Lightning Transients in Control Circuit Wiring in HV Substations

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Abstract: This paper presents the mathematical model of a direct lightning stroke into an open air high-voltage HV substation. Lightning current flowing through the conductive-earthed structures over the ground and in grounding grids induced transients in control, measurement and secondary circuits. Some calculation results of these transients in low-voltage cables are presented.

Keywords: Lightning protection, lightning overvoltages, control systems, HV substation

1. Introduction

In HV substation the damages or malfunctions of the electric and electronic equipment were very often caused by switching operations in primary circuits, earthing faults and lightning strokes. In this paper a direct lightning stroke into an open air high-voltage HV substation is considered. In this case lightning current flows through the conductive-earthed structures over the ground and in earthing grids and induced voltage and currents in low-voltage cables.

The problem with lightning transients has been particularly observed in HV substation with electronic devices in measuring and controlling systems. This concerns specially the digital devices in high voltage measuring and controlling techniques. The older electro-mechanical elements were very well insulated and required sustained signals to operate. This is the contrast to microprocessors base equipments that are more sensitive to overvoltages and overcurrents in control cables.

2. HV small electric power system

The energetic system being modeled consists with 3 HV substation S1, S2 and S3 and overhead transmission HV lines between them (Fig.1). On each substation there were the same arrangements of HV equipment and control cables. In substation 110/15/0,4 kV electronic devices can be applied for Automatic Voltage Control, Load Shedding and common alarm, integration, configuration and display of over 100 protection relays.

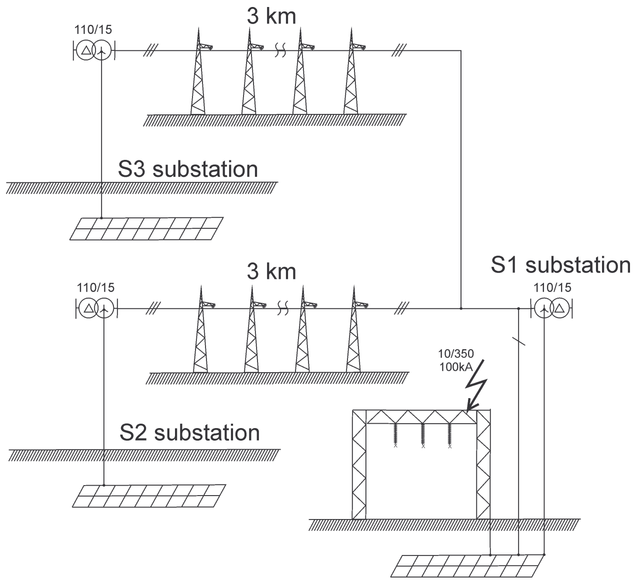

Figure1: Typical distribution substations layout

These protection relays include auxiliary add-on functions, such as auto-redosing, sequential event recording, disturbance oscillographic recording, fault location, power quality measurement and programmable logic equations. Further add-on functions include breaker supervision, magnitudes (I, V, W, Var, Wh, Varh, etc.), local and remote communication (IEC 870-5, DNP v3.0 compatible) and fiber-optics, RS-232 and RS-485 interface ports. Probability of electronic device damage is directly proportional to number of it.

The arrangements of control cables and same part of substation S1 model are presented in Fig.2. The earthing system is considered to be an arbitrary network of connected buried conductors. The rectangular grid 107m x 62m is made of 6 equal space conductors along the X axis and 10 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 $\rho = 100\ \Omega m$ and relative permittivity $\varepsilon_r = 1$.

Fig.2b illustrates the earthing system adopted for analysis.

