Assessment of the electric shock hazard during lightning at the small electric power system

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Abstract: The main objective of this paper is assessment of the electric shock hazard during the lightning. This hazard depends on many factors such as step and touch voltages. They occur when a lightning current is injected into the earthing system of the electric power substation. Reliable approximation method for the distribution of the surface potential, step and touch voltage will be presented. The final design is to limit touch and step voltage to safe levels for personnel within the substation area during lightning strikes.

Keywords: Electric shock hazard, lightning, power system

1. Introduction

Most important effect of electric current on the body, perhaps the most significant in terms of hazard, regards the nervous system. This network of special cells in the body called "nerve cells" or "neurons" which process and conduct the multitude of signals responsible for regulation of many body functions. The brain, spinal cord, and sensory/motor organs in the body function together to allow it to sense, move, respond, think, and remember.

This problem is especially dangerous if the victim contacts an energized conductor with his or her hands. If the conductor delivering current to the victim faces the palm of his or her hand, this clenching action will force the hand to grasp the wire firmly, thus worsening the situation by securing excellent contact with the wire. The victim will be completely unable to let go of the wire.

Electric current is able to affect more than just skeletal muscles in a shock victim, however. The diaphragm muscle controlling the lungs and the heart - which is a muscle in itself - can also be "frozen" in a state of tetanus by electric current. Even currents too low to induce tetanus are often able to scramble nerve cell signals enough that the heart cannot beat properly, sending the heart into a condition known as fibrillation.

Electric shock hazard at the HV substation area depends on the quality of grounding system. Grounding system directly influence to the touch and step voltage level. These voltages determine electric shock hazard. In this paper these voltages are going to be approximated by computer simulation.

2. Assumptions and definitions

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 lightning. This conditions aren't described in any national or international standrads [2,3,4,5,6]. Touch and step potentials are addressed within various national and international standards only for earth-faulth conditions.

An illustration of touch, step, mesh and transferred potentials is provided in Figure 2. 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.

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]. All calculation has been performed according to IEEE 80 Std.

In calculations the lightning 100kA 10/350µs stroke to the point A – shown at figure 1.

