Decreasing lightning shock hazard at the HV substation by the modification of the grounding system

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***Abstract* — One of the tasks of the grounding system is to ensure safety for people during various fault conditions. Fatal lightning shock hazard depend on surface potential that occurs when a lightning current is injected into the grounding system or induced in it. The main objective of this paper is to improve grounding system of the typical HV substation. Quality of this modification will be measured by the drop of the step voltage distribution and by the cost of it.**

Keywords – grounding; shock hazard; surface potential; step voltage; modification

I. INTRODUCTION

A lightning strike to any grounded structure or a high-voltage flashover from a power line to a grounded structure will cause the surface potential differences on the ground in the vicinity. In some cases these potential differences rise to dangerously high levels, which can electrocute persons standing on the ground in this area and damage or destroy electronic equipment connected to ground.

There are two objectives of a safe grounding system. The first is to provide, under normal and fault conditions, the path of least impedance from the ground system components to earth ground. The second, all components are connected together with the least impedance between them This will minimize the potential differences when surge currents occur and persons in the vicinity of grounded facilities are not exposed to the danger of critical electric shock under normal and fault conditions.

Still not much information, concerning the actual values of step and touch voltages, that persons can be exposed during lightning strokes to HV, substation is provided,

Step voltage, which will be analyzed, is a difference in surface potential experienced by a person bridging the distance of 1 m with the feet without contacting any grounded object. Standard [1] gives some information about the protection of persons who work within substations and who may approach a substation. Though we can partially reduce the hazard to workers within a substation by the requiring them to wear personal protective equipment like insulated footwear. The hazard to the public, someone outside the fence, can only be reduced by proper design of the grounding system. This problem will be analyzed taking into account the hazard cause by lightning stoke.

II. HV SUBSTATION

A typical HV/MV substation (according the real plan), which was analyzed, 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 (Fig.1.).

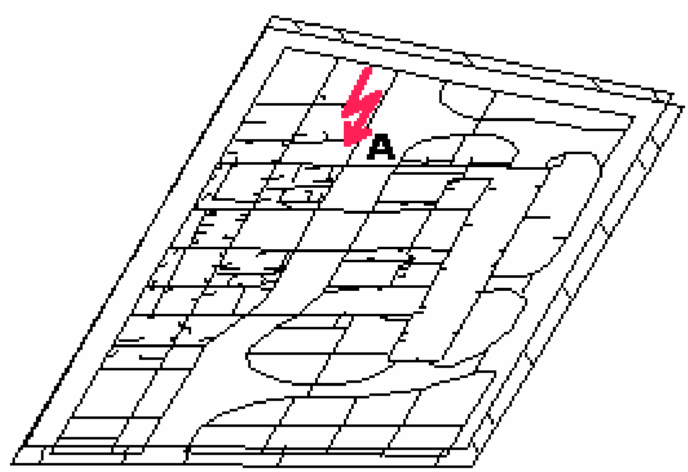

Figure 1. HV substation grounding gird – 3D view.

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The gird is made of 4 not equal spaced conductors along the X axis and 11 equally spaced conductors along the Y axis.

All steel conductors with cross section 80 mm^2 were buried at 0,8 m depth in homogeneous soil (uniform ground model) with resistivity $\rho = 100\ \Omega\cdot$m and relative permittivity $\varepsilon_r = 1$.

The perimeter of the grid was placed such that the outermost conductors are located exactly 5m outside the edge of the fence.

III. EXCITATION SOURCE

In the analysis, the lightning currents: 100 kA -10/350µs, 25 kA - 0.25/100, 10kA - 8/20µs (adequately peak value – shape) were used for simulation the first and subsequent lightning strokes.

These lightning currents were defined by typical equation:

$$i = \frac{I}{\eta} \cdot \frac{(t/\tau_1)^{10}}{1 + (t/\tau_1)^{10}} \cdot e^{-\frac{t}{\tau_2}} \qquad (1)$$

where:

I – peak current, η – correction factor for the peak current

t – time, τ_1 and τ_2 respectively front and tail time constants.

In the case of theoretical model, the lightning current represents ideal current source which was connected to the differnt points in HV substation.

