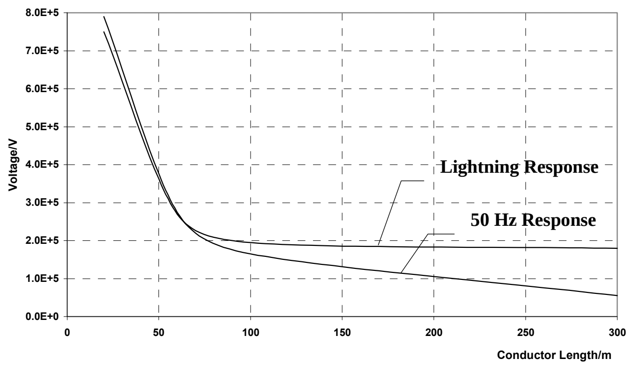


Figure 7: Max Ground Potential rise values vs. conductor length

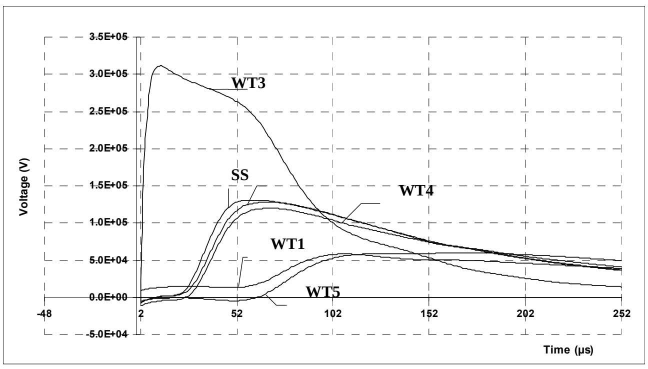


Figure 8

In figure 10 GPRs produced by the injection of 30kA impulse current at the middle of 5 WTs connected in series have been plotted. Grounding resistance of each windturbine base is equal to 24.8 Ohms. Consequently impulse current injection at a single WT would produce a max GPR equal to 744 kV. If the reactive component is neglected, the same impulse current at the middle of 5 interconnected WTs would produce 150kV. In this case the max GPR at the injection point is equal to 311440V.

Transferred potentials to neighboring WTs in case a lightning current is injected are larger than in case of short circuit. This is due to the grounding system reactance.

6. CONCLUSIONS

In this paper existing software packages have been used to calculate the response of windturbine grounding system under short circuit of lightning current injection. The scope of the analysis is the effective design of grounding arrangement in order to minimize raised potentials and total system grounding resistance.

In case a windfarm is examined, then suitable calculations are needed in order to decide if it is better to interconnect windturbine grounding arrangements.

7. REFERENCES

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