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HV Substation Earthing Design for Mines

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Abstract:-High Voltage (HV) substation forms important assets for the mining industries. The existences of these substations necessitate earthing design to ensure safety compliance to the mine regulations. The HV system within the mines is consisted of multiple substations which are connected throughout and underground cable. These substations provide the load with the required electrical power to perform its tasks. This paper endeavours to provide information in regards to the different types of connections between the load and the substations (TT, TN and IT Systems). Furthermore, the earthing arrangements under different connection were assessed. A case study is addressed to show the different earthing arrangements under different connection systems

Keywords:- Earth Grid, EPR, Fault Current, High Voltage, Mines, TN and TT systems

I. INTRODUCTION

Mining sector is considered to be one of the main sources of energy worldwide. Many countries invest in the mining sector due to its high return. Electrical power is considered one of the main requirements to perform the mining tasks. High voltage power consists of substations and transmission lines. These substations are located within the mining site and fed by a transmission lines from the source. These substations provide the required electrical power to machineries within the mining systems. The connection between these substations and the load can be represented by three systems:

- TN system. Under this system, the substation transformer neutral is earthed and the electrical load frames are connected to neutral.
- TT system. Under this system, the substation transformer neutral is earthed and the load frames are earthed to a different earth grid to the transformer neutral.
- IT system. The transformer neutral is not earthed. This is theoretically unearthed. In real case, the neutral is earthed by high impedance resistor. The electrical loads are earthed.

Each of these connection systems has its own earthing requirements to ensure its compliance to the relevant standards. The earthing system shall be designed to limit the danger transfer voltage between low voltage and high voltage system.

This paper endeavors to provide information in regards earthing each of these systems; it addresses the transfer voltage between substations, also the transfer to nearby structures including load frames. Furthermore, a flow chart diagram to explain the most efficient road for the design to be completed

A case study is addressed to show the impact of different earthing system under different connection system

II. DESIGN FACTORS

The earthing system design is united by the following factors:

- Fault location
- Fault current magnitude
- Type of connections (load connection system)
- Electrical Source Connection (overhead or underground transmission line)
- Soil resistivity structure
- Surrounding infrastructure

In this paper, TT and TN systems are discussed. The earthing system arrangements for this two systems are analyzed theoretically and assessed with a case study

III. THEORETICAL STUDY

The mining site consists of multiple substations which are located within the mining area. The earth grids of these substations are connected by the high voltage cable screen (this case is for an underground site). Figure 1 represents the electrical arrangement between these substations. In this figure, the incoming feeder is feeding three substations.

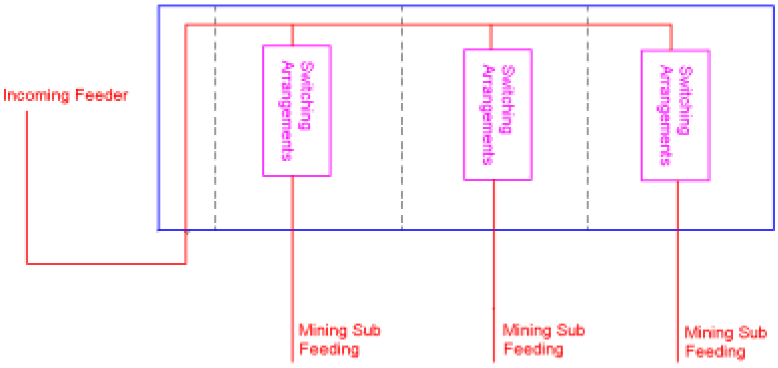

Figure1: High voltage mining substation arrangements

In many cases, it is possible for the clearance time of the incoming feeder to have a different value to the mining substations clearance time. Under this condition, a fault at the switching arrangement shall be treated under the incoming feeder clearance time. Furthermore, the touch voltage to the mining substation under fault at the switching arrangement shall be treated for the incoming feeder clearance time.

One of the main reasons behind the earthing design is to achieve a safe environment in the vicinity of high voltage infrastructure for people and workers. The hazard can jeopardize two categories of people:

- The public that can be affected by the step and touch voltages.
- Workers who can be affected by the step and touch voltages as well as the earth potential rise (EPR).