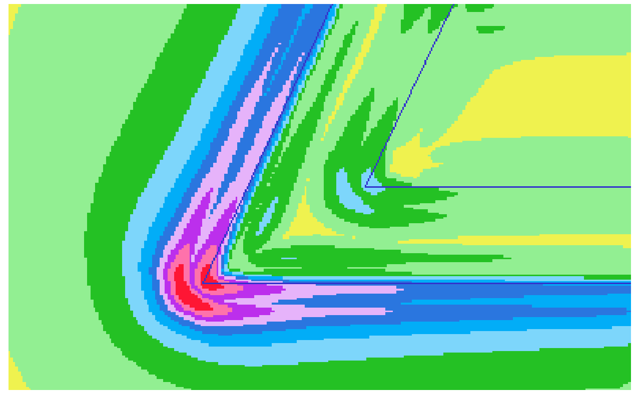
IV. STEP VOLTAGE DISTRIBUTION

Mathematical model was employed for the prediction of step voltage levels during lightning strike to the substation's area. For each metallic conductor which substation consists of, one unknown occurs in the equations used for current distribution computation during lighting excitation. In this paper the results are presented only for the lightning current 100 kA 10/350µs, which as spread out by Fast Fourier Transform into 32 frequencies. This current excites the point appointed by letter A (Fig.1.).

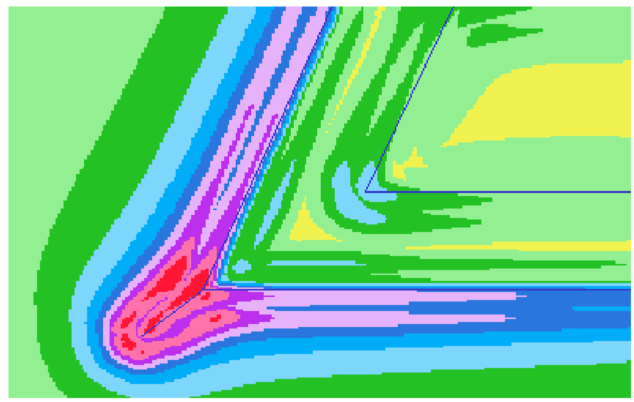
Analyzed substation was divided on 1453 segments. The lengths of the segments are chosen so that the current can be assumed to vary linearly along with them for all the analyzed frequencies. Thus, the segments can be represented as electric dipoles and all the electromagnetic quantities at any observation point can be expressed as a sum of contributions from all the dipoles. 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 step voltage distribution TGA graphic file with computation results was produced. Full range of step voltage was spited to 10 voltage levels. The corners in substations were one of the most dangerous places. At the corners scalar potential drops rapidly and forces large value of step voltages distributions.

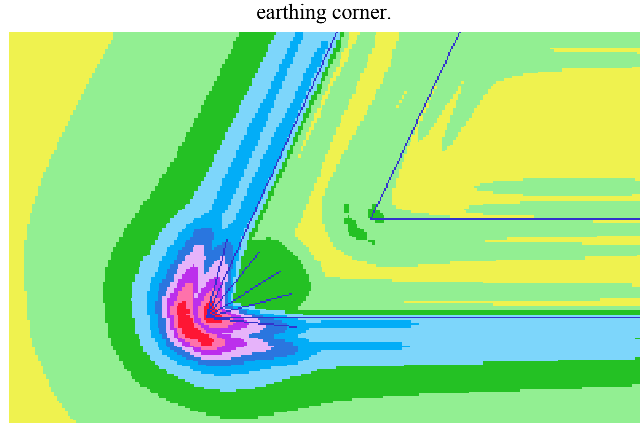
During research 37 different shapes of corner for surge current 100 kA, 10/350 was considered. Some results for different modifications are presented on the Fig. 2, 3 and 4.



Original configuration of the substation earthing corner.



Configuration no. 4 - 3m long ground connexion added outside the substation earthing corner.



Configuration no. 18 - 3m long triple ground connexion added inside the substation-earthing corner.

