Innovative earthing systems for electric power substations using conductive nanoparticles

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ABSTRACT

The earthing system is very important to safe human's lives and protect power system from normal and abnormal faults. High soil resistivity regions is the main problem of installation the earthing systems in electric power substations to pass the current through the earth's surface. This paper has been overcome on high soil resistivity regions by penetrating conductive nanoparticles to have extremely low grounding resistance. Moreover, it has been succeeded to examine the methodology of the proposed Nano-Tech earthing systems in case of single rods, multiple rods and grids. Also, it has been defined optimal types and concentrations of nanoparticles for Nano-Tech grounding system to provide excellence protection for electrical substations with respect to built beneath of soil where substation is located. A comparative study has been discussed and analyzed the results of traditional and nanotechnology grounding systems.

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1. INTRODUCTION

Every electrical equipment's, apparatus, system must be earthed or grounded to acquire a low resistance path for dissipation of excess current flow into the earth. Earthing plays a significant role in generation, transmission and distribution for safe operation of any electrical power substation. Ground shortcoming current affects human safety. Significant mishaps occur because of inappropriate earthing. Indeed, every overhead line/Substation/Generator station which is presented are at risk to injury from lightning. In power stations systems, an earthing or establishing system is hardware which interfaces parts of the electric circuit with the ground, along these lines characterizing the electric capability of the transmitters comparative with the world's conductive surface. Specifically, it influences the extent and appropriation of short current out flows through the system, and the impacts it makes on hardware and individuals in the vicinity of the circuit.

The grounding system drive the ground fault current efficiently to the earth, and to protect the people within and in the surroundings of the substation. The main objective of earthing systems is carrying and dissipation the electrical currents that are produced during fault conditions into the ground, in order to ensure that a worker in the vicinity of the grounded installation is not exposed to a critical electrical shock and to ensure the proper upper limits for the step and the touch voltages have been set by international standards. Due to increasing number and complexity of AC substation, more important needs for both safety and accurate design procedures for the grounding systems. In fact, soil resistivity data is the key factor in designing a good grounding system because of the soil conducts electrical current to earth. The resistivity of soil varies widely throughout the world and changes dramatically within small areas.

Many theoretical methods have been discussed the calculation the earthing resistance and earth surface potentials of variant electric substation earthing systems, i.e., starting from a grid consists of one mesh or rod to a final design consisting of many regular meshes or rods [1, 2]. In recent years, as the shortage of fossil energy, distributed generation becomes the development trend of new design of earthing systems with its specialties of economy and environmental protection. and energy storage [3-5]. In case of a prospective fault current, step voltage, touch voltages and earth potential rise are kept below a safe limit. Thus, this may occur a change in soil characteristics (moisture, pH, and organics), corrosion, accelerated aging from lightning and earth current [6-12]. As a novel solution to these problems, nanotechnology soil has aimed to both increase soil conductivity and reduce corrosion. This paper presented the effect of nanoparticles in characterization of soil earthing system and analysis the ground resistance for new nanotechnology earthing system for reducing ground resistance then enhancing ground potential performance. Thus, it has been obvious the progressive in earthing systems of electrical power systems by using nanoparticles in variant soils; it is presented new creation based on nanoparticles technique in order to design new enhancement performance of electrical power substation.

2. GROUNDING SYSTEM

The reason for earthing in an electric power system is to limit, concerning the general mass of earth, the capability of current flow conductors, which are a piece of the equipment, non-current carrying metal works, accessories with the equipment, mechanical assembly and appliances connected to the system framework. It is also necessary to maintained earthing properly of all electrical installation. Thus, there are two types of the earthing systems which are using electrodes or grids systems. In this section, Nano-Tech earthing system followed after the traditional earthing system models to explain the relation between resistance and length of grounding systems and the importance of nanoparticles in Nano-Tech grounding systems. In the past, the soil was treated with salt and coal there is salt and coal to help reduce the soil resistivity that the rods or the grids are buried down, whatever, this research proposed distribution of nanoparticles in the soil has been controlled in soil resistivity then affected on grounding system resistance.