The step and touch voltages can be determined from the two equations 1 and 2, these two equations are calculated using the resistance from a 50 Kg person. This is used when assessing the public access area. Equations 3 and 4 calculate step and touch voltages using 70Kg body weight, this calculations can be used in restricted areas within the site. [1]

$$V_{touch} = \frac{116 + 0.174 C_s \rho_s}{\sqrt{t}} \tag{1}$$

$$V_{step} = \frac{116 + 0.696 C_s \rho_s}{\sqrt{t}} \tag{2}$$

$$V_{touch} = \frac{157 + 0.236 C_s \rho_s}{\sqrt{t}} \tag{2}$$

$$V_{touch} = \frac{157 + 0.942 C_s \rho_s}{\sqrt{t}} \tag{4}$$

$$C_s = 1 - \frac{0.09\left(1 - \frac{\rho}{\rho_s}\right)}{2h_s + 0.09} \tag{5}$$

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

These equations show the relation between the clearance time and the allowable safety limits. Increasing the clearance time will lead to reduction in the allowable safety limits. Thus, it is important to apply the highest primary clearance time when designing the earthing for the circuit shown in figure 1.

Figure 2 represents the connection between the mining substation and the load. This connection can be represented by three types:

- TN system
- TT system
- IT system.

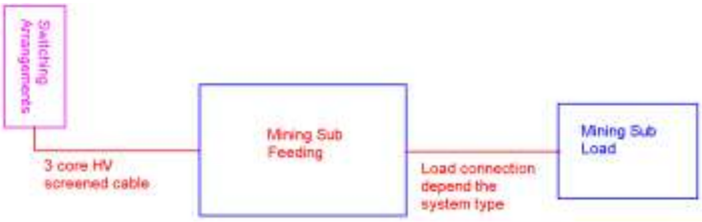

Figure 2: Electrical Connection between mine sub and load

A. TN System

Under the TN system, the substation transformer neutral is earthed and the electrical load frames are connected to neutral. Figure 3 represents the connection under TN system. Under this system, the load form part of the earth grid. Under any fault at the substation, EPR will be transferred to the load using the connection screen and not only the ground. When designing an earthing system for a TN arrangement, the load foundations and steel shall be modelled as part of the substation earth grid.

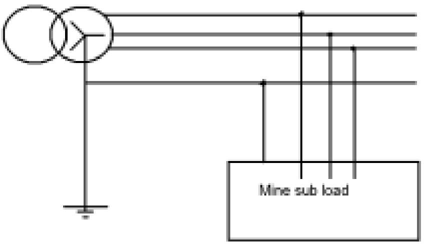

Figure 3: TN system connection

B. TT System

Under the TT system, the substation transformer neutral is earthed and the load frames are earthed to a different earth grid to the transformer neutral. Under this system, the load does not form a part of the substation earth grid. Under substation fault, the load will be exposed to EPR under soil voltage profile. When designing an earthing system for a TT arrangement, the load foundations and steels shall be modelled as part of a buried material near the substation. Figure 4 represents the TT system connection

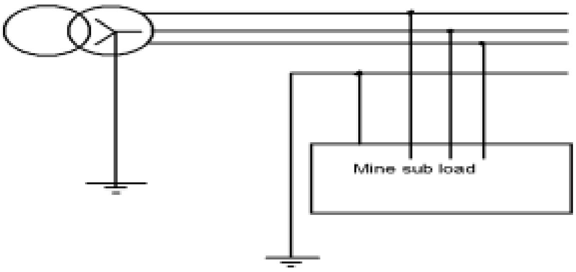

Figure 4: TT system connection

C. IT System

Under IT system, the transformer neutral is not earthed. This is theoretically unearthed. In real case, the neutral is earthed by high impedance resistor. The electrical loads are earthed. Under this system the fault current is limited by the high impedance resistor. Figure 5 represents the IT system arrangement

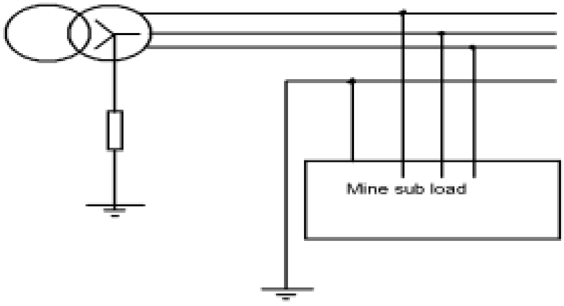

Figure 5: IT system connection

Soil Resistivity Structure

The earth plays important role in absorbing the fault and malfunction energy of these plants. Soil resistivity structure is the key in this operation. The soil resistivity will establish the conductivity of the ground which determines its capability to form an easy path for the fault or malfunction in the electrical system. The most three popular methods to perform soil resistivity tests are: [2]