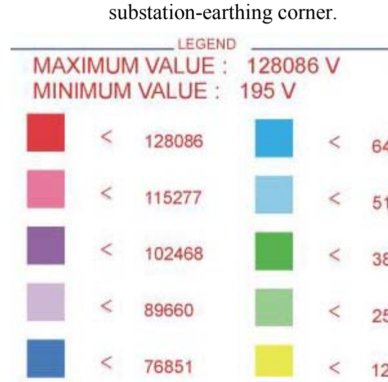
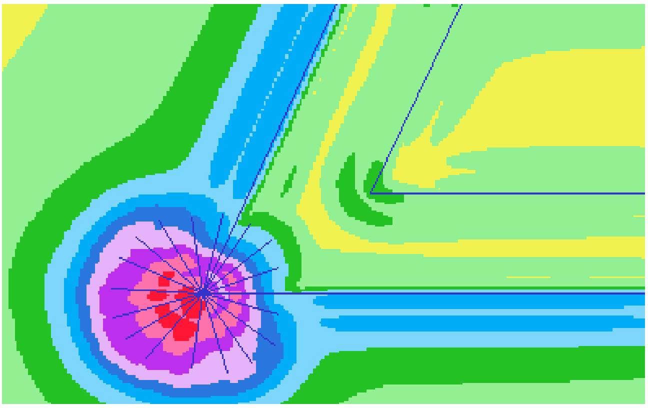
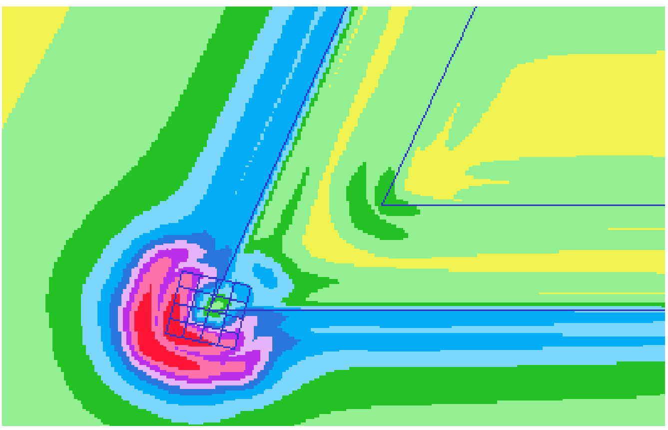


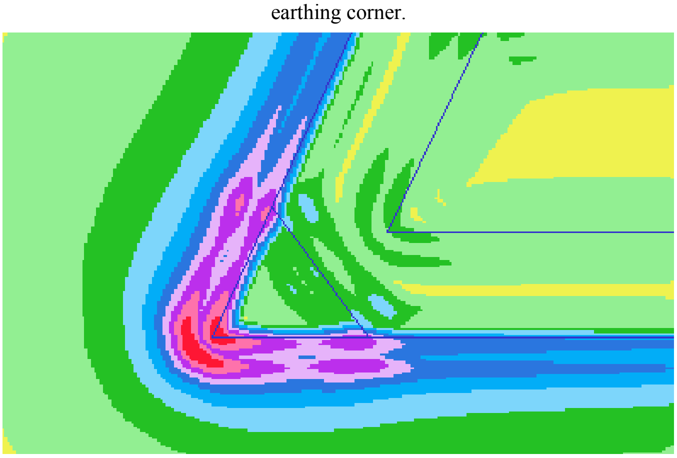
Figure 2. Step voltage distribution at the substation's corner



Configuration no. 22 – equipotential star added to the substation earthing corner.



configuration no. 23 – equipotential steel truss added to the substation earthing corner.



Configuration no. 24 – isosceles triangle (a=4m) ground connexion added to the substation earthing corner..

Figure 3. Step voltage distribution at the substation's corner.

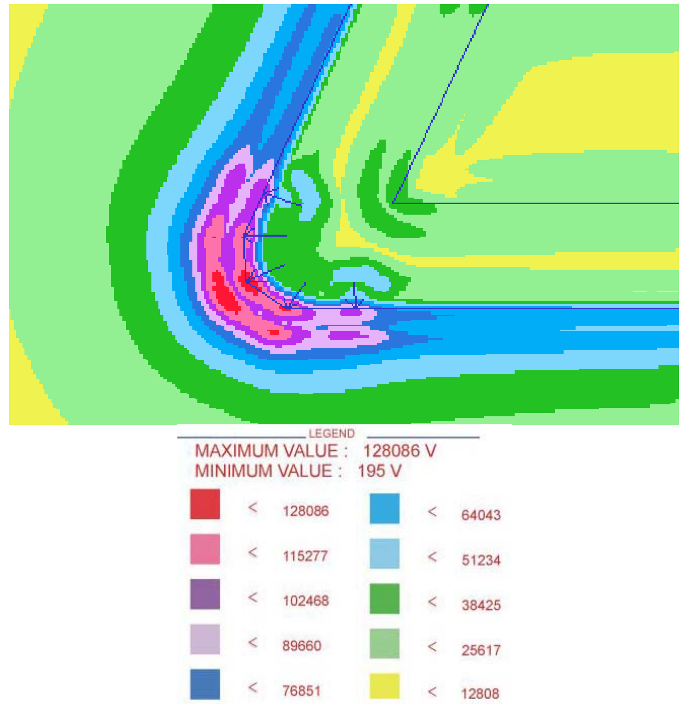


Figure 4. Step voltage distribution – analyzed configuration no. 37 for 10/350µs 100 kA lightning surge – subangular ground connexion added to the substation earthing corner.

