XIII International Conference on
ELECTROMAGNETIC DISTURBANCES
24-26 September 2003 Bialystok, POLAND
EMD 2003

DISTRIBUTION OF STEP AND TOUCH VOLTAGES AT THE TYPICAL HV/MV SUBSTATION DURING LIGHTNING

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Abstract: The main objective of this paper is to develop a reliable approximation method for the distribution of the surface potential, step and touch voltage that occurs when a lightning current is injected into the earthing system of the electric power substation. The final design is to limit touch and step voltage to safe levels for personnel within the substation area during lightning strikes. Calculations have been provided by the HIFREQ and FFTSES computer software.

1. INTRODUCTION

Good substation earthing is essential for the safe and reliable power system. The main objective of this paper is to develop a reliable approximation method for the distribution of the surface potential that occurs when a lightning current is injected into the earthing system of the electric power substation.

The proper design of an AC substation earthing grid involves ensuring that the substation environment and immediate perimeter is free from the possibility of fatal electric shock and that it provides a low impedance path for fault, earth and lightning leakage currents.

The two primary functions of a safe earthing system are: to ensure that a person who is in the vicinity of earthed facilities during a fault is not exposed to the possibility of a fatal electric shock. And to provide a low impedance path to earth for currents occurring under normal and fault conditions.

The commercial computer program package CDEGS has been found to be one of the best currently available to compute scalar potential distribution. HIFREQ and FFTSES are being tested with experimental results and also Earthing Standards and literatures formulas available [1].

2. EARTHING STANDARDS

There are a variety of national and international standards available, which provide empirical formulae for the calculation of earthing design parameters and shock potential safety limits.

- BS 7354 - 1990: Code of practice for Design of high-voltage open-terminal stations [2].
- IEEE Std 80-2002: IEEE Guide for Safety in AC Substation Grounding [3].
- Electricity Association Technical Specification 41-24: Guidelines for the Design, Installation, Testing and Maintenance of Main Earthing Systems in Substations [4].
- PN-E-05115:2002 [5].

Table 1. Safety table according to IEEE Std 80-2002 [3].

Surface Layer Resist-ivity	Fault Clearing Time					
	.100 sec.		.200 sec.		.300 sec.	
	Step Voltage	Touch Voltage	Step Voltage	Touch Voltage	Step Voltage	Touch Voltage
[Ω·m]	[V]	[V]	[V]	[V]	[V]	[V]
None	985,0	469,5	763,0	363,7	645,9	307,9
500	1162,0	513,8	900,1	398,0	762,0	336,9
1000	1802,3	673,9	1396,1	522,0	1181,9	441,9
1500	2422,8	829,0	1876,7	642,1	1588,8	543,6
2000	3036,8	982,5	2352,4	761,1	1991,5	644,3
2500	3647,9	1135,3	2825,8	879,4	2392,2	744,5
3000	4257,5	1287,7	3298,0	997,5	2792,0	844,4
3500	4866,2	1439,8	3769,5	1115,3	3191,2	944,2
4000	5474,3	1591,9	4240,6	1233,1	3590,0	1043,9
4500	6082,0	1743,8	4711,3	1350,8	3988,5	1143,5

Table 2. Safety table according to PN-E-05115:2002 [5].

Fault Clearing Time	Touch Voltage
[s]	[V]
0,04	800
0,08	700
0,14	600
0,2	500
0,29	400
0,39	300
0,49	250
0,64	220
0,72	150
1,1	125
10	80

3. ASSUMPTIONS AND DEFINITIONS

The substation earth grid is used as an electrical connection to earth at zero potential reference. This connection, however, is not ideal due to the resistivity of the soil within which the earth grid is buried. During typical earth fault conditions, the flow of current via the grid to earth will therefore result in the grid rising in potential relative to remote earth to which other system neutrals are also connected. This produces potential gradients within and around the substation ground area as depicted in Figure 1. This is defined as ground potential rise or GPR.

The GPR of a substation under earth fault conditions must be limited so that step and touch potential limits are not exceeded, and is controlled by keeping the earthing grid resistance as low as possible.

In order to ensure the safety of people at a substation, it is necessary to ensure that step and touch potentials in and around the yard during earth-fault conditions are kept below set limits. These maximum permitted touch and step potentials are addressed within various national and international standards. An illustration of touch, step, mesh and transferred potentials is provided in Figure 1.

The touch potential is defined as the potential difference between a person's outstretched hand, touching an earthed structure, and his foot. A person's maximum reach is normally assumed to be 1 meter.

The mesh potential is defined as the potential difference between the centre of an earthing grid mesh and a structure earthed to the buried grid conductors. This is effectively a worst-case touch potential. For a grid consisting of equal size meshes, it is the meshes at the corner of the grid that will have the highest mesh potential.