- Wenner Method
- Schlumberger Array
- Driven Rod Method

The wenner method is the most popular one. Figure 6 shows Wenner method arrangement which the soil resistivity formula related to Wenner method is given as equation 6.

$$\rho = 2\pi a R \tag{6}$$

Where

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

The determination of the soil structure allows for the earth grid computation.

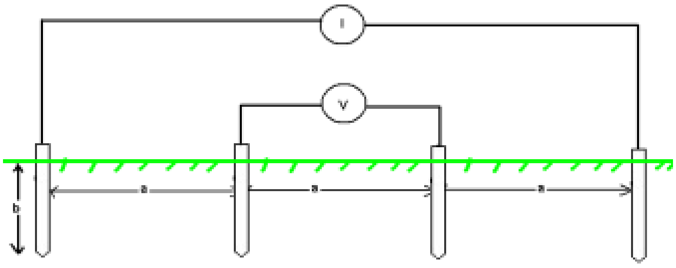

Figure 6: Wenner Method for Soil Resistivity Test

D. Grid Resistance

The grid can be varied in shape and contents depending on the job nature; the aim of the grid design is to achieve a low resistance path to accompany the fault current without exceeding the drop voltage safe limit. The grid can consist of a vertical electrode in the ground; the resistance of this electrode can be calculated using equation 7[3]:

$$R_g = \frac{\rho}{2\pi L}\left(\ln\left(\frac{8L}{d}\right) - 1\right) \tag{7}$$

Where

L is the buried length of the electrode in meters
D the diameter of the electrode in meters

If one electrode could not achieve the required resistance level, placing few electrodes in parallel will help in reducing the grid resistance, equation 8 shows the resistance for the grid formed with few electrodes in parallel [3].

$$R = \frac{\rho}{\pi L}\left(\ln\left(\frac{2L}{b}\right) - 1\right) \tag{8}$$

Where

L is the buried length of the electrode
b equivalent radius off the electrode at the surface

$$b = (dhsS)^{0.25} \qquad S = (4h_2 + s^2)^{0.5} \tag{9}$$

Where:

d is the diameter of the electrode
h buried depth
s distance between 2 parallel electrode
S distance from one electrode to the image of the other in meters

The earth grid could also consist of mesh grid buried at a depth of 0.5 meters or more, the mesh could consist of multiple horizontal conductors buried at the required depth. Equation 10 shows the resistance of this mesh:

$$R = \frac{\rho}{\pi L}\left(\ln\left(\frac{4L}{(dh)^{0.5}}\right) - 1\right) \tag{10}$$

Where

h is the buried depth

L length of the electrode
d diameter of the electrode

IV. EARTHING DESIGN DIAGRAM

As discussed earlier, depend on the connection (TT, TN and IT) the earthing arrangement shall be assessed. The bellow diagram includes the main steps that shall be considered during the earthing design for a TT and TN systems. The diagram highlight when the load foundations shall be considered as part of the earth grid assessment and when it should be considered as a buried structure located near the substation

