The effect of grid mesh density on substation earth impedance

Mohamed A. Abdallah
Electrical Power Eng., Faculty of Eng., Alexandria University, Alexandria, Egypt

An investigation was carried out to examine the effect of Earthing grid impedance. Simulation were carried out using a field-theory based software to evaluate the response of the earth grid for different soil conditions over a range of frequencies, from DC to 1 MHz. It is shown that increasing the mesh density of the grid lowers the earth grid impedance over a specific frequency range corresponding to a particular soil resistivity. The investigations have shown that the earth grid impedance increases with frequency with the inductive effects becoming significant above specific frequencies. These inductive effects are found to be more significant at lower frequencies for low soil resistivity media. In addition, it was shown that soil permittivity has an effect at high frequencies in high soil resistivity, and the increase of grid density lowers the grid impedance for a specific range depending on the soil resistivity of the media.

يقوم هذا البحث على دراسة معاوقة شبكة التأريض. تمت هذه الدراسه بإستخدام برنامج كومبيوتر يعتمد على نظرية المجالات، لدراسة إستجابة شبكة التأريض ، فى أنواع مختلفه من التربه، وبإستخدام ترددات تتراوح من صفر(حالة التيار المستمر) إلى ١,٠ ميجاهيرتز. وجد من نتائج البحث أن زيادة كثافة شبكة التأريض يقلل من معاوقة شبكه التأريض لكل الترددات المستخدمه فى كل حاله من حالات المقاومه النوعيه للتربه. ومن نتائج البحث، أن معاوقة شبكة التأريض تزداد بزيادة التردد حيث يظهر التأثير الحثى بشكل كبير عند الترددات العاليه. كما أن التأثير الحثى يظهر عند ترددات منخفضه فى حالة إنخفاض المقاومه النوعيه للتربه. أما بالنسبه لممانعة التربه، يظهر تأثيرها عندالترددات العاليه، للتربه ذات المقاومه النوعيه المرتفعه.

Keywords: Earth grid, Mesh density, Inductive effect, Soil resistivity media

1. Introduction

In high voltage substation, the buried earth grid provides a low impedance connection to earth. During earth fault, a high magnitude current flows to the earth grid and results in large potential differences across the surface of the ground in the vicinity of the substation. The mesh density of earth grid controls these potential differences within the substation, which is important for human safety. Detailed guidelines are given in the national standards [1,2] for designing grids for this safety purpose. However, connections are also made to earth grids from high voltage devices such as surge arresters and Capacitor Voltage Transformers (CVTs). An industry standard [2] specifies that there should be a high frequency earth electrode placed directly beneath devices which are likely to conduct transient currents. However, these recommendations are only qualitative and provide little guidance for the practical design of earth grids or rod systems.

Earthing systems behavior at power frequencies is well understood. The analysis of earthing systems subjected to lightning current impulses is more complex, and much of the previous work on this subject concentrated only on simple ground arrangements such as horizontal or vertical electrodes. More recently, the transient and frequency response of earth grids has been studied [3,4]. Investigations have been carried out using simple lumped parameter equivalent circuit models [3, 4] and transmission line models [5-8]. An electromagnetic field theory technique for earthing systems analysis has also been used [9]. Some of this recent work [7,8] has specifically considered the frequency response of earth electrodes and has indicated that inductive and capacitive effects are significant at high frequency.

The aim of the present work is to carry out a more comprehensive parametric study of the frequency response of sample earth grids. In particular, the effect of varying the mesh density is considered. A range of soil conditions is examined by varying both the soil resistivity and permittivity over a frequency range from DC to 1 MHz. An established earthing software package was used to carry out the simulation [9].

2. Earth grid models

Fig. 1 shows the four arrangements of substation earth grid adopted for the simulation.

Each grid has overall dimension of 100m × 100m and the number of meshes is varied between 4 and 100. The grid's copper conductors are assumed to have a diameter of 1 cm and buried at depth of 1m. In the simulations, the grid is energized at the center point.