V. Lightning Shock Hazard

The primary variable for determining the severity of electric shock is the electric current which passes through the body. This current is of course dependent upon the voltage and the resistance of the path it follows through the body. Human body resistance is well known. However, the effect of electric shock on the body depends not only on the strength of the current, but on such factors as wetness of the skin, area of contact, duration of contact, constitution of the victim, and whether or not the victim is well grounded. Step voltage during the lightning strike is computed above.

Fatal lightning shock hazard factor kr was based on the step voltage area. Paper presents algorithm, which enables easy calculation of selected step voltage level area.

For this, especially task was developed special computer program based on the TGA graphic format (Fig. 5.). It can be implemented to any graphic format. Quality of modification describes lightning hazard factor k_r:

$$k_r = \frac{\sum_{i=1}^{n} \frac{i}{n} \cdot P_i \cdot U_n}{\left(\sum_{i=1}^{n} P_i\right) \cdot U_n} = \frac{\sum_{i=1}^{n} \frac{i}{n} \cdot Pi}{\sum_{i=1}^{n} P_i} \qquad (2)$$

where:

n - quantity range of the step voltage area

P_i - step voltage area

U_n - max value of step voltage on the analyzed area

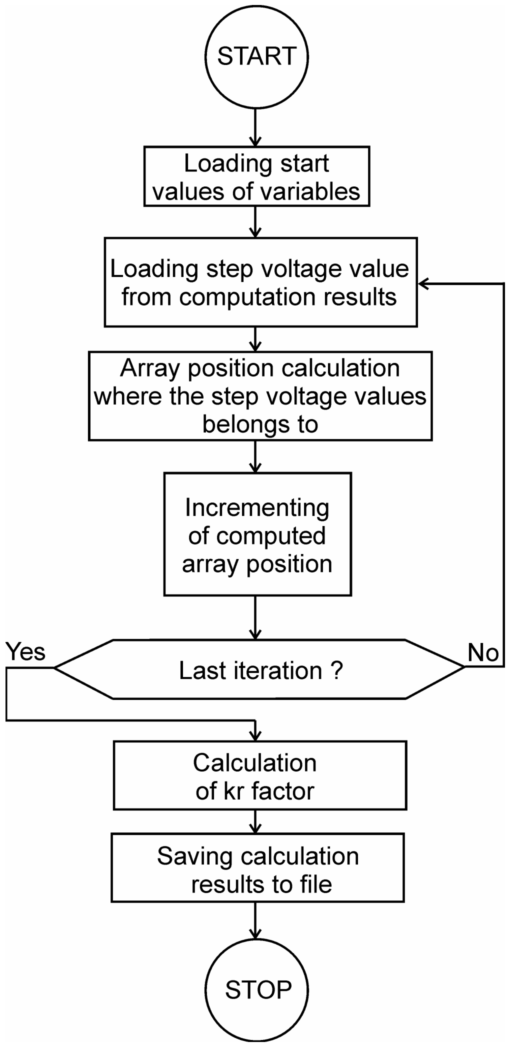


Figure 5. Algorithm for kr factor calculation on the TGA file format ground .

Second lighting shock hazard factor is k_{pmax}. It base on maximal value of step voltage. It is described by proportion of the area with maximal value of step voltage and the area with minimal value of step voltage.

It must be made one assumption in this moment that the area is splitted to 3 proportional sections. First section consists of area with maximal values of step voltage. Second one - with medium values of step voltage. Third one consists of area with lowest values of step voltage.

$$k_{p\max} = \frac{P_{MAX}}{P_{MIN}} \tag{3}$$

where:

P_{MAX} - proportional area with maximal values of step voltage (P_{MAX}>0),

P_{MIN} - proportional area with minimal values of step voltage (P_{MIN}>0)

In Table 1 the values of lightning shock hazard factors k_r and k_{pmax} are presented for these shapes of corners, which were analyzed (Fig.2 – 4).

TABLE I. LIGHTNING SHOCK HAZARD FACTORS

Configuration No.	k_{pmax}	k_r
18	0,03323505	0,248833
23	0,06598193	0,292659
37	0,07417387	0,295037
ORG	0,08908292	0,315801
22	0,11759733	0,316389
24	0,10651787	0,32038
4	0,19220737	0,357464

VI. CONCLUSIONS

The results show a strong dependence of the quantities upon the safe value of step 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.

By the right choose of the grounding gird shape it is possible to minimize lighting shock hazard. Cheap and easy to do grounding system modification can decrease lightning hazard shock up to 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.

ACKNOWLEDGMENT

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