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Frequency Analysis and Simulation of a Good Ground System to Protect Medical Electric Equipment Installed In Ilam Hospital

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Abstract

Background: Nowadays, most of hospitals and medical centers are concerned about electrical safety in their devices. Use of a good ground system in medical devices is a crucial element in the operation of electrical medical devices and it can effectively enhance human health and safety. Bioinstrumental systems might be damaged under a lightning stroke or an impulse electromagnetic (EM) wave. To avoid these hazards due to induced currents and remaining medical equipment in their high performances, the earthing system with low impedance is necessary. This earthing system must have low resistant at low frequencies and good performance in high frequencies range of 1 MHz or above in order to reach the highest signal to noise ratio and getting images with good quality. MRI earthing electrodes should be placed in close proximity to other electrodes. Close proximity to other earthing electrodes can increase the likelihood that electrical noise will adversely impact the quality of the image taken by the MRI unit.

Results: This paper will be aimed to analyze the dynamic behavior of a typical earthing system based on the data collected from earthing system of the MRI system installed in Ilam hospital and also simulating and manipulating of the earthing system that include vertical rod electrode on frequency range of 0 to 20 MHz. In soils with low resistance, with increasing frequency, the impedance rises sharply. However, in soils with moderate resistance, this increment is dramatic and in soils with high resistance, there is an Oscillating behavior.

Keywords: Bioinstrumental; Electromagnetic wave; Earth electrode; Frequency response; High frequency

Introduction

Hospital equipment including MRI systems are extremely sensitive and good electrical earthing (grounding) has been shown to improve the image quality. The dynamic behavior of the ground during strong impulse strikes like a lightning or a strong electromagnetic wave is complex and usually depends on the ground electrode geometry, electrical properties of the soil and waveform of excitation current. This paper is more concerned with two specific types of makeups for simple electrodes; vertical and horizontal rod electrodes. Nowadays, the electrode plate arrangement is used in the most of the residential buildings, while horizontal electrodes are more common in hospital and medical centers than elsewhere.

Usually, there is a huge difference on the behavior of the ground in high and low frequency. The high frequency current can degrade the performance of earthing, so in this mode, an earting system cannot be effective for current disposal. This is because that the parameters and electrical properties of the earth are frequency dependent [1].

In high intensity currents, the electrical field of electrode may become higher than electrical field of the surrounding soil; in this case, a break or an impulse discharge will be happened. This electric field around of electrode plays as a threshold field that greater value of this threshold can cause soil dielectric breakdown. It improves the functions of the earth system that are usually ignored in the calculations because it is more secure [2].

The exclusive designing of an earthing system plays a key role in the proper functioning of bioelectrical systems such as human safety, protecting equipment and electromagnetic compatibility [3,4].

The frequency dependence of the soil electrical conductivity and consequently the electric permeability is usually ignored in the designing. In fact, despite the physical nature of the soil, the conductivity and permeability have been considered as constant values, like as the low frequency cases. So, a better designing of the earth system can be obtained with using an accurate model of the soil and land. Earlier, the frequency dependence of the conductivity and permeability of the soil have been investigated by experimental tests [5]. Recently, an empirical test was conducted on the frequency dependent conductivity and permeability for a horizontal electrode to use the behavior of the hybrid electromagnetic model [6,7]. This paper shows the frequency dependences and describes a model for the electrodes embedded in the medical equipment. In addition, it analyses the impedance of several types of earthing systems that contain horizontal and vertical rod electrodes in the soils with three different electrical conductivities as 10, 100 and 1000 Ω .

Ground Resistance

Ground resistance is equal to ratio of electrical voltage on the electrode to the discharged electrode current in low frequency. There are three major parameters in this definition. The first parameter is the electric potential that it defines as the ratio of the highest point of the electrode (where the conductor is connected to the ground) to the zero

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reference point (This point is usually defined at a point far from the main electrode). The far point is the point that is not located at the range of main electrode, so voltage of main electrode doesn't any effect on it. The second parameter is the discharged current of electrode. This includes the unwanted currents, short circuit current, and any other dangerous current (other than lightning). The last parameter is the low frequency (DC or semi-DC) that usually refers to frequencies from zero to 60 Hz. However, in ground discussion at some case, frequencies to 100 kHz and even to 600 kHz have been known as low frequencies [8,9].