The step potential is defined as the potential difference between a people's outstretched feet, normally 1 meter apart, without the person touching any earthed structure.

Transferred potential is a special case of a touch potential in which a voltage is transferred into or out of a substation for some distance by means of an earth referenced metallic conductor. This can be a very high touch potential as, during fault conditions, the resulting potential to ground may equal the full GPR.

The maximum permitted values of step and touch potentials vary widely between the different standards. The value of maximum permitted touch potential has a dominant role in determining the design of the earthing grid. As a general rule, if an earthing grid design satisfies the requirements for safe touch potentials, it is very unlikely that the maximum permitted step potential will be exceeded.

The IEEE 80 standard uses the maximum mesh voltage as the touch voltage, and this usually exists at the corner mesh. UK practice defines the touch voltage differently. In practice the voltage at the surface of the ground is a maximum adjacent to a corner of a grid. UK practice is to define touch voltage as the sum of the step voltage plus the voltage difference between the ground surface adjacent to a corner and the grid beneath [3].

Although the mesh voltage is used as the defining touch voltage in American practice, the maximum permitted touch voltage used is less than that used in British Standards. In practice, compliance with American usage thus also ensures the arrangement will comply with UK requirements.

Polish Standard PN-E-05115:2002 specify only touch voltage safe value level. PN-E don't specific safe step voltage value level. In this point Polish Standard is far behind American or British regulations [5].

CENELEC have issues a harmonization document HD 637 S1 containing references to the maximum body impedance and permitted touch voltage [6].

All calculation has been performed according to IEEE 80 Std. Lightning 10/350μs 100kA stroke to the point A – shown at figure 2a.

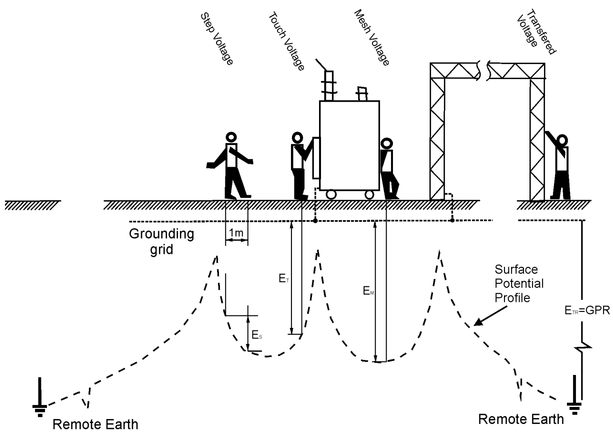

Fig. 1. Surface potential distribution

4. SUBSTATION DESCRIPTION

A typical KSU 110/15 kV substation will be analyzed. The HV/MV substation consists of:

- open terminal air-insulated design,
- single busbar design with the busbar being split into to sections and interconnected via a bus section circuit-breaker,
- two incoming circuits – one feeding each section of busbar,
- two outgoing circuits feeding multi-radial networks for overhead rural systems and ring circuits for urban cable connected networks,
- two distribution substation transformers 110/15 kV 6% 16MVA,
- grounding system consists of a 107m by 62m rectangular grid buried at a depth of 0.8m. The gird is made of 6 equal spaced conductors along the X axis and 10 equally spaced conductors along the Y axis. The perimeter of the grid was placed such that the outermost conductors are located exactly 5m outside the edge of the fence. The fence is regularly connected to the outermost conductors. Ground resistivity was assumed 100 Ω•m (uniform ground model).