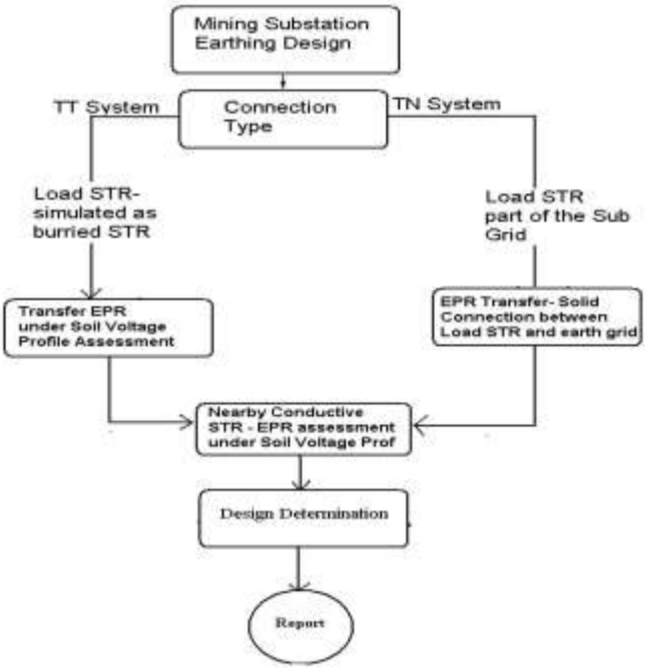

Figure 7: Design Diagram

The connection between the load structure and the substation earth grid can be represented by the Neutral connection, cable screen, earth continuity cable (ECC) or direct buried underground bare copper located under the cable (the cable that is connecting the load to the substation).
Under the TN system, if the load structure wasn't solidly connected to the earth grid of the substation during the simulation, the output of the design will not yield accurate results.

V. FAULT CURRENT DISTRIBUTIONS

As shows in figure 1, the substations will be fed from the main high voltage switch room, the earth grid of these substations are connected using cable screen under underground connection. Depending on the size of the mine site, for a fault at the main high voltage switch room, the fault current splits between the earth grid and the return path. Total resistance (combined all substation grid resistance) shall be used for this split study. Equation 11 shows the relation between the total resistance and the split factor. It should be noted that the absence of the mutual factor will create worst case scenario.

$$\delta_f = \frac{Z_{return-path}}{Z_{return-path} + Z_{total}} \tag{11}$$

Where

$Z_{return-path}$ is the return path input impedance

Z_{total} is the total impedance as seen from the high voltage switch room

δ_f is the split factor

Maximum high voltage switch room fault current can be found using equation 12:

$$I_{grid} = I_f \times \delta_f \tag{12}$$

Where

I_{grid} is the maximum fault current into the grid

I_f is the fault current

VI. CASE STUDY

Approvals for new mine site were granted in Central area, the HV electrical network for the new site is consisted of 4 new substations (33kV/415V), these substations are feeding the low voltage (LV) MCC's. These HV substations are fed by an OH transmission line with OHEW for the first 10 spans. The system shall be assessed based on TT and TN approach The design inputs are as follow:

- SLG at the transmission line connection is 2000A
- Clearance time for the input transmission line is 300ms
- Clearance time for fault within the mine site is 100ms
- SLG fault for a fault within the mine site is 2000A
- Each MCC is located 10 meters from its substation
- MCC foundations dimensions:
  - Width 6 meters
  - Length 20 meters

E. Soil Resistivity Test

4 soil resistivity tests were conducted onsite, each test at the nominated substation location. Wenner method was used to complete the test. RESAP from CDEGS engineering software was used to compute the soil structure of these 4 tests. The output of these tests shows similar soil structure. Figure 8 represents the computed soil structure. The area is consisted of two layers soil structure. Lower resistivity layer over high resistivity layer

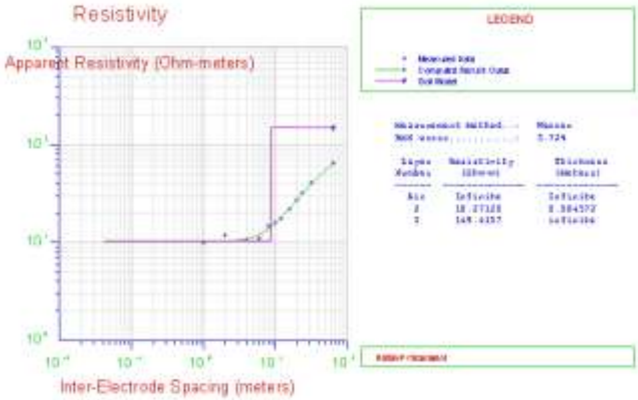

Figure 8: Soil Resistivity Structure

F. Substation Grid

Each substation consisted of a grading ring with 4 electrodes on each corner. All substations earth grid occupy the same area. The standalone of each substation grid was computed to be 2.1 ohms.

