Engineering Science and Technology, an International Journal xxx (2018) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

JESTECH

Full Length Article

Comparative assessment of the effect of earthing grid configurations on the earthing system using IEEE and Finite Element Methods

T.R. Ayodele, A.S.O. Ogunjuyigbe *, O.E. Oyewole

Power, Energy, Machine & Drive Research Group, Electrical and Electronic Engineering Department, Faculty of Technology, University of Ibadan, Ibadan, Nigeria

A R T I C L E   I N F O

Article history:
Received 10 April 2018
Accepted 8 July 2018
Available online xxxx

Keywords:
Earthing grid system
Earthing Configurations Electrical Transient Analyser Program (ETAP)
Finite Element Method (FEM)
IEEE earthing technique

A B S T R A C T

In this paper, comparative assessments of four earthing grid system configurations (the triangular shape, the rectangular shape, the T-shape and the L-shape) are performed with the aim of determining the best earthing grid configuration in terms of earthing grid resistance, Ground Potential Rise (GPR), touch voltage and step voltage for a typical food and beverages industry in Nigeria. The IEEE earthing technique and the Finite Element Method (FEM) are employed to simulate the earthing grid system configurations using commercially available software (Electrical Transient Analyser Program, ETAP 12.0). The results revealed that L-shape is the most preferred earthing configuration in terms of grid resistance, GPR and step voltage with the IEEE values of 0.292Ω, 1610.9 V and 436.5 V, respectively and FEM values of 0.195Ω, 1077.1 V and 186.6 V, respectively. Meanwhile, the rectangular shape gives the best result for designed touch voltage with the value of 284.5 V for the IEEE method and 286 V for the FEM method followed by the L-shape with the values of 340.8 V for the IEEE technique and 294.8 V for the FEM. Both the IEEE method and the FEM return the same trend of result for all grids. However, IEEE method is much better in terms of computational speed.

1. Introduction

Over the years, earthing system is considered a very important aspect of electrical power system designs for industries. The integrity of earthing system in terms of reliability, dependency and safety is always taken with optimum priority in every electricity dependent industry. This is because; it has to do with the safety of both the personnel and equipment within the industry. Food and beverage industry is one of the industries with high number of personnel and electricity dependent equipment [1,2]. The industry relies on electricity for their daily activities, especially for providing mechanical power to drive equipment like conveyors, electric pumps, compressors, condensers heat and ventilation appliances [3]. Hence, a reliable and dependable earthing grid system is one of the main requirement of electrical installations in food and beverage industries.

Earthing system is a system of various electrical connections to the earth mass. It can be generally understood from two points of view, the equipment earthing and the system earthing. The equipment earthing is the connection of non-current carrying metallic parts associated with electrical plant to earth [4]. It is basically the preventions attached to various equipment in factories to prevent shock to human beings in case of high fault current arising from machines and equipment. On the other hand, system earthing is the connection of electrical systems conductor which makes up the total electrical system to earth. The earth itself is a semiconductor while the grounding electrodes are pure conductors. The *earth electrodes* are metal conductors or interconnection of conductors while the *earth rod* is a vertical metal conductor that reaches the depth of the earth depending on its length and diameter. The main reason for earthing design is to provide a low resistance path to dissipate current in other to protect personnel from excess current which may lead to equipment breakdown and loss of lives. If the resistance is too high according to ohms law, there will be an increase in voltage drop which will increase the mesh potential [5]. A vertical rod is more effective than a horizontal rod in the sense that they dissipate more current in the soil at a sufficient depth which helps in the reduction of Ground Potential Rise (GPR).

The difference in soil characteristics at different industrial plants places a careful demand on the earth grid design in order to accomplish a design that is sensitive to the peculiarity of each soil type. Various authors have worked on the relationship

* Corresponding author.
E-mail addresses: tr.ayodele@ui.edu.ng (T.R. Ayodele), a.ogunjuyigbe@ui.edu.ng (A.S.O. Ogunjuyigbe).

Peer review under responsibility of Karabuk University.

https://doi.org/10.1016/j.jestch.2018.07.003
2215-0986/© 2018 Karabuk University. Publishing services by Elsevier B.V.