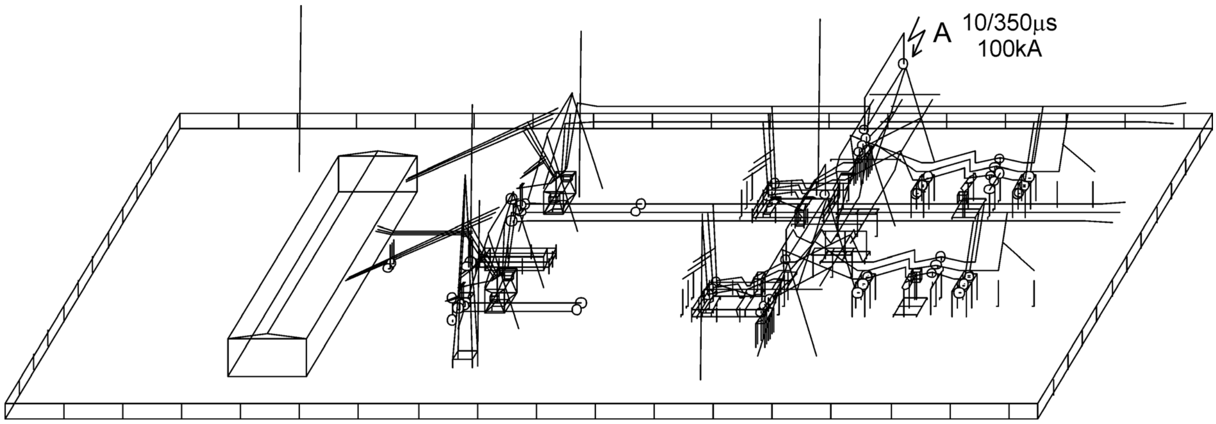

Fig. 2a. Illustration of the Lightning Analysis Problem.3D substation model

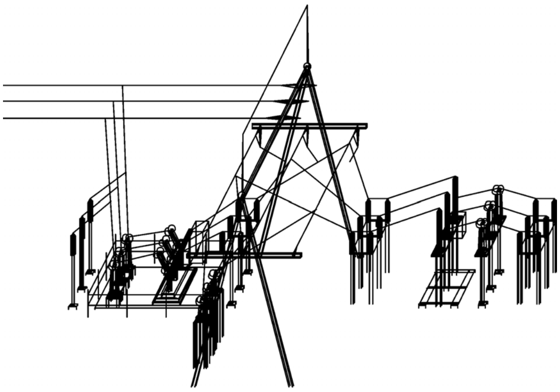

Fig. 2b. Substation feeder

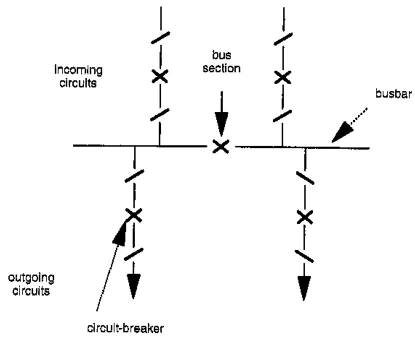

Fig. 2d. Typical distribution primary substation layout: single busbar

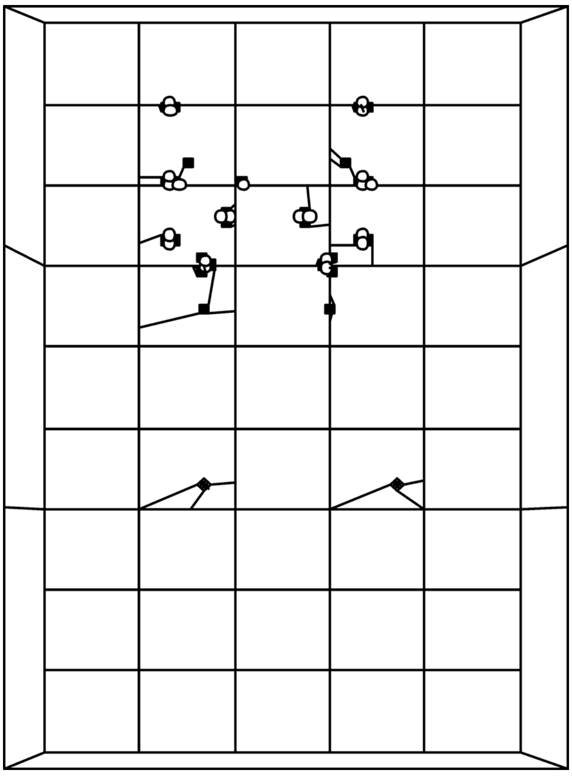

Fig. 2c. Substation grounding grid

4. COMPUTATION RESULTS

The touch and step voltages obtained in calculations indicate that analyzed HV/MV KSU 110/15kV substation design is quite far away from providing a safe ground grid design. The touch and step voltages exceed the safe value at most locations of the substation. The highest values occur in the corner meshes of the grounding grid, which suggests that there is a need to have more conductors towards the edge of the grounding system and less in the central portion. Moreover, practical considerations often introduce additional constraints, which must be accounted for.

4. CONCLUSIONS

The simulations allowed an evaluation of surface potential in a typical HV/MV substation, giving information about the magnitude of crest value of step and touch voltages and the graphical distribution of it during lightning strike. This is relevant information for selecting the grounding system modification design.

The results show a strong dependence of the quantities upon the safe value of step and touch voltages and the grounding system configuration. In general, the obtained values tend to increase with increasing values of lightning current parameters and ground resistivity.