These substations are connected throughout a HV cable with the screen bonded both end. Figure 9 shows the earth grid connections between these substations and the in-feed transmission line OHEW. At the substation 1 is where the switch yard is located. The in-feed transmission line fault can only occur at the sub1 location, for a fault at this location the clearance time is 300ms. Fault at other substation has a clearance time of 100ms

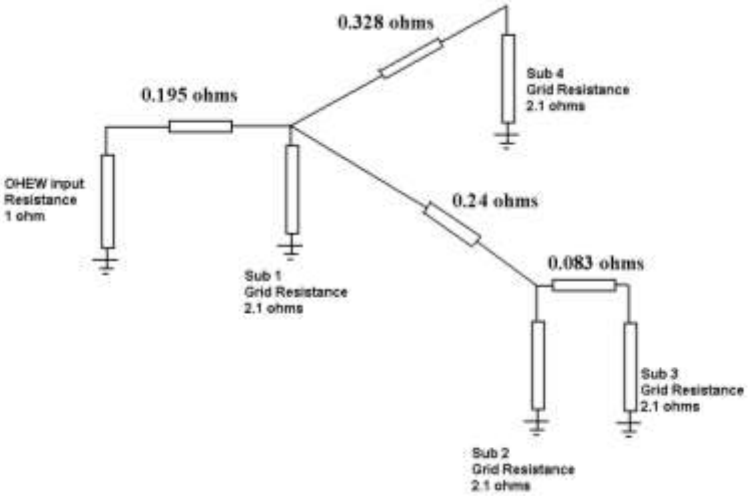

Figure 9: Substations earth grid connections

G. TT System Earthing

As per the definition, under TT system, the load earth grid is separate to the substation earth grid. The transfer touch and step to the MCC is made throughout the soil voltage grading. For an in-feed fault at substation 1, the allowable touch voltage is 180V as per AS3007.

The fault current at substation 1 due to the in-feed feeder will be split into the followings:

- In-Feed OHEW
- Sub 2 earth grid
- Sub 3 earth grid
- Sub 4 earth grid

The simulations show the following current distributions

- 277 A into Sub 4, Sub4 EPR is 581V
- 513 A into Sub 2&3 combined, EPR is 538V
- 889 A into the OHEW to the in-feed line
- 321 A into Sub 1, EPR is 674V

Figure 10 shows the touch voltage under TT system for a fault at the sub 4 under sub 1 fault. The maximum touch voltage at the sub is computed to be 168V which is within the 180V allowable limits. The maximum touch voltage at the MCC was computed to be 28V

Figure 11 shows the touch voltage at sub 4 under sub 4 SLG fault. The maximum allowable touch voltage under sub 4 fault is computed to be 260V. This voltage is assessed under 100ms clearance time. According to AS3007, the allowable touch voltage under this clearance time is 300V, therefore the system is compliance.