2.1. Problem of traditional grounding systems

Soils made up of gravel, sand or stone have the highest soil resistivity that present a big problem in installation earthing system of electrical power substations in them. Moisture content, temperature and salts also affect soil resistivity. Granite, millstone, and all rock formations found in site area and all types of rock have a high electrical resistivity-a real headache when designing/installing a high voltage and low voltage electrical earthing systems. Thus, the soil resistivity is a measure of how much the soil resists or conducts electric current. It is a critical factor in design of systems that rely on passing current through the earth's surface. The grounding electrodes provide the essential function of connecting the electrical system to the earth. The earth is considered to be at zero potential. The primary purpose of the grounding electrode is to maintain the electrical equipment at the earth potential present at the grounding electrode. In addition, the purpose of grounding grid is to serve the dual purpose of carrying currents into the earth without exceeding the operating tolerances of any protected equipment while assuring that personnel in the vicinity are not exposed to electric shock as would result from excessive step or touch potentials. Considering resistivity of soil and length and diameter of the rod following (1) show the relation between resistance and length of one rod [1, 3, 13],

$$R = \frac{\rho}{2\pi L}\left[\log\left(\frac{8L}{d}\right) - 1\right] \tag{1}$$

In case of two rods set in series, two option are available when spacing between rods is greater than length of the rod as in (2), whatever, when spacing between rods is smaller than length of the rod as in (3):

$$R = \frac{\rho}{4\pi L}\left[\log\left(\frac{8L}{d}\right) - 1\right] + \frac{\rho}{4\pi S}\left[1 - \frac{L^2}{3S^2}\right] \tag{2}$$

$$R = \frac{\rho}{4\pi L}\left[\log\left(\frac{32L^2}{dS}\right) - 2 + \frac{S}{3L} - \frac{S^2}{16L^2}\right] \tag{3}$$

where:

ρ : is the resistivity of soil, in ohm meter (Ω.m)

L : is the length of reinforcing rod below ground level, in meter (m)

d : is the diameter of the rod, in meter (m)
S : is the spacing (distance) between two rods, in meter (m)

A typical technique for getting a low ground opposition at higher voltage substations is to utilize interconnected ground networks. A typical grid system ground rods may be connected to the grid for further reduction of the ground resistance when the upper layer of soil is of much higher resistivity than that of the soil underneath. The resistance to ground determines the maximum rise of the grounding system during a ground fault [1, 3, 13].

The following (4) for grid resistance could be used:

$$R = \frac{\rho}{\pi L}\ln\left(\frac{2L}{\sqrt{dh}}\right) + \frac{K_1 L}{\sqrt{A}} - K_2 \quad (4)$$

where:
L : is the total length of all conductors,
A : is the total area of the grid,
h : is the depth at which the grid is located d is the grid conductors' diameter,
ρ : is the resistivity of the soil
d : is the diameter of the grid
K_1 and K_2 : are factors presented graphically as functions of length-to-width ratio of the grid area

2.2. Proposed grounding systems

In fact, soil resistivity is the resistive parameter in the grounding system for current flow to earth. Low ground obstruction is prefered or even require. If the soil has high resistivity, and the grounding system is not sufficiently arranged to power system stability, the dissipation of the electrical current running through the power system will be a result in a higher voltage on the grounding system. In addition, this has suggestions in certain application, for example, higher touch or step possibilities, or in more extraordinary cases disappointment of dependable activity of over-current or over voltage devices. According to the properties of many conventional materials that have been changed when formed or mixed with nanoparticles, the proposed Nano-Tech earthing system have been designed how to use nanoparticles distribution for changing properties of soil. Therefore, the nanometric soil resistivity has been droppd forcing the fault current to go with the earthing path, causing the efficiency and the reliability to increase and reduce the hazards of electric shocks. The (1-4) are used as the same in the new earthing system but the only difference is changing in soil resistivity (ρ) to be effective resistivity (ρ_{eff}) [14-20]. Effective resistivity presents the combination resistivity of nanoparticles and soil resistivities. The new conversion parameters of grounding system is being as (5) and (6):

$$\sigma_{eff} = (1-q)\sigma_{soil} + q\,\sigma_{nanoparticles} \quad (5)$$

$$\rho_{eff} = \frac{1}{\sigma_{eff}} \quad (6)$$

where:
σ_{eff} is the effective conductivity, in siemens per meter (S/m)
ρ_{eff} is the effective resistivity, in ohm meter (Ω.m)

As shown in Figure 1, Nano-Tech earthing systems for electrical power substations has been explained the distribution of nanoparticles inside the soil medium of electrodes grounding systems and grids grounding systems respectively. In case of Electrodes nanotechnology grounding system the calculation of ground resistance is being as (7-9).