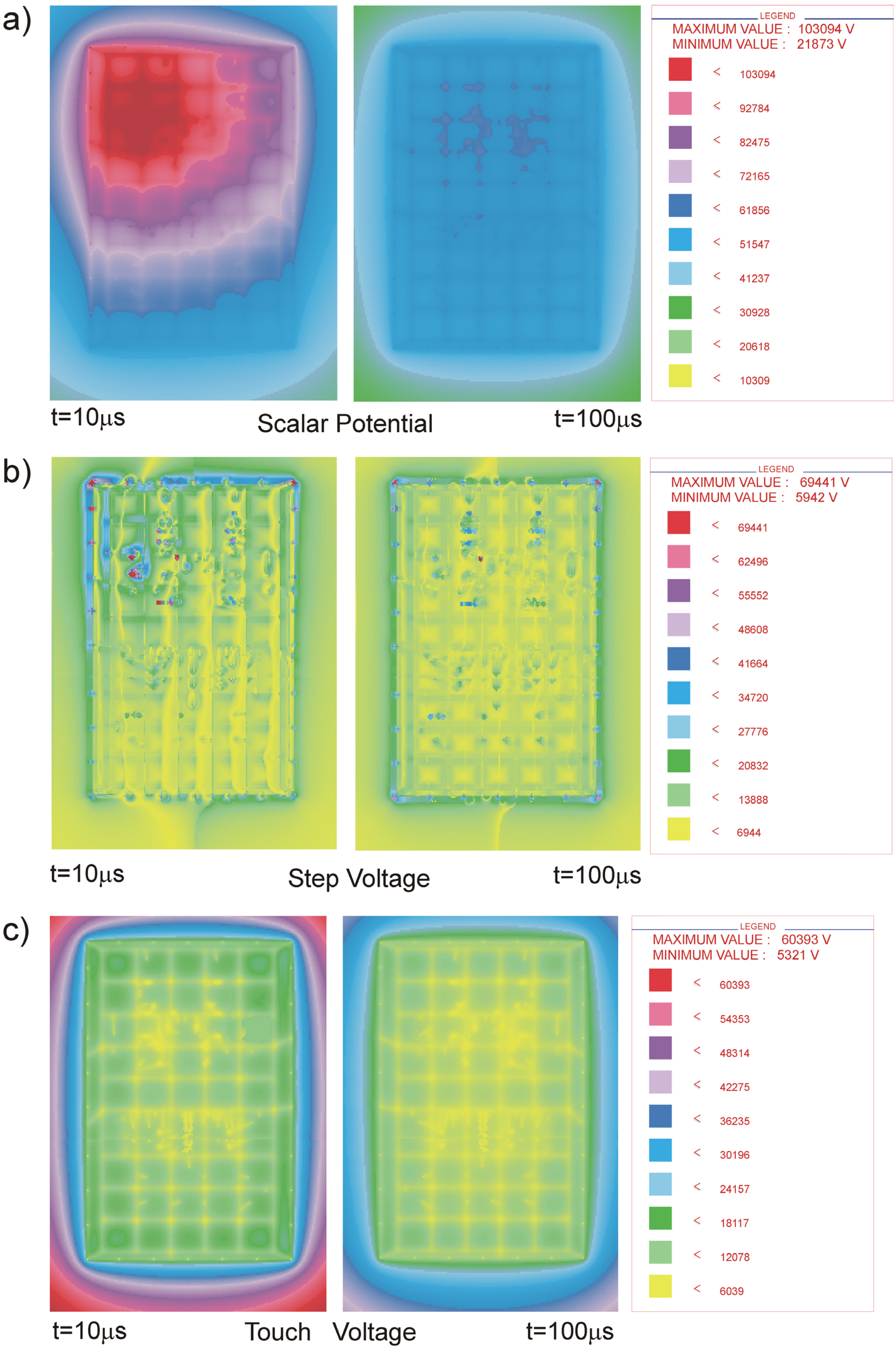

Fig. 3. Distribution of scalar potential (a), step voltage (b), touch voltage (c) at the typical HV/MV substation

Computer analysis of this problem seems to be rights choose and it's economical for energy distributors.

5. REFERENCES

1. „CDEGS User's Manual", Safe Engineering Services & Technologies Ltd., Montreal Canada.
2. PN-E-05115:2002 Instalacje elektroenergetyczne prądu przemiennego o napięciu wyższym niż 1kV. PKN, Warszawa 2002.
3. BS 7354 - 1990: Code of practice for Design of high-voltage open-terminal stations.
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6. PN-E-05115:2002 Instalacje elektroenergetyczne prądu przemiennego o napięciu wyższym niż 1kV. PKN, Warszawa 2002.
7. HD 637 S1. CENELEC harmonization document.

BIOGRAPHICAL NOTES

MSc Jaroslaw Wiater
Graduated in power system at Electric Power System Faculty of Technical University, Bialystok in 2002. Main research area is application of computer technology in damage analysis at electric power substation during direct lightning strikes.