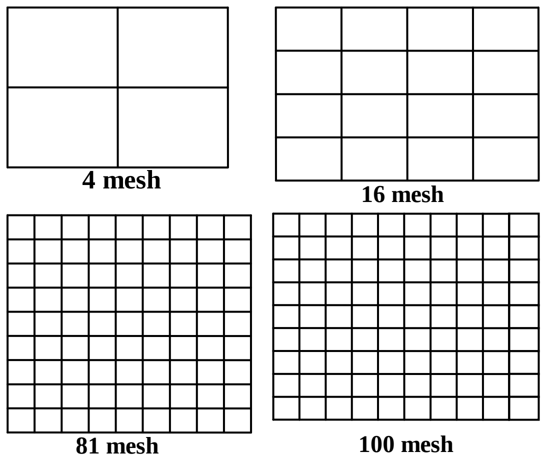

Fig.1. Earth grid models (100m × 100m).

3. Simulation results

3.1. Frequency response

Fig. 2-a shows the variation of the impedance magnitude of the 4 mesh earth grid with frequency (up to 1 MHz) for different soil resistivities (10 to 10000 Ωm). Each curve has a lower frequency range over which the impedance is nearly constant. Above a particular frequency, which is related to the value of soil resistivity, the impedance increase markedly with frequency. This increase in impedance can be attributed to the inductance of the earth grid, which is illustrated in the plot of impedance angle shown in fig. 2-b. As expected, the inductive effects, are more significant at high frequencies for different soil resistivities. These impedance results exhibit similar trends to those obtained by Greev [8].

3.2. Effect of soil permittivity

Figs. 3-a and 3-b illustrate the effect of soil permittivity on the earth impedance of the 81 mesh earth grid. The frequency response was investigated over the same range (DC to 1 MHz), and the results are shown for one low and one high soil resistivity conditions. For the low value of soil resistivity (ρ=10Ωm), there is no significant influence of soil permittivity on impedance. Also for the high resistivity condition (ρ=10000Ωm), there is no noticeable permittivity effect up to 10 kHz. However, at 100 kHz, increasing the relative permittivity from 1 to 30 results in significant reduction in earth impedance. For ϵr = 30 at 100 kHz, the capacitive current is of the same order as the conductive current. The impedance angle at this frequency indicates a significant capacitive effect. At the higher frequency of 1 MHz, the impedance magnitudes for all values of permittivity are higher. The impedance angle indicates that the grid behaves inductively at this frequency.

3.3. Effect of mesh density

Fig. 4 shows the influence of grid mesh density on earth impedance for different frequencies. Again results are presented for one low and one high soil resistivity conditions (10 Ωm and 10000 Ωm). As expected, at power frequencies, varying the mesh density has little effect on the earth grid impedance since the impedance is predominantly resistive. At higher frequencies, increasing the mesh density has a significant effect in lowering the earth grid impedance. As can be seen in fig. 4, there is a particular frequency range, where the mesh density has a pronounced effect, and this frequency range is different for low and high soil resistivity conditions. In case of soil resistivity 10 Ωm, there is no significant effect for the mish density on the earth impedance. In case of soil resistivity 10000 Ωm, for frequencies higher than 10 kHz, the decrease in the mesh density increase the earth impedance. This behavior could be attributed to the different effective areas of the earthing system for different soil resistivities.

3.4. Effect of Conductor segmentation

In the simulation software, the grid conductors are modeled as cylindrical segments. The degree of segmentation used can affect the accuracy of the results, particularly at higher frequencies. Accordingly, a sensitivity analysis was carried out to determine appropriate levels of segmentation for the main simulations.

Table 1 and 2 summarize the influence of conductor segmentation on the impedance magnitude results for the (100m × 100m) earth grid and for different mesh densities. The results are for soil resistivity of 100Ωm and a unity relative permittivity.

It was found that increasing the segmentation affected the computed impedance, particularly for the 100 mish earth grid. At 1 MHz for the 4 mesh earth grid, 30 segments per conductor is sufficient (minimum earth impedance).