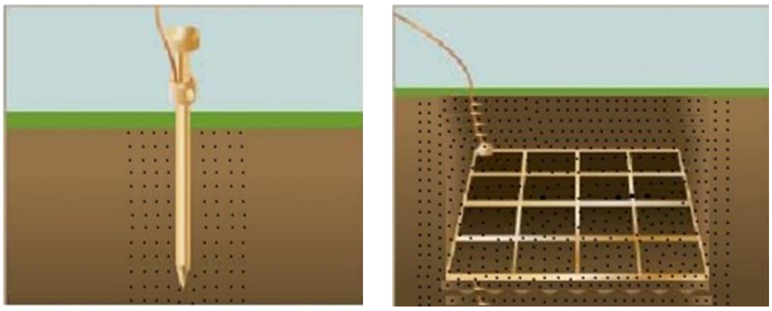
$$R = \frac{\rho_{eff}}{2\pi L}\left[\log\left(\frac{8L}{d}\right) - 1\right] \quad (7)$$

$$R = \frac{\rho_{eff}}{4\pi L}\left[\log\left(\frac{8L}{d}\right) - 1\right] + \frac{\rho_{eff}}{4\pi S}\left[1 - \frac{L^2}{3S^2}\right], \text{ for } S>L \quad (8)$$

$$R = \frac{\rho_{eff}}{4\pi L}\left[\log\left(\frac{32L^2}{dS}\right) - 2 + \frac{S}{3L} - \frac{S^2}{16L^2}\right], \text{ for } S<L \quad (9)$$

whatever, the calculation of ground resistance of grids nanotechnology grounding system is being as (10).

$$R = \frac{\rho_{eff}}{\pi L}\ln\left(\frac{2L}{\sqrt{dh}}\right) + \frac{K_1 L}{\sqrt{A}} - K_2 \quad (10)$$



(a) (b)

Figure 1. Nano-tech earthing systems for electrical power substations, (a) nano-tech electrodes grounding systems, (b) nano-tech grid grounding systems

3. PROPOSED NANOMETRIC SOIL MEDIA

Nanoparticles, and nanomaterials in general, have become one of the new active materials being put into soil earthing system formulation to make the more efficient Nano-Tech earthing system. There are many reasons why this is being done, with the most common being that some nanomaterials have extremely high electrically conductive properties that can be utilized in soil formulation [21, 22]. Here, the conductive nanoparticles display extraordinary guarantee as options in contrast to ordinary conductive materials. As of late, utilization of conductive nanomaterials, for example, conductive metal nanomaterials have opened new opportunities for electronic and optoelectronic devices. Besides, adding adaptability to conductive nanomaterials improves the application in the fields of wearable electronics, electromagnetic interference (EMI) shielding, and wearable antennas. Consequently, the conductive nanomaterials have been utilized as options for developing grounding systems in contrast to customary conductive metals of traditional grounding systems. The need of the conductive metal nanomaterials industry is finding the best technique for delivering practical, excellent conductive metal nanomaterials at a mechanical scale. Conductive nanoparticles offer several advantages in soil of Nano-Tech earting systems. Table 1 depicts nanoparticles types and specific soil resistance of the soil.

Table 1. Types of nanoparticles and soil resistivity of the soil [23-25]

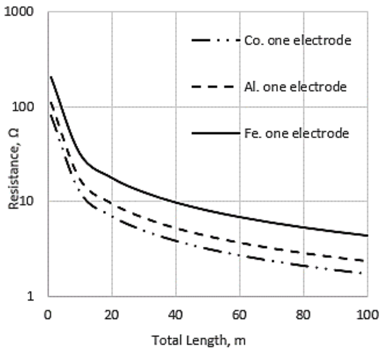
Materials	Specific Earth Resistance ρ [Ω.m]
Sandy Soil	450
Nanoparticles	
Copper	1.694
Aluminum	2.67
Iron	10.1

4. RESULTS AND DISCUSSION

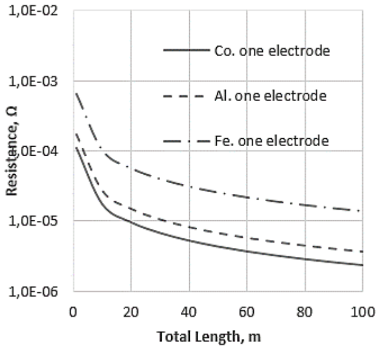
This research is enhancing the traditional ground system performance in electrical power substation by using new Nano-Tech earthing system that provide earthing resistance equal to nano-Ohm order. Due to the importance of types and concentrations of nanoparticles in traditional grounding systems for electrical power substations, the following results are illustrated an efficient nanoparticles and concentrations for obtaining the best ground system performance.