Many factors play key roles in determining ground resistance. These factors include Soil resistivity, reducing resistance materials, length, diameter and burial depth of each electrode, type, material and arrangements of electrodes and how to connect ground conductors to ground electrodes. The soil resistance is the most important factor among them. To run an earth well, a cylindrical hole drilled to a depth of several meters for the insertion of the electrode. The electrode is inserted as horizontally or vertically on it (usually vertical is preferred because it has lower resistance). Ground conductor is connected to ground electrode using explosive welding. In addition, the ground conductor is connected to ground bus. Around the electrode and the hole filled with reducing resistance materials. Sometimes a cavity or tube is installed to add water to well for resistance reduction in the dry season. The below Figure 1 shows a typical earthing system.

Soil resistivity is expressed in Ohm metres (Ω .m). This corresponds to the theoretical resistance in Ohms of a cylinder of earth with a crosssection area of 1 m² and a length of 1 m. By measuring it, it would be possible to find out how well the soil conducts electric currents. So the lower the resistivity, the lower the earth electrode resistance required at that location. Resistivity varies significantly according to the region and the type of soil because it depends on the level of humidity and the temperature. As temperature and humidity levels become more stable the further electrode dig from the ground surface, the deeper the earthing system, the less sensitive it is to environmental variations. It is highly recommended to bury the earth electrode as deep as possible. The soid resistivity based on seasonal variation for two electrode depths is shown in Figure 2.

The High Frequency Behavior of Ground

The high frequency behavior of ground is found on the lighting studies and it is related to high frequency components of lighting pulse



current. Due to existence of high frequencies components in a pulse spectrum, usually the lighting pulse has the most intense frequency during ascent that is first time of strike. Earthing in low frequencies is related to safety and protection of devices and people. However, running and performance of earthing in high frequencies may be worse or much worse than low frequencies. Therefore, the effect of protection is removed during the increase of the pulse such as lightning.

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Earthing may be shown using a circuit with ideal current I that a terminal head is connected to ground electrode and other head of terminal is connected to far ground terminal. Usually, the effects of these connections are neglected. The voltage between direct current sources is equivalent to the ground electrode potential to the far reference point.

$$R = \frac{V}{I}$$
(1)

With considering I as i(t) (variable with time) and v as v(t), Transient impedance is calculated as:

$$z(t) = \frac{v(t)}{i(t)} \tag{2}$$

While the Transient impedance is the characteristic that depends on the shape of excitation wave i(t), It's defined as ratio of ground electrode voltage to far ground on the discharged current on it as shows in Figure 3.

Consideration on Basic Field

Circuit considerations mentioned in the previous section is the basic of engineering analysis, but due to existence of circuit limitation,





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real and physical analysis needs to be considered on basic field. Basic field consideration is essential for ground impedance determination especially in more complex arrangement of electrodes at high frequencies and more conductive areas (less resistance). The simple natural ground is an isotropic and homogeneous half-space with physical properties similar to an air interface is formed by parameters independent of frequency. These parameters include:

Among of these parameters, electrical conductivity has the largest changes with increment of distance. In these analysis, the non-linear behaviors that caused by high intensity currents are neglected. There is a great difference between electromagnetic emissions in the air and on the ground at the same frequency. Γ is the propagation constant that is below Figure 4;

$$\Gamma = \alpha + j\beta = \sqrt{j\omega\mu_0(+j\omega\epsilon)}$$
(3a)

$$\beta = \omega \sqrt{\epsilon \mu_0} \left\{ \frac{1}{2} \left[\sqrt{1 + \left(\frac{\sigma}{\omega \epsilon}\right)^2} + 1 \right] \right\}^{1/2}$$
(3b)

$$\beta = \omega \sqrt{\epsilon \mu_0} \left\{ \frac{1}{2} \left[\sqrt{1 + \left(\frac{\sigma}{\omega \epsilon}\right)^2 + 1} \right] \right\}^{\frac{1}{2}}$$
(3c)

