Effective Design of Extended Grounding Systems

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Abstract. Grounding systems have to be effectively designed in order to prevent electrical installation from excessive overvoltages and potential gradients when lightning occurs or in case of short circuit. Effective design of extended grounding systems as in case of windfarms grounding is investigated in terms of combining good performance in high and in low frequencies.

1. Introduction

Large or extended grounding systems have lower grounding resistance and better behavior under low and high frequency excitation. In case a sinusoidal current source is applied at a point of a grounding conductor, grounding systems have lower grounding resistance and better behavior under low and high frequency excitation. In case a sinusoidal current source is applied at a point of a grounding conductor, maximum GPR (Ground Potential Rise) decreases continuously as its dimensions increase. However, when high frequency components are injected as in the case of lightning, there is an upper limit in the area of the system that substantially effects the maximum GPR value observed.

In this paper, effective dimensioning of a grounding system is investigated. The contribution of grounding system elements located far from the energization source is calculated in order to improve grounding system design. Calculation results are obtained for concentrated grounding systems interconnected by a long grounding conductor, forming an extended system. This case is typical for a windfarm grounding system where individual wind turbine grounds are connected to each other with the armor of the power cable and/or additional grounding conductors. It is very common for lightning to strike windfarms, as they are situated in places of high altitude, where the wind potential is high. The effect of interconnection electrodes in lowering max. transient GPR, and transferred overvoltages is investigated.

2. Calculation Methodology

2.a Impulse Current

In the following analysis the impulse current source considered has a double exponential waveform of 8/20 μ s and a 31 kA peak current value. This is a typical lightning waveform[11] and it is described using the following relationship

$$i(t) = I_0 \cdot \left(e^{at} - e^{\beta t}\right) \quad \text{where } I_0 = 32\text{kA}, \ a = -9091, \ \beta = -727300$$

2.b Calculations using EMTP

EMTP (ElectroMagnetic Transients Program)[1] has been used for calculation of grounding system response. In literature EMTP-based and other methods are summarized in two categories:

1. Pi-circuits methods which involve division of the electrode in elementary segments and its analysis as ladder network with lumped parameters [2-5]
2. Methods based in modeling grounding electrodes as lossy transmission lines[6-10]. More particularly the J.Marti model for transmission lines calculations has been successfully applied[7-10].

In this paper the second methodology has been applied, as it is valid for a wide frequency range. Thus the method is suitable for calculations involving high frequencies as lightning.

2.c Impulse response calculation using a suitable code

The frequency behavior of grounding systems elements has been calculated for frequencies up to 10MHz using the algorithm shown in fig.1. The method of moments has been used for the solution of the potentials problems[14-17]. Inverse Fourier Transformation is used to translate frequency domain to time domain results.

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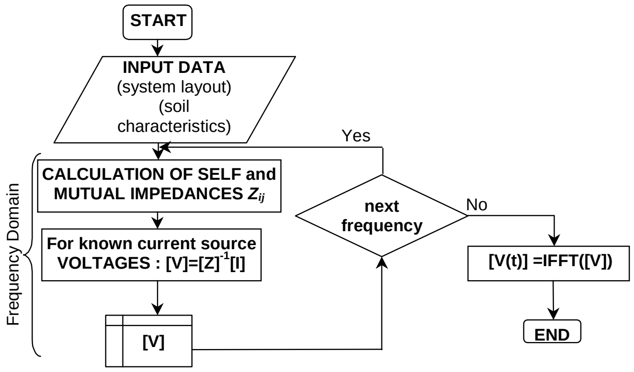


Fig 1: Flowchart of grounding system analysis program

3. Application Results

3.a Contribution of points located far from the energization Point – Long Horizontal Conductor

Effective dimensioning of extended grounding systems usually involves calculation of the effective length of horizontal grounding electrodes. Effective length is the length above which, no considerable reduction of the high frequency impedance of the electrode is observed. It depends on the frequency and can be determined using a diagram of |Z| vs. length or |Z| vs frequency. Grounding electrode is considered equivalent to an open-ended transmission line, thus having input impedance $Z = Z_c\, coth(\gamma\ell)$