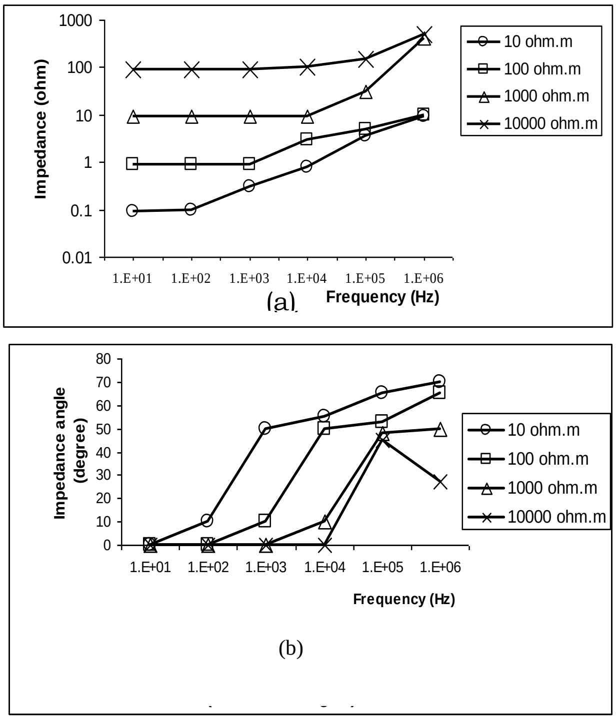

Fig. 2. Frequency response of the earth grid for different soil resistivities and relative soil permittivity = 1 (4 mesh earth grid).

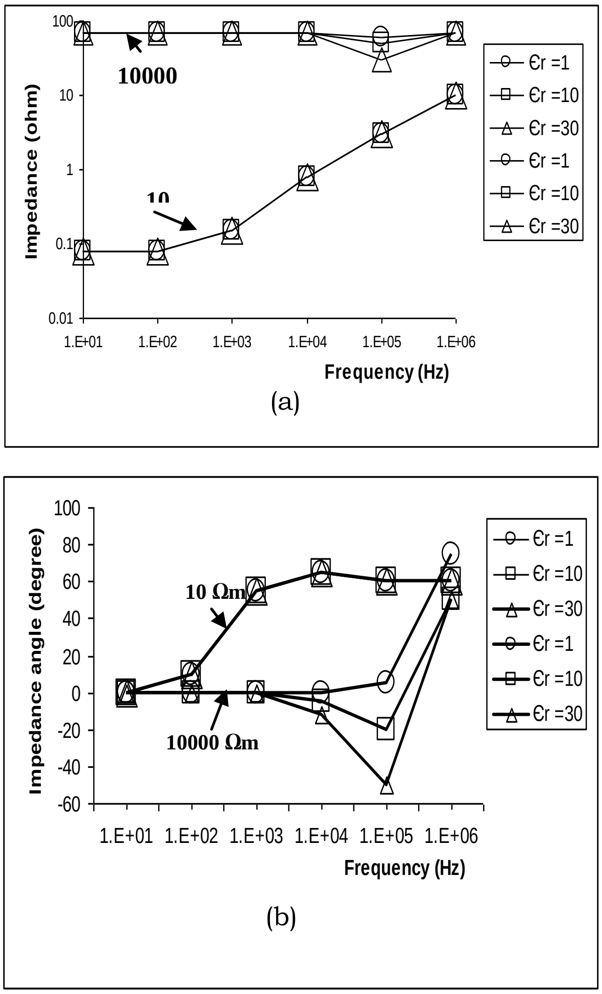

Fig. 3. Effect of soil permittivity on earth grid impedance (81 mesh earth grid).

4. Discussion

The mesh density has a sufficient influence. The increase of mesh density, decreases the earth impedance, at high frequencies, specially for high resistive soil.

For low resistive soil (10Ωm), the inductance of the earth grid has a great influence at high frequencies. The earth impedance at 1MHz is about 89 times the impedance at power frequency.

The soil permittivity has not effect on the earth impedance except, at high frequencies, for high resistive soil.

The number of conductor segmentation can control the grid inductance, which reduce the earth impedance.

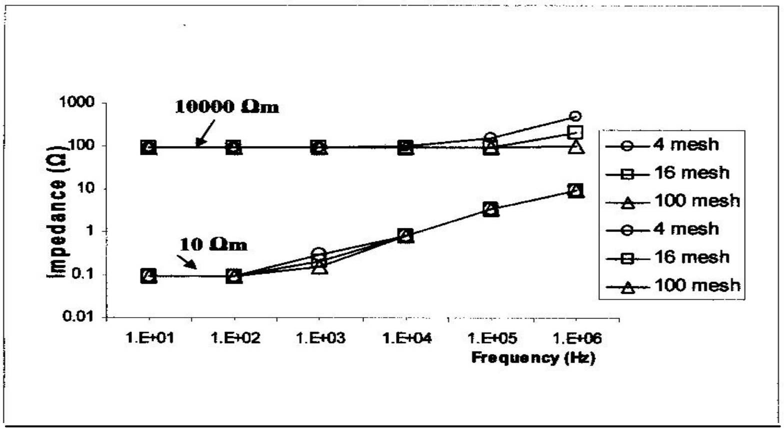

Fig. 4. Frequency response for different mesh densities, for different soil resistivities.