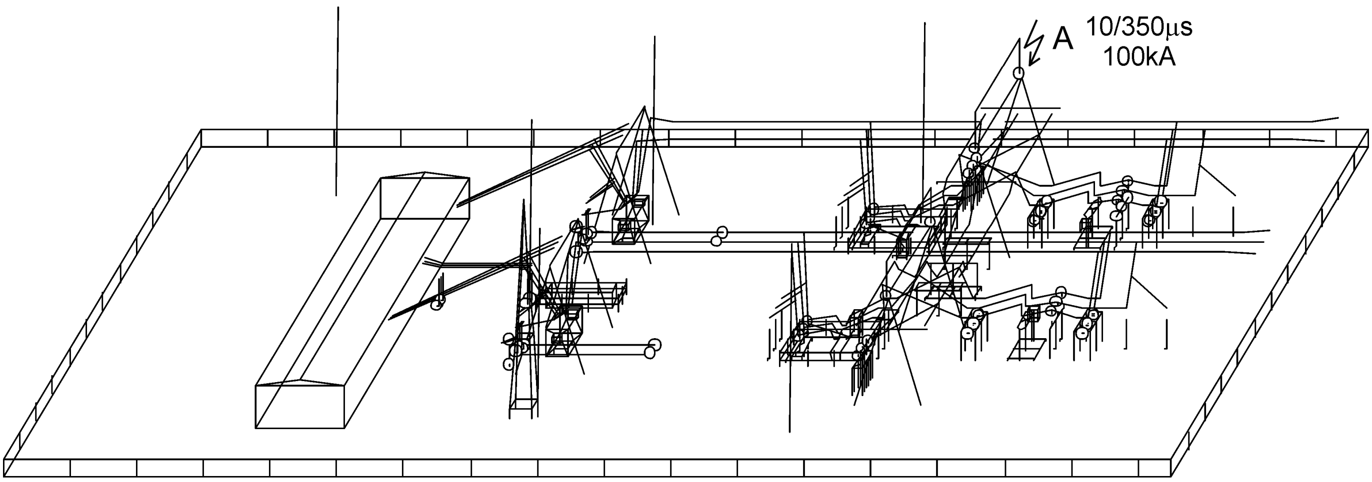

Figure 1: Illustration of the Lightning Analysis 3D substation model

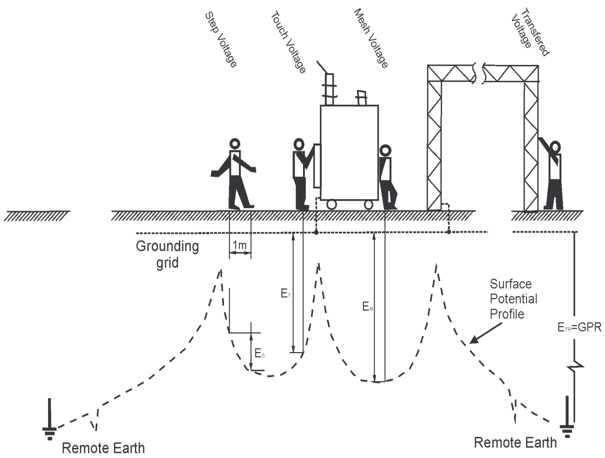

Figure 2: Surface potential distribution

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 (fig.3),
- two incoming circuits – one feeding each section of busbar (fig.5),
- 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.4.

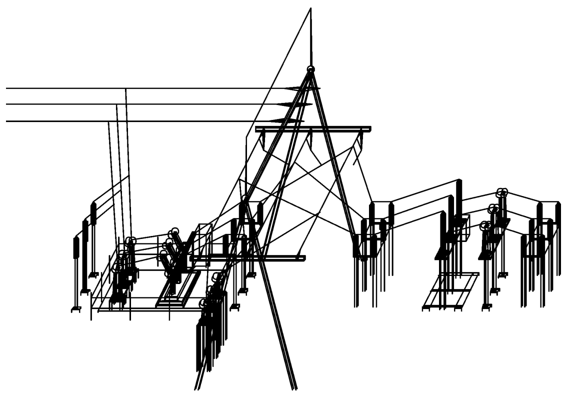

Figure 3: Substation feeder – closer 3D view

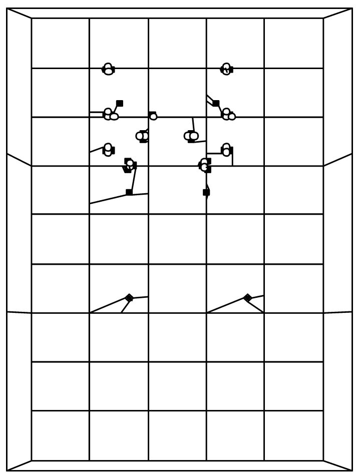

Figure 4: Substation grounding grid

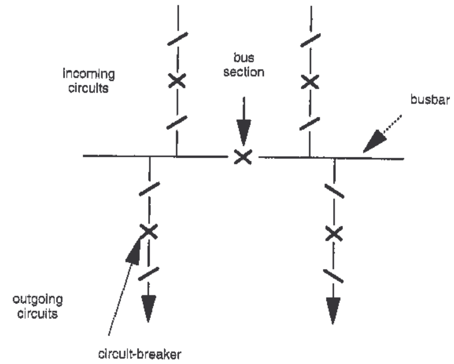

Figure 5: Typical distribution primary substation layout: single busbar

3. Computation results

Mathematical model was employed for the prediction of step voltage levels during lightning strike to the substation area. For each metallic conductor which substation consists of, one unknown occurs in the equations used for current distribution computation during lighting excitation. Analyzed substation consists of 1453 conductor. This means 1453 unknowns. Lightning surge was spread out by Fast Fourier Transform into 32 frequencies. All computation of the step voltage distribution was performed by the CDEGS Hifreq software [1]. The numerical model includes an earthing network as well as simplified models of aboveground elements such as pylon structure, bonding network and metallic fence around the station.