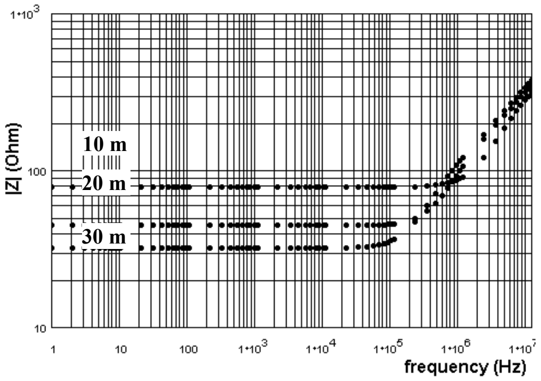


Fig 2: Impedance of horizontal conductor in 500 Ωm soil vs. frequency

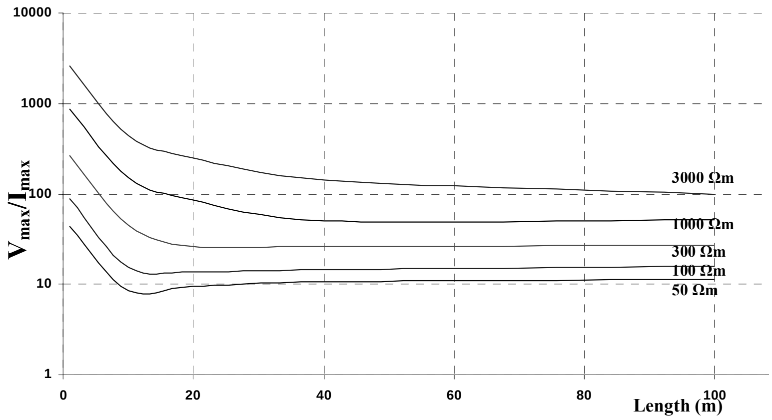


Fig 3: V_{max}/I_{max} of horizontal conductor under fast impulse

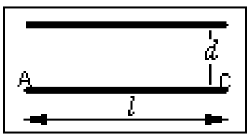
In fig 2, |Z| of 10, 20 and 30m long electrodes vs. frequency have been plotted. For the 20m long it remains to a low value until 100kHz where it begins to increase. Plot of |Z| of a longer electrode would show the expected increase at a lower frequency value, as it would be more reactive. However the effective length of any longer electrode above a certain high frequency f is almost equal.

The ratio of peak voltage to peak current has been plotted when a fast 1/4 μ s impulse current has been injected to show the influence of effective length (Fig 3).

The faster the injection current rises to its maximum value, the shorter the effective length value. It can be generally observed that lengths which can be used to notably reduce raised potentials in all cases do not exceed 25-30m.

3.b Contribution of conductors located far from the energization point

The effect of components of the grounding system located far from the energization point is examined. Two horizontal conductors have been placed in parallel as shown below.



d=1 to 50 m
l=1 to 3 m
Conductor radius=.005m
Burial Depth=.5 m
Soil Resistivity =500 Ωm

Mutual conductance is calculated according to [18]. Mutual inductance is given by Grover's formula [19]

Mutual inductance is not dependent on soil resistivity. It depends on the length of conductors and their separation distance. It can be observed in fig 4 that mutual inductance values decrease considerably when electrodes separation exceeds 10m.

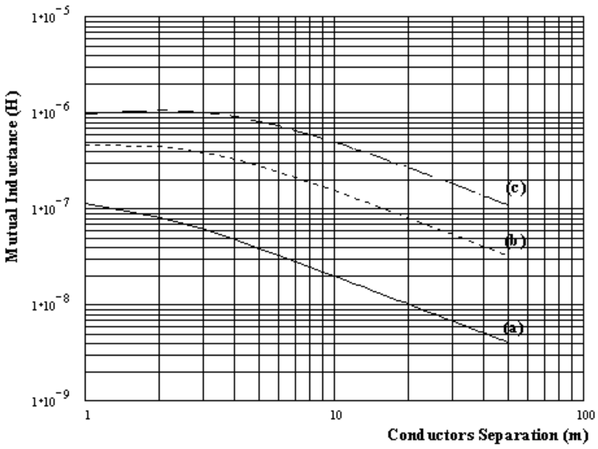


Fig 4: Mutual Inductance vs. conductor separation for Conductors length a)1m, b)2m, c)3m

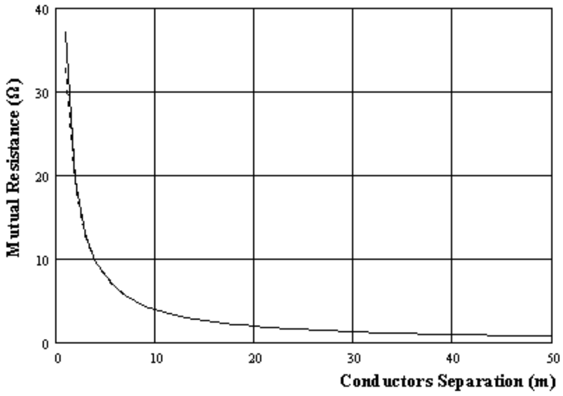


Fig 5: Mutual Resistance vs. conductor separation for Conductors length a) 1m, b) 2m

Mutual conductance is dependent on soil characteristics and conductors separation. In fig 5 it can be observed that only the electrodes placed in a distance <15m from energization seriously contribute to the grounding resistance decrease. A similar conclusion can be drawn in case of non-parallel grounding segments.

