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Earth Grid Safety Consideration: Civil Upgrade Works for an Energised Substation

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***Abstract*—**The demand on High voltage (HV) infrastructures is growing due to the corresponding growth in industries and population. Many areas are being developed and therefore require additional electrical power to comply with the demand. Substation upgrade is one of the rapid solutions to ensure the continuous supply of power to customers. This upgrade requires civil modifications to structures and fences. The civil work requires excavation and steel works that may create unsafe touch conditions. This paper presents a brief theoretical overview of the touch voltage inside and around substations and uses CDEGS software to simulate a case study.

***Keywords*—**Earth safety, High Voltage, AC interference, Earthing Design.

I. Introduction

ELECTRICAL infrastructure upgrade are expending worldwide to keep up with the power demands. The upgrade of high voltage electrical infrastructure is done by the construction of additional bay or upgrading the existing circuit breaker. The civil scope of works involves tempering with the existing soil structure, installing additional foundations and steel works. In addition, it requires heavy machinery within the substation boundary and modification of the existing fence or the extension of the existing fence.

The earthing system of the existing operational substation is assumed to be in a state of compliance with the relevant safety regulation. The civil scope required for upgrading the system can potentially jeopardise the safety of the workers and presents a Touch, Step voltage hazards.

The majority of substations are covered with crush blue stone rock to mitigate the touch and step risk. Civil works will remove the effect of the blue stone rocks; this removal is leading to a higher touch and step voltage in relation to the natural first layer of soil resistivity and even to the second layer of the soil resistivity.

The construction of new foundations required steel installation in the ground to a certain depth that reaches in some projects few meters. The steel acts as an electrode under any fault, while workers installing the steel poles it can become energized and cause unsafe condition.

This paper presents an overview on the theory of touch and step voltage and providing a case study to validate the need to revise the touch and step voltage after any infrastructure change.

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II. Soil Resistivity, Step, Touch and Mesh Voltage

Before the detailed design of the earth grid, it is imperative to study the ground around the site. Soil resistivity plays a fundamental part in determining the earthing grid design. Soil resistivity can be carried out using different methods. It is essential for an efficient earthing design to have more than one test carried out onsite. The most three popular methods to perform soil resistivity test are Wenner method, Schlumberger Array and driven Rod method. However we will use in this study the Wenner method.

A. Wenner Method

Wenner method consists of four electrodes; two are for current injection and two for potential measurement [1, 2], as shown in Fig. 1.

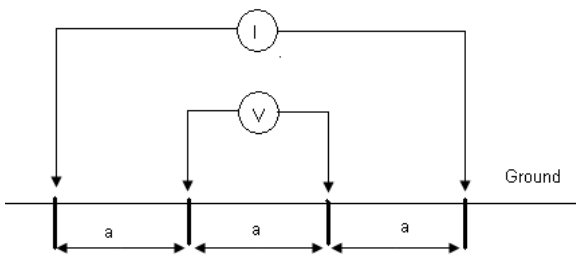


Fig. 1 Wenner four probe arrangement

The soil resistivity formula related to Wenner method is shown in equation 1.

$$\rho = 2\pi aR \tag{1}$$

Where
R is the resistance measured by the machine,
a is the spacing of the probe

Wenner array is considered to be the least efficient from labor perception, as it requires four people to perform the task in a short time. On the other hand it is considered to be the most competent method when it comes to ratio of received voltage per unit of transmitted current [3, 4].

The step and touch voltage can be determined from the two equations 2 and 3, these two equations are calculated using the resistance from a 50 Kg person That is used when assessing the public access area. Equations 4 and 5 calculate step and touch voltage using 70Kg body weight, this calculation can be used in restricted areas within the site [5,6].

$$V_{touch} = \frac{116 + 0.174 C_s \rho_s}{\sqrt{t}} \tag{2}$$

$$V_{step} = \frac{116 + 0.696 C_s \rho_s}{\sqrt{t}} \tag{3}$$

$$V_{touch} = \frac{157 + 0.236 C_s \rho_s}{\sqrt{t}} \tag{4}$$

$$V_{touch} = \frac{157 + 0.942 C_s \rho_s}{\sqrt{t}} \tag{5}$$

$$C_s = 1 - \frac{0.09\left(1 - \frac{\rho}{\rho_s}\right)}{2h_s + 0.09} \tag{6}$$