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. Computation results are presented on figure 7.

4. Assesment of the electric shock hazard

Electric shock hazard as the result of lightning strike depends on many parameters:

- lightning current parameters (maximum magnitude, time duration),
- ground resitivity (season),
- distribution of step and touch voltage (grounding gird).

Fatal lightning shock hazard factor *kr* was based on the step voltage area. The numerical model includes an earthing network as well as simplified models of aboveground elements such as pylon structure, bonding network and metallic fence around the station. During computer simulation of the distribution of the step voltage was produced TGA graphic file with computation results. Full range of step voltage was spited to 10 voltage levels.

Algorithm enables easy calculation of selected step voltage level area is presented on figure 6.

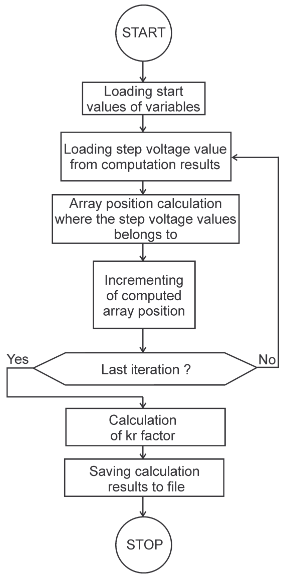

Figure 6: Algorithm for kr factor calculation on the TGA file format ground

For this especially task was developed special computer program based on the TGA graphic format. It can be implemented to any graphic format.

Electric shock kr factor:

$$k_r = \frac{\sum_{i=1}^{n} \frac{i}{n} \cdot Pi \cdot U_n}{\left(\sum_{i=1}^{n} P_i\right) \cdot U_n} = \frac{\sum_{i=1}^{n} \frac{i}{n} \cdot Pi}{\sum_{i=1}^{n} P_i} \qquad (1)$$

where:

n	- quantity range of the step voltage area
Pi	- step voltage area
Un	- max value of step voltage on the analyzed area
kr	- lightning hazard factor

Cheap and easy to do grounding system modification can decrease lightning hazard shock five times. It isn’t necessary to do any major grounding system changes. It can be adapt to any existing grounding system. Presented modification example base on typical HV substation and can be easily bring to live.

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.