4.1. Effect of nanoparticles on electrode earthing systems

Developing electrode earthing systems has shown in Figure 2, it obvious that performance of traditional electrode earthing system (0 %wt. nanoparticles) as shown in Figure 2(a), whatever, the development of electrode earthing system has been depicted due to small penetration amount of conductive nanoparticles (0.0 %wt. up to 0.01 %wt.) in sand soil as shown in Figure 2(b). It is obavious that the conduction of electrode ground systems decreases with increasing nanoparticles volume fractions. In addition, it has been cleared that the copper materials of electrodes and nanoparticles have an efficient conduction material with respect to aluminum and iron materials. Also, developing electrode earthing systems are shown in Figure 3, it obvious that performance of traditional electrode earthing system (0.0 %wt. nanoparticles). Distribution of nanoparticles (0.01 %wt.) inside sand soil tends to reduce electrode resistance then enhancing the conduction of Nano-Tech electrodes grounding systems. In addition, it has been cleared that the nanoparticles materials have an efficient factor for reduction the ground resistance with respect to length of electrodes materials. In case of using Nano-Tech electrodes grounding systems, it has been cleared that using copper nanoparticles as shown in Figure 3(a) provided more reduction in ground resistance for electrical substations that reach to nano-ohm with respect to traditional ground systems. On the other wise, Figure 3(b) shows the effect of Aluminum nanoparticles for enhancing grounding systems with variant nanoparticles concentrations, whatever, the effect of Iron nanoparticles on grounding systems have been shown in Figure 3(c).

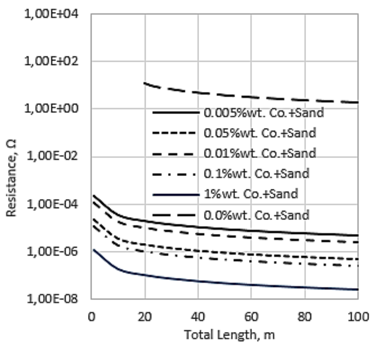


(a)

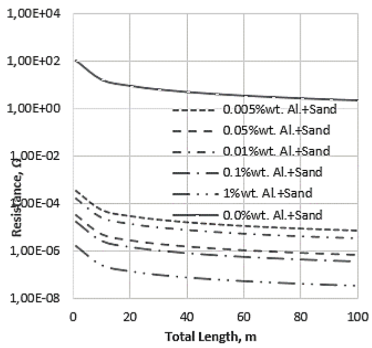


(b)

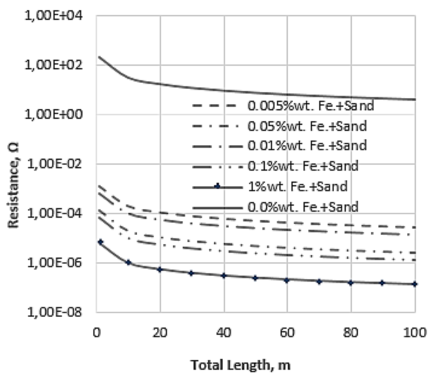
Figure 2. Modified electrode using sand nanoparticles by variations of number of electrodes, (a) 0.0 %wt. nanoparticles+sand, (b) 0.01 %wt. nanoparticles+sand



(a)



(b)

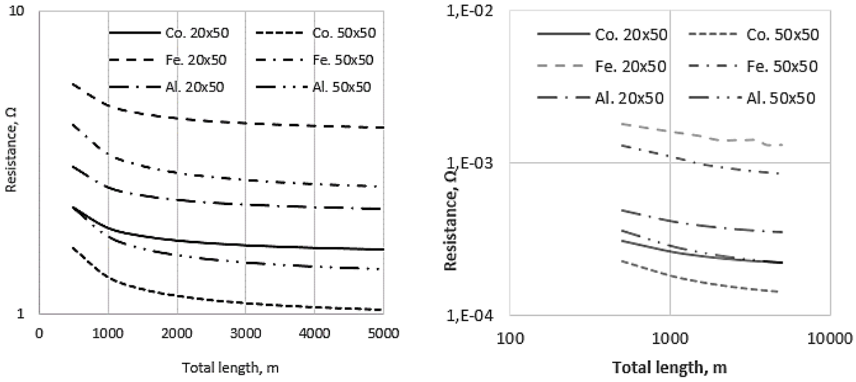


(c)