Where

Cs is the de-rating factor relating to surface layer thickness and resistivity

ρ_s is the top surface layer

t is the primary clearance time

The mesh voltage can be computed using equation 7.

$$V_{mesh} = \frac{\rho . K_m . K_i . I_g}{L_M} \tag{7}$$

Where L_M can be calculated using equation 8, when the grid has electrodes on the corner [7, 9]:

$$L_M = L_C + . L_R \tag{8}$$

Where

L_C total length of the horizontal conductor

L_R total length of ground rod

$$K_m = \alpha + \beta \tag{9}$$

$$\alpha = 0.1\left[\ln \frac{D^2}{16hd} + \frac{(D + 2h)^2}{8dD} - \frac{h}{4d}\right] \tag{10}$$

$$\beta = \frac{K_{ii}}{K_h} \ln\left[\frac{8}{\pi(2n-1)}\right] \tag{11}$$

$$K_h = \sqrt{1 + h} \tag{12}$$

Where

$$K_{ii} = \frac{1}{(2n)^{\frac{2}{n}}} \tag{13}$$

III. Case Study

Part of an upgrade project, it is required two additional 66kV feeders for Harbata ZS. The bay is located between 2 new energized 66kV bays. The scope of works is as follows:

- Civil works to accommodate new CB, Disconnector, VT's and Landing structure
- Extend the fence 2 meters to accommodate the new bay
- Installation of the steel works for the Disconnetor, CT's and Landing structure
- Wiring works

The earthing characteristics of the existing substation are as follows:

- SL fault current: 5000A
- Clearance Time: 350 mS
- Harbata earth grid resistance is 0.9 Ω
- Average Soil Resistivity for the line is 100 Ω /m
- 100 mm of blue stone crush rocks to mitigate the touch and step voltage
- Safety touch voltage under 350ms and 100 Ω /m is 195V
- Safety touch voltage under 350 ms and 100 mm of crushed blue stone is 1000V

Fig. 2 shows the earth grid arrangement of the existing substation.

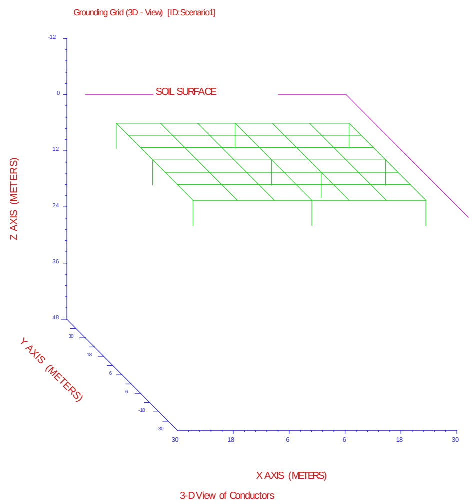


Fig. 2 Harbata ZS existing earth grid arrangement

Before any works occurs, Fig. 3 represent the touch voltage of the existing earth grid arrangement, the maximum touch voltage is computed to be 947V which is within the allowable touch voltage under the existence of the 100mm blue stone crush rock.

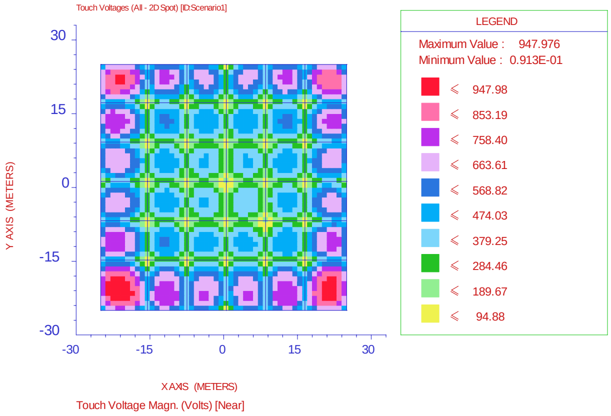


Fig. 3 Harbata Existing Touch Voltage profile

The erection of the bay requires cutting the earth grid to allow for the foundation to be completed, Fig. 4 shows the touch voltage profile when the earth grid is changed.