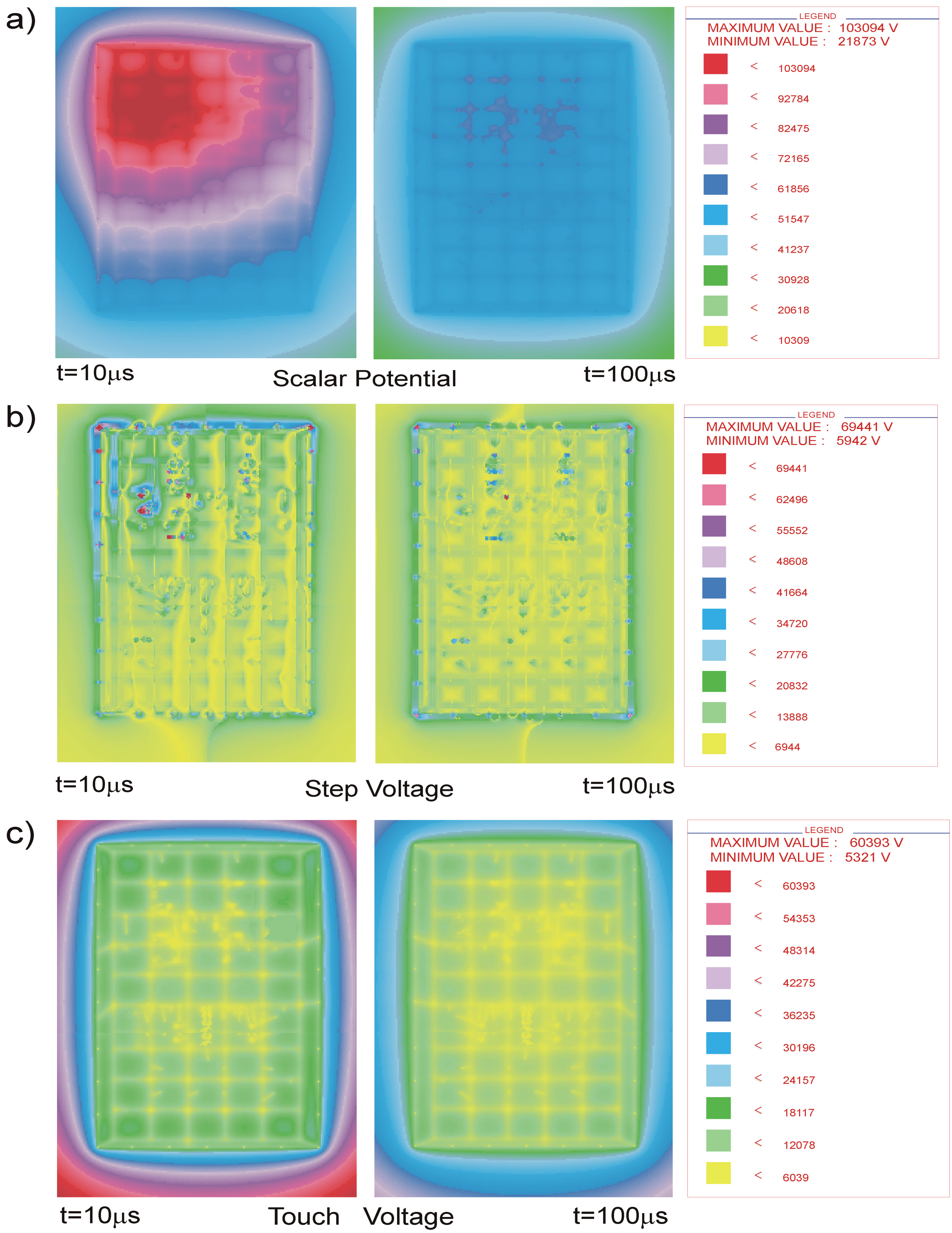

Figure 7: Distribution of scalar potential (a), step voltage (b), touch voltage (c) at the typical HV/MV substation

According to a number of publications [2,4,7] that has investigated problem electric shock hazard it generally depends on dangerous voltage time duration. Every voltage beyond 100V makes danger to human body. Of course if time duration is short, value of safe voltage level rises. In our case, safe voltage value is 13,4 kV for time duration 100μs – fig. 8. The most dangerous place in the substation area is edge of it, near the fence. Substation grounds seem to be safe according to computer simulation.

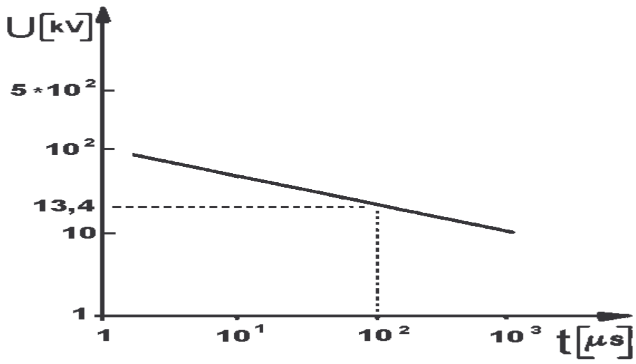

Figure 8: Admissible electric shock voltage U as a function of acting time t

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

Electric current is capable of producing deep and severe burns in the body due to power dissipation across the body's electrical resistance. Practice and training increase recreation performance. Similarly, preparedness can reduce the risk of the lightning hazard. Education is the single most important means to achieve lightning safety. A lightning safety program should be implemented at every facility.

6. Acknowledgment

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7. References

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