Figure 3. Modified electrode using sand nanoparticles by variations of volume fractions, (a) unique copper electrode, (b) unique aluminum electrode, (c) unique iron electrode

4.2. Effect of nanoparticles on grid earthing systems

Figure 4 shows the developing of grid earthing systems and obvious that effect of nanoparticles on grid resistance and conduction of grid ground systems variant volume fractions. Figure 4(a) shows the effect of traditional grid earthing systems for natural sand soil (0.0 %wt nanoparticles). Whatever, Figure 4(b) shows that penetration of small amount of nanoparticles (0.0001 %wt.) in the sand soil earthing system to make a huge reduction of ground resistance of earthing system. It has been cleared that type of grid materials still more efficient for increasing conduction of ground system.



(a) (b)

Figure 4. Modified grid using sand nanoparticles by variations of volume fractions, (a) 0.0 %wt. nanoparticles+sand, (b) 0.0001 %wt. nanoparticles+sand

5. TREND OF NANOPARTICLES IN SOIL EARTHIG SYSTEMS

Exact structure of the grounding system requires a precise evaluation of the site's soil conditions. In any case, even a little site will frequently have broadly fluctuating soil resistivity starting with one spot then onto the next. Soil resistivity is an element of a few factors, these variables incorporate the kind of soil, dampness content, temperature, mineral substance, granularity and conservatives. In convention earthing systems, dampness, minerals, and broke up salts are the main factors that can be impacted by any reasonable control idea. Information on the nearby soil conditions is compulsory and is the initial phase in the structure procedure. This incorporates its dampness substance, temperature, and resistivity under a given arrangement of conditions. Since about 94% of the grounding resistance of a given electrode is dictated by the character of the soil inside grounding system, with nanotechnology science, the penetration process of conductive nanoparticles inside grounding soil site is an efficient solution to get more conductive pass of excessive current pass in power station. In case of Nano-Tch ground system design, the ground resistance reached micro or nano ohm resistance that is investigated the stability and reliability of the electric power stations. A more practical action may be to replace only that part of the soil that exercises the greatest influence on the ultimate grounding resistance and to use the lowest resistivity “soil” available [23-25].

In Nano-Tech earthing system, Nanoparticles can be embedded in soil of earthing system and the structure of soil composite is random. It does not help to develop highly conductive particles for composites if they do not touch each other: The electrons have to tunnel through the gaps, and electric conductivity is improving control of the distribution of the particles inside the soil. Conductive nanoparticles (NPs) can increase the number of electroporated cells, they have a more pronounced impact on the soil electrification. Thus, it can be available to be controlled the soil resistivity by varying the structure of soil. Mixing conductive nanoparticles through soil of grounding site has been effective methodology for reducing soil resistivity and then make a lowest earthing resistance for electric power substations. Table 2 shows a comparative result between electrodes grounding systems in pure sand soil and Nano-Tech electrode earthing systems. It has been cleared that a small concentration (0.005 %wt.) of conductive nanoparticles of the same electrode material helps to reduction earthing resistance to be micro-ohm. Moreover, Tables 3 and 4 show the result difference between grids grounding systems (20 m x 50 m^2 and 50 m x 50 m^2) in pure sand soil and nano-tech electrode earthing systems. It has been cleared that a very small concentration (0.00001 %wt.) of conductive nanoparticles of the same grid material helps to reduction earthing resistance to be micro-ohm.

Table 2. Traditional and nano-tech electrode earthing systems (copper, aluminum, iron)

Length (m)	0 %wt. nanoparticles+Sand			0.005 %wt. nanoparticles+Sand		
	Copper	Aluminum	Iron	Copper	Aluminum	Iron
1	79.82	108.69	201.91	2.20×10^{-04}	3.46×10^{-04}	1.31×10^{-03}
10	12.49	17.01	31.60	3.44×10^{-05}	5.42×10^{-05}	2.05×10^{-04}
20	6.93	9.43	17.52	1.91×10^{-05}	3.00×10^{-05}	1.14×10^{-04}
30	4.88	6.65	12.35	1.34×10^{-05}	2.12×10^{-05}	8.01×10^{-05}
40	3.80	5.18	9.62	1.05×10^{-05}	1.65×10^{-05}	6.24×10^{-05}
50	3.13	4.26	7.91	8.61×10^{-06}	1.36×10^{-05}	5.14×10^{-05}
60	2.67	3.63	6.75	7.34×10^{-06}	1.16×10^{-05}	4.38×10^{-05}
70	2.33	3.17	5.89	6.41×10^{-06}	1.01×10^{-05}	3.82×10^{-05}
80	2.07	2.82	5.24	5.70×10^{-06}	8.98×10^{-06}	3.40×10^{-05}
90	1.87	2.54	4.72	5.14×10^{-06}	8.10×10^{-06}	3.06×10^{-05}
100	1.70	2.32	4.30	4.68×10^{-06}	7.38×10^{-06}	2.79×10^{-05}