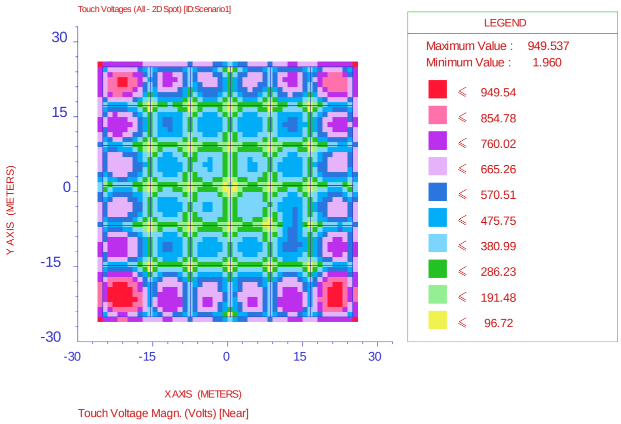
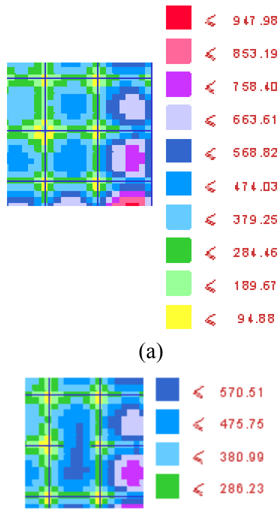


Fig. 4 Touch voltage after tempering with the existing earth grid

Fig. 5a shows the touch voltage where the new bay foundation is taking place and Fig. 5b shows the touch voltage after cutting the section of the earth grid to accommodate the new foundations.

It is shown that before any works, the touch voltage is at 379 and this result is within the allowable touch voltage under the existing of the blue stone crush rock. The touch voltage after commencing works is shown to be 570V which is above the allowable touch voltage under the natural soil resistivity. Excavation is eliminating the existing blue stone rock and this clear is forcing the usage of natural ground as the surface soil resistivity.



(a)

(b)

Fig. 5 Touch voltage profile (a) before and (b) after tempering with the earth grid

Similar simulation is completed while working on the fence, Fig. 6 shows the touch voltage on the fence line after the completion of the work.

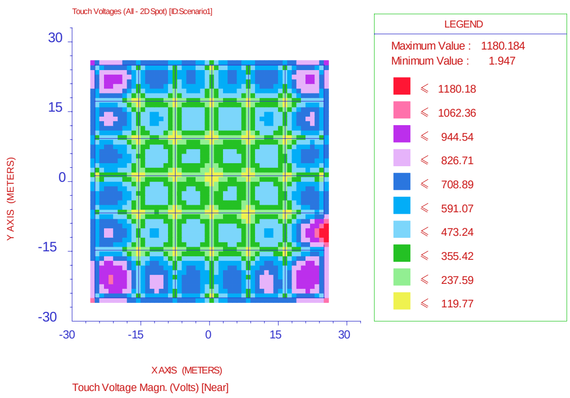
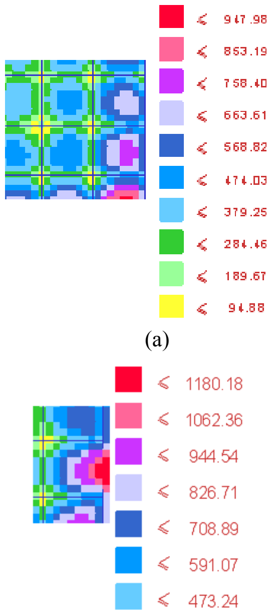


Fig. 6 Touch Voltage profile on the fence area after cutting the earth grid

Fig. 7a and 7b shows the touch voltage before and after on the fence. Before any works is conducted the touch voltage was within the safety limit, and after commencing works and the removable of the crush blue stone rocks, the touch voltage is computed to be 1100V which is above the safety limit under natural soil structure.



(a)

(b)

Fig. 7 Fence touch voltage profile before and after commencing works

IV. Conclusion

This paper shows the need of analyzing the touch and step voltage for the feeders in case there is a need to perform an upgrade to a ZS to ensure the compliance of the system under fault condition. In addition, this paper proves that it is vital to assess the implication on the earth grid under any civil works at an energised substation to ensure the compliance of the touch/step voltage and to ensure the safety requirements.

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