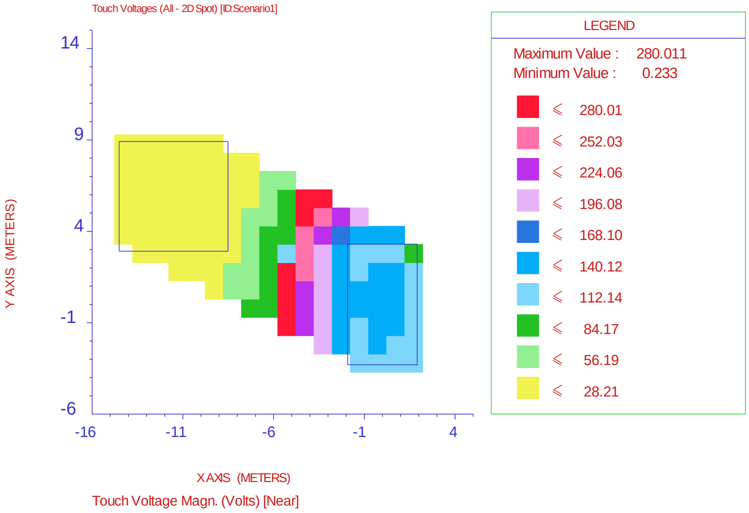

Figure 10: Sub 4 touch voltage under Sub 1 fault

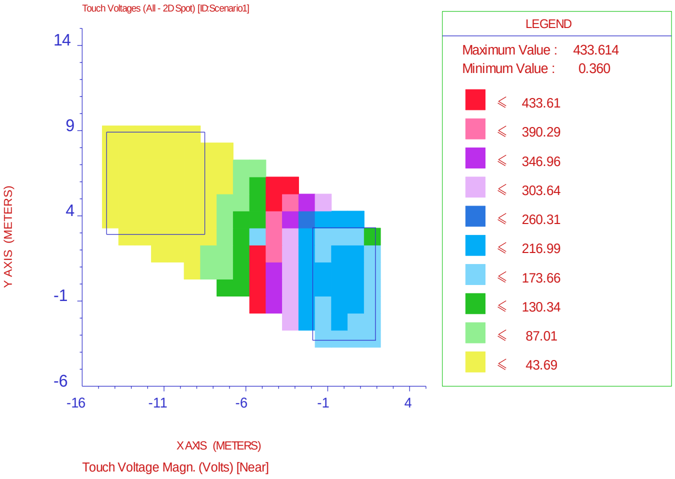

Figure 11: Sub 4 touch voltage under Sub 4 fault

Similar works was completed for the rest of the substations, the results shows its compliance to the standard.

H. TN system

As per the definition, under TN system, the load earth grid is connected to the substation earth grid, this will reduce the resistance of the substation earth grid. Figure 12 shows the earth grid resistance for each substation

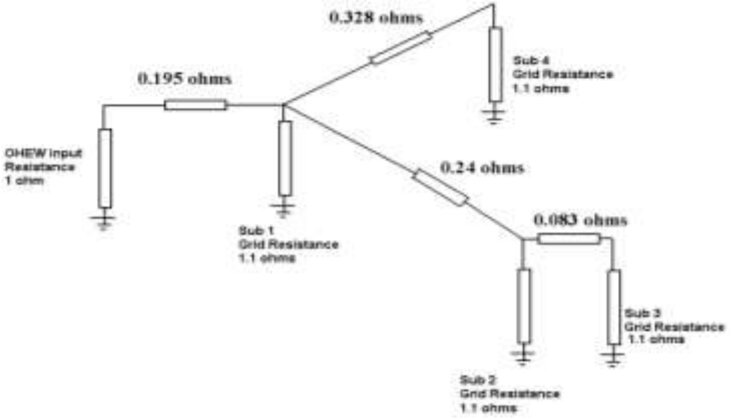

Figure 12: TN earth grid system

Under this arrangement, the simulations show the following current distributions under sub 1 fault on the incoming feeder:

- 318 A into Sub 4, EPR is 350V
- 561 A into Sub 2&3 combined, EPR is 308V
- 706 A into the OHEW to the in-feed line
- 413 A into Sub 1, EPR is 454V

VII. CONCLUSION

This paper shows the importance of choosing the type of the connection and its impact on the earthing design. The case study shows, under different system (TT or TN) the current distributions within the site will change. Also the earth potential rise at the substations will change which will lead to alteration in the touch voltage on the load structures under.
This paper shows NEEC design diagram for mine substations and how the design process varies between TT and TN. Furthermore, It shows how by following this diagram, the design outputs yield accurate results.

REFERENCES

[1]. IEEE guide to safety in AC substation grounding, 2000' (IEEE, New York, 2000).

[2]. Nassereddine M, Hellany A, Nagrial M. Rizk J. "*Soil Resistivity Structure and its implication on the Earth Grid of HV substation*" 2011 World Academy of Science, engineering and Technology , Vol 60, pp 1322-1326

[3]. Nassereddine M, Hellany A, Rizk J, 2009, *How to design an effective earthing system to ensure the safety of the people*, 2009 International Conference on Advances in Computational Tools for Engineering Applications, pp 416-421, [ORS ID: 210202]

[4]. Nassereddine M, Hellany A, Nagrial M, "*Analysis of the impact of the OHEW under full load and fault current*" 2010, International Jurnal of Energy and Environment (IJEE), Volume 1, Issue 4, pp. 727-736. [ORS ID: 216605]

[5]. Andrenyi J. "*Analysis of Transmission Tower Potentials During Ground Faults*" 1967 IEEE Transaction on Power Apparatus and Systems, Vol. Pas-86, No. 10

[6]. Nassereddine M, Hellany A, Nagrial M. Rizk J. " *Safety Compliance of Substation Earthing Design*" 2011 World Academy of Science, engineering and Technology , Vol 60, pp 525-529, [ORS ID: 222495]

[7]. Dawalibi F. "*Effects of Sustained Ground Fault Current on Concrete poles*", 1982 IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101

[8]. Verma, R. "*Ground fault current distribution in substation, tower and ground wire*" IEEE transactions on power apparatus and systems, Vol. PAS-98, 1979