The parameters that have large effects on consideration include; Λ (wave length), υ (propagation speed) and δ (skin depth)

$$\delta = \frac{1}{\alpha}, v = \frac{\omega}{\beta}\lambda = \frac{2\pi}{\beta}$$
(4)

 Λ at ground is smaller than in the air even for large σ and lower frequencies. An important parameter that is related to Λ is the electrical dimension that is equal to ratio of physical dimension of 1 to Λ . If the electrical dimension is much smaller than the one, then electromagnetic waves do not experience significant changes in the path length and diffusion effects can be neglected. In this case, the semi-static approximation can be used for analysis. It's important to determine that a system may has lager electrical dimension for same frequency at ground to air due to smaller Λ in ground. Therefore, semi-static approximation may be acceptable in air, but it not be acceptable for same buried system and frequency at ground.

Frequency-Dependent Characteristics of the Soil

Despite the extensive use of frequency independent models, Constitutive parameters of $\sigma \mathfrak{z} \mathfrak{e}$ in the ground can be a function of frequency with large changes at their values [10]. Following equation



shows $\sigma \in c$ components:

Е

$$\underline{\sigma} = \sigma' - j\sigma'' \tag{5a}$$

$$\underline{\varepsilon} = \varepsilon' - j\varepsilon'' \tag{5b}$$

Where σ' is the real part and σ'' is the imaginary part of σ . Effective frequency dependent $\sigma \ge \epsilon$ defined as following:

$$\sigma eff(\omega) = \omega \sigma'' + \sigma' \tag{6a}$$

$$eff(\omega) = \varepsilon' - \frac{\sigma''}{\omega} \tag{6b}$$

The Figure 5 shows the measured frequency dependence of effective $\varepsilon_{,3} \sigma$ for the sandy soil on the different volume of water.

Dependent Behavior to the Ground Frequency

According to the above formulas, due to dependence of the ground and its impedance to the some parameters such as $\mu \mathfrak{g} \mathfrak{e} \mathfrak{g} \mathfrak{g} \sigma$ and dependence of these cases to the frequency, dependence of the ground to frequency can be resulted. Below Figure 6 shows frequency dependence of a typical harmonic impedance for a ground system as ratio of absolute value of impedance ($|Z(\omega)|$) to DC resistance. Two-frequency range may be cleared. A low frequency range, the impedance is almost constant and independent of frequency and the high frequency range that the impedance is frequency dependent. The frequency dependent behavior may be classified as follows:









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An Important parameter of inductive behavior is the limiting frequency, between high frequency and low frequency that named as characteristic frequency FC [2]. Also, the below Figure 6 shows the impact of p of soil to high frequency behavior of ground; because the same electrode in the different p soils has different behavior. Always the inductive/capacitive behavior has advantage on inductive behavior because the high frequency impedance is equal to or smaller than earth resistance and so the performance of the high frequency ground is similar to low frequency (Resistive) or even better than it. Of course, this happen generally in smaller size electrodes and more resistive soils (higher p) [11,12].

The electrode length and ground feature causes to the ground usually have inductive behavior. So, its performance is worse in high frequency.

Frequency Simulation

For comparison of high frequency of a ground to low frequency of it, an electrode with 3 m length, 0.0125 m radius at the soil with 10 electrical permeability (clay soil), magnetic Permeability 1 at 3 different electrical resistivity as 10, 100 and 1000 Ω /m was used in this study. The above figure in each part (a, b and c) show the calculated values of reference [13] and the below Figure 7 in each part show the simulation values using MATLAB software.

Conclusion

At low frequency, the resistance of an earthing system determines



its performance. Usually this resistance should be lower than 2, 5 and 10 Ω (according to location) in order to earthing system can be considered acceptable. While at high frequencies, impedance has the more impact. This impedance has high frequency dependence to the soil resistivity. In soils with low resistance, with increasing frequency, the impedance rises sharply. However, in soils with moderate resistance, this increment is dramatic and in soils with high resistance, there is an Oscillating behavior.

Declarations

Authors' contributions

MM: Searched databases for studies, analyzed the results and prepared manuscript, editing the manuscript and discussion on study design.

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