3.d Interconnected grounding arrangements

The case of interconnected grounding arrangements is examined next with particular reference to windfarms. A practical windfarm consisting of 12 windturbines as shown in fig. 6 has been used as study case. Windturbines are connected in series with horizontal electrodes. Single windturbine arrangement has a grounding resistance of 12Ω, in 500Ωm soil. Impedance "seen" in windturbine 9 is lower than impedance in WT 1 but increases rapidly in high frequencies. The effective length of interconnection electrodes results in slightly lower high frequency values of the impedance seen from WT 1. In fig. 7 the voltages at WT1, WT2 and WT3 are plotted. Lightning is supposed to strike WT1. Transferred potentials to wind turbines situated at a distance greater than 500 m from WT1, are less than 5% of the max GPR (Ground Potential Rise)

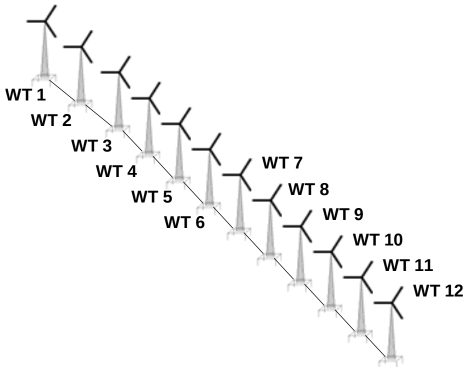


Fig 6: Schematic representation of the windfarm used as study case

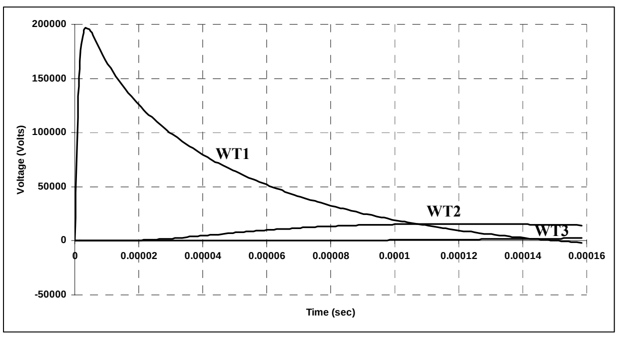


Fig 7: Potential at WT1 and transferred potentials to WT2 and WT3 when lightning hits WT1

In fig. 8 the voltages at WT9, WT10 and WT11 are plotted. Lightning strikes WT9. Transferred potentials to other wind turbines except from WT10 and WT8 are negligible. It is generally observed that:

- Interconnection electrodes reduce the max GPR values compared to a single WT arrangement. It is also lower in case the WT arrangement is connected from both sizes to other WTs
- Percentage of Transferred GPRs to neighboring WTs is lower when lightning hits WT9 rather than if it hits WT1.
- Transient impedance is maximum when lightning hits the first or last WT. It can be observed that it reduces in case lightning strikes a middle WT.

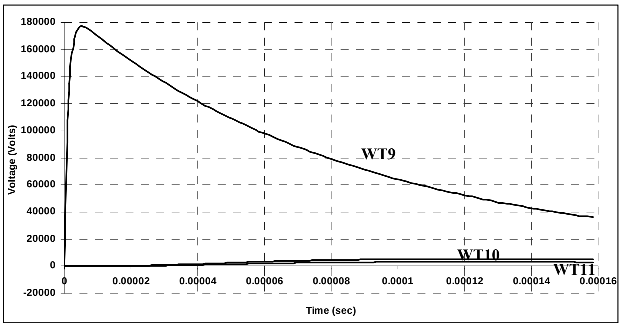


Fig 8: Potential at WT9 and transferred potentials to WT10 and WT11 when lightning hits WT9

4. Conclusions

Grounding systems serve the purpose of effectively dispersing fault or lightning currents into the ground. Dimensioning of grounding systems for lightning protection involves calculation of their transient response. In this paper, impulse response of extended grounding systems is calculated and the results are commented. The impulse impedance of an extended system is higher than their low frequency grounding resistance resulting in higher values of raised potentials. The following examples of extended grounding systems have been analyzed :

- Long horizontal electrodes
- Interconnected grounding arrangements resulting in a large grounding system with particular reference to windfarms.

Effective length values are given for most practical cases of grounding electrodes, while effective area of grounding grids is limited to few square meters around the energization point. In case of a windfarm, interconnection electrodes, lower low frequency grounding resistance but result in transferred potentials to the neighboring windturbines. In addition not all the length of interconnections contributes to the reduction of transient potential rise.

5. References

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