Soil resistivity 10000 Ωm 1 MHz, frequency of the injected current to the mesh earth grid	
Earth grid	% increase of earth impedance, with respect to it at power frequency.
4 mesh	11
16 mesh	110
100 mesh	456

Table 1
Influence of conductor segmentation on the calculated earth grid impedance at 1 MHz

No. Segments	4 mesh		16 mesh		100 mesh	
	Z	*Φ*	*Z*	*Φ*	*Z*	*Φ*
5	18.309	69.113	18.423	69.087	25.079	60.035
10	18.533	69.056	18.533	69.063	18.958	68.368
15	17.873	66.626	17.966	64.915	18.272	64.482
20	17.765	65.414	17.768	65.419	18.049	65.027
25	17.817	64.979	17.820	64.984	18.105	64.639
30	17.763	64.917	17.766	64.922	18.045	64.857
35	17.765	64.888	17.768	64.892	18.051	64.571

Table 2
Influence of conductor segmentation on the calculated earth grid impedance at 100 kHz

No. Segments	4 mesh		16 mesh		100 mesh	
	Z	*Φ*	*Z*	*Φ*	*Z*	*Φ*
5	4.373	49.596	4.55	50.974	5.395	65.173
10	4.298	49.182	4.507	50.852	3.988	61.755
15	4.312	48.965	4.523	50.689	4.012	60.721
20	4.312	48.86	4.522	50.564	3.986	61.332
25	4.309	48.861	4.518	50.593	3.977	61.350
30	4.312	48.834	4.521	50.573	3.981	61.313
35	4.308	48.835	4.517	50.583	3.973	61.322

5. Conclusions

This paper has demonstrated the influence of soil resistivity, soil permittivity and mesh density on the frequency response of a (100m×100m) earth grid. The parametric studies considered for frequencies ranging from DC to 1 MHz and for soil resistivity values between 10 Ωm and 10000Ωm. The relative permittivity was varied between 1 and 30.

The investigations have shown that the earth grid impedance increases with frequency with the inductive effects becoming significant above specific frequencies. These inductive effects are found to be more significant at lower frequencies for low soil resistivity media. In addition, it was shown that soil permittivity has an effect at high frequencies in high soil resistivity, and the increase on grid density lowers the grid impedance for a specific range depending on the soil resistivity of the media.

6. References

[1] Electricity Association: Technical, 41-24, "Guidelines for the Design, Installation, Testing and Maintenance of Main Earthing Systems in Substations", issue 1 (1992).

[2] IEEE80:2000, Guide for Safety in AC Substation Grounding, IEEE, New York (2000).

[3] B.R. Gupta and B. Thapar, "Impulse Impedance of Grounding Grids," IEEE Trans. PAS-99, Vol. 6, pp. 2357-2362 (1980)

[4] R. Verma and D. Mukedkar, "Fundamental Consideration and Impulse of Ground Grids," IEEE Trans. PAS-100, Vol. 3, pp. 1023-1030 (1981).

[5] M. et al., Rammoorty, "Transient Performance of Ground Grid," IEEE Trans. PWRD. Vol. 4, pp. 2053-2059 (1989).

[6] A.P. Meliopoulos and M.G. Moharam, "Transient Analysis of Grounding System," IEEE Trans. PAS-102, Vol. 2, pp. 389-399 (1983).

[7] A.D. Papalexopoulos, and A.P. Meliopoulos, "Frequency Dependent Characteristics of Grounding Systems," IEEE Trans. PWRD-2, Vol. 4, pp. 1073-1081 (1987).

[8] L.D. Greev, and M. Heimbach, "Frequency Dependent and Transient Characteristics oif Substation Grounding Systems," IEEE Trans. on Power Delivery, Vol. 12 (1), pp. 566-570 (1997).

[9] CDEGS, HIFREQ Module, Safe Engineering Services, Montreal Canada (1996).

Received August 7, 2004
Accepted March 7, 2005