Nomenclature

I_o	Fault current in kA
$A_{mm}{}^2$	Conductor cross section in mm^2
Tm	Maximum allowable temperature in °C = 1048 °C
Ta	Ambient temperature in °C = 20 °C
Tr	Reference temperature for material constants in °C at 20 °C
α_o	Thermal coefficient of resistivity at 0 °C in 1/°C
α_r	Thermal coefficient of resistivity at reference temperature Tr
Pr	The resistivity of the ground conductor at reference temperature Tr in μΩ-cm
Ko	1/αo or (1/αr) – Tr in °C
Tc	Duration of current in 0. 3 s
TCAP	Thermal Capacity Factor in J/(cm^3. °C)
h_s	Thickness of surface layer
h_2	Depth of the soil second layer
r_s	Surface material resistivity
t_s	Duration of current exposure/fault clearing time
R_G	Grid resistance
A	Area occupied by ground grid
L_t	Effective length of grounding system conductors including grid rods
n	Effective number of parallel conductors
h	depth of grid in meters
I_G	Maximum Grid Current
D_f	Decrement factor for entire fault duration
I_g	RMS symmetrical grid current in amperes
S_f	Fault current division factor
D	Spacing between parallel conductors
d	Diameter of the ground grid conductor
k_i	Irregularity factor/corrective factor accounting for errors introduced in assuming K_m and K_s
K_t	Geometrical factor in calculating ground designed touch Potential
K_s	Geometrical Factor in calculating Step Potential
L_R	Total length of all ground rods in meters
L_r	Length of each rod in meters
L_t	Effective buried length for touch Potential in meters
L_s	Effective buried length for Step Potential in meters
L_C	length of conductor in horizontal grid in meters
L_p	Peripheral length of grid in meters
A	Area of grid in meter sq
L_x	Maximum length of grid in x direction
L_y	Maximum length of grid in y direction
ρ	The uniform soil resistivity
ρ_s	The surface layer soil resistivity

between the soil characteristics and the earth grid design. For example, Dawalibi [5] determined the effect of earth resistance to earth value of an earthing grid design for a substation constructed on a two layered soil type. In another work, Dawalibi and Barbeito [6] showed that a uniform soil layer could be implemented for resistance to earth calculation for a two layered and multi layered soil type. The authors made a comparison of the results obtained from the two scenarios [6]. Similarly, Ma et al. performed an extensive study on the equivalence of uniform and two layer soils to multi-layered soil. They showed the methodology to obtain an approximate uniform or two layered resistivity for some multi-layered soil. It was concluded that a good equivalent soil with respect to ground resistance is not necessarily good with respect to touch voltages [7].

Nassereddine et al. [8] further extended the work by determining when it is acceptable to use a uniform soil resistivity for earthing calculations and when to use a single/multi-layered soil structure for such calculations. Ma et al. [9] in their paper compared the IEEE standards made for substation earthing (IEEE 80-2000 and IEEE 80-1986). They considered the effects of uniform and layered soil in earthing designs and made adequate comparisons between the two standards. Similarly, Vyas and Jamnani [10] considered the grounding system of HV/EHV substation in a layered soil. In their work, the significance of two layered soil and uniform soils were discussed. The authors are of the opinion that the actual soil layers should be used in earthing grid design but in simulation such layers have to be converted to uniform equivalence.

Different researchers have proposed various ways to obtain a low earth to ground resistance which is the desire of every earthing system. Meng et al. [11] have proposed a method that could help achieved a low earth resistance. They suggested that drilling a deep hole in the ground, developing cracks in the soil by means of explosion and filling holes with low resistivity materials could provide a mean of achieving low earth resistance in earthing system. Furthermore, Adelian [12] has also explored the grounding potential of a substation earthing design by proposing the following to improve substation earth to ground resistance: the use of earth pits in proper positions, making moisture contents available at the earth pits and the use of bentonite powder, soft coal and black soil for improving earthing resistance.

Literature has also revealed that different soil types have different soil resistivity which in turn has impact on the earthing grid design. Soils with high soil resistivity can have negative effect in earthing grid designs. An investigation into the impact of high soil resistivity on the AC substations grounding systems designs has been performed by Mustafa with the aim of contributing to existing earthing standards [13]. In similar study, Adeboyega and Odeyemi [14] have conducted a study to ascertain the effect of soil resistivity in different soil layer type on the calculation of earthing grid designs along 330KV transmission line in the North Eastern part of Nigeria. Aside the substation earth design, some researchers in recent times are given considerations also to industrial earthing system design. For example, Zotos [15] proposed a modified calculation of IEEE standard to show that a near zero soil resistivity should be used in earthing design calculations for industries. Mitilo et al. [16] gave illustrations of how industrial plants could have increased fault currents and how this could lead to an increase in the touch and step potentials of an industrial outfit [16]. More on the earthing design system of substation can be found in [17,18].

While several works have been performed on the design of earthing system for both substations and manufacturing industries to achieve low earthing resistance as discussed in the aforementioned studies, little considerations have been given to the effect of different earthing grid configurations. It is intuitive to believe that the configuration of earthing grid could have influence on the earthing resistance. This paper therefore performs a study on the possible impact of earthing grid design configurations on the performance of earthing system. using a typical food and beverage manufacturing plant located in Lagos, Nigeria as a case study.

2. Soil resistivity

Soil parameters are the main factors that influence earthing grid design. These parameters include: the moisture content of the soil,

Please cite this article in press as: T.R. Ayodele et al., Comparative assessment of the effect of earthing grid configurations on the earthing system using IEEE and Finite Element Methods, Eng. Sci. Tech., Int. J. (2018), https://doi.org/10.1016/j.jestch.2018.07.003