Table 3. Traditional grid earthing systems (copper, aluminum, iron)

Length (m)	0 %wt. nanoparticles+Sand					
	Copper (m^2)		Aluminum (m^2)		Iron (m^2)	
	20x50	50x50	20x50	50x50	20x50	50x50
500	2.2457	1.6487	3.0608	2.2471	5.7043	4.1879
1000	1.9191	1.3221	2.6156	1.8020	4.8747	3.3583
1500	1.8027	1.2057	2.4570	1.6433	4.5790	3.0626
2000	1.7422	1.1452	2.3745	1.5608	4.4253	2.9089
2500	1.7049	1.1079	2.3236	1.5100	4.3305	2.8141
3000	1.6794	1.0824	2.2890	1.4753	4.2660	2.7495
3500	1.6610	1.0640	2.2638	1.4501	4.2190	2.7026
4000	1.6469	1.0499	2.2447	1.4310	4.1833	2.6669
4500	1.6358	1.0389	2.2296	1.4159	4.1552	2.6388
5000	1.6269	1.0299	2.2174	1.4037	4.1325	2.6160

Table 4. Nano-Tech grid earthing systems (copper, aluminum, iron)

Length (m)	0.00001 %wt. nanoparticles+Sand					
	Copper (m^2)		Aluminum (m^2)		Iron (m^2)	
	20x50	50x50	20x50	50x50	20x50	50x50
500	3.10×10^{-03}	2.30×10^{-03}	4.80×10^{-03}	3.60×10^{-03}	0.0182	1.33×10^{-02}
1000	2.60×10^{-03}	1.80×10^{-03}	4.10×10^{-03}	2.80×10^{-03}	0.0155	1.07×10^{-02}
1500	2.50×10^{-03}	1.70×10^{-03}	3.90×10^{-03}	2.60×10^{-03}	0.0146	9.80×10^{-03}
2000	2.40×10^{-03}	1.60×10^{-03}	3.80×10^{-03}	2.50×10^{-03}	0.0141	9.30×10^{-03}
2500	2.30×10^{-03}	1.50×10^{-03}	3.70×10^{-03}	2.40×10^{-03}	1.38×10^{-02}	9.00×10^{-03}
3000	2.30×10^{-03}	1.50×10^{-03}	3.60×10^{-03}	2.30×10^{-03}	1.36×10^{-02}	8.80×10^{-03}
3500	2.30×10^{-03}	1.50×10^{-03}	3.50×10^{-03}	2.30×10^{-03}	1.34×10^{-02}	8.60×10^{-03}
4000	2.30×10^{-03}	1.40×10^{-03}	3.50×10^{-03}	2.30×10^{-03}	1.33×10^{-02}	8.50×10^{-03}
4500	2.30×10^{-03}	1.40×10^{-03}	3.50×10^{-03}	2.20×10^{-03}	1.32×10^{-02}	8.40×10^{-03}
5000	2.30×10^{-03}	1.40×10^{-03}	3.50×10^{-03}	2.20×10^{-03}	1.32×10^{-02}	8.30×10^{-03}

6. CONCLUSION

Nanoparticles distribution in the soil has been controlled in reduction of soil resistivity that has affected on grounding resistance of earthing system. Penetration of nanoparticles inside soil matrix is accepting changing the electrical properties of soil resistivity that has been increasing conductivity to flow the fault currents from the electric power system. A small concentration of conductive nanoparticles of the same electrode material helps to reduction the earthing resistance to be micro-ohm. Nano-Tech earthing methodology has been treated power substation soil with nanoparticles that has been deduced more efficient procedure for obtaining soil resistivity reduction with respect to traditional methodology. Nano-Tech earthing systems is more efficient for controlling in grounding system parameters of electrical substations with respect to type and concentration of inclusions because of the conductive nanoparticles increase the number of electroporated cells, they have a more pronounced impact on the soil electrification

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