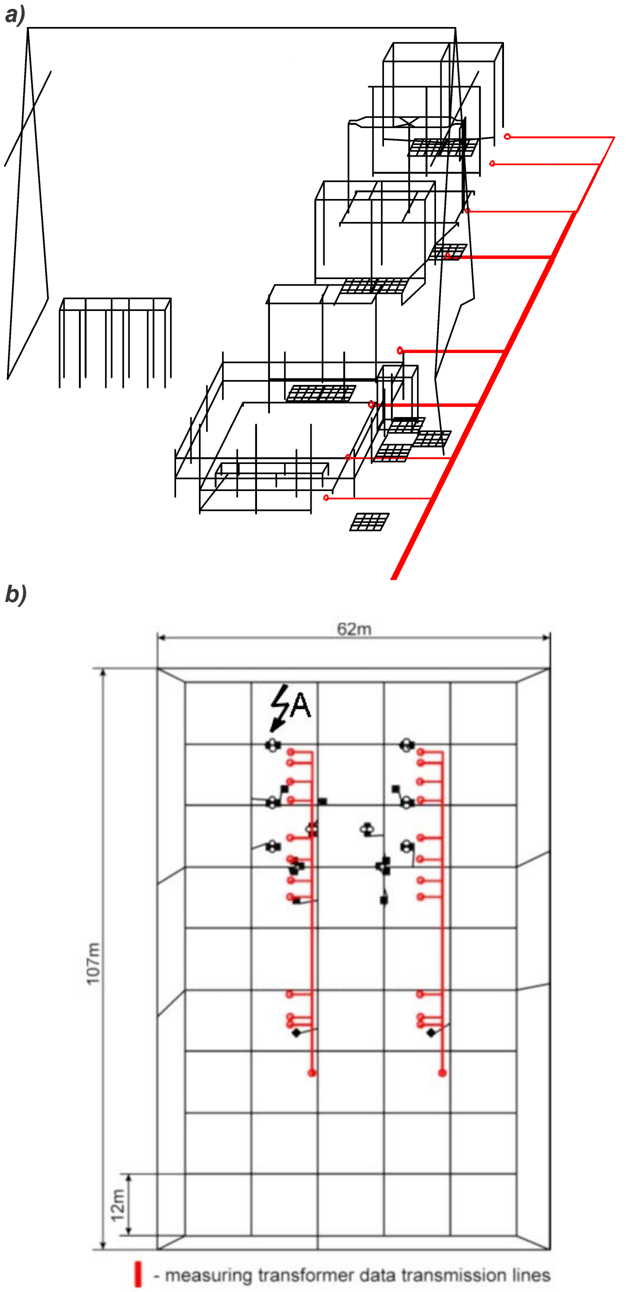

Figure 2: The part of substation model (a) and substation earthing grid with control circuit wiring and a point A of lightning stroke (b)

3. Theoretical background for computer simulation

The computation of electromagnetic fields due to energized conductors is a two-step process. At the beginning the current distribution in the conductors must be obtained and then the electromagnetic fields caused by these circulating currents was computed using Maxwell's equations. Both of these steps rest on the ability to compute the electromagnetic fields caused by a given current distribution. The field of the current source is expressed as a sum of contributions from electric dipoles.

Generally, Maxwell's equations with source terms in a uniform medium can be written as:

$$\begin{aligned} \nabla \cdot \vec{D} &= \rho \\ \nabla \cdot \vec{B} &= 0 \\ \nabla \times \vec{E} &= \dot{\vec{B}} \\ \nabla \times \vec{H} &= \dot{\vec{D}} + \vec{J}_{total} \end{aligned} \qquad [1]$$

The total current density consist a conduction term and an external source:

$$\vec{J}_{total} = \sigma \vec{E} + \vec{J}_{ext} \qquad [2]$$

where σ is the conductivity of the medium.
Assuming a harmonic time-dependence of the form exp(jωt) and the constitutive relations

$$\begin{aligned} \vec{D} &= \varepsilon \vec{E} \\ \vec{B} &= \mu \vec{H} \end{aligned} \qquad [3]$$

where ε is the permittivity of the medium and μ its permeability these equations reduce to:

$$\begin{aligned} \varepsilon \nabla \cdot \vec{E} &= \rho \\ \nabla \cdot \vec{H} &= 0 \\ \nabla \times \vec{E} &= j\omega\mu \vec{H} \\ \nabla \times \vec{H} &= \theta \vec{E} + \vec{J}_{ext} \end{aligned} \qquad [4]$$

where $\theta = \sigma + j\omega\varepsilon$ is the complex conductivity of the medium.
With a horizontally layered medium, Eqs. [3] are obeyed in each layer. The continuity of the tangential components of the electric and magnetic fields is used as a boundary condition to connect the results in the different layers [2].
A direct lightning stroke is simulated by an ideal current source injected the surge current in different points of station's area. This current has the following mathematical expression:

$$i(t) = \frac{I}{\eta}\left(e^{-\alpha t} - e^{-\beta t}\right)$$

where:

t - time, I - peak current, η - correcting factor
α and β - reciprocals of time constants

The parameters of the lightning current, for the first lightning stroke, were taken according to the IEC 61312-1 [7] for the III-IV protection level. The parameters used in equation for obtaining the lightning current 100 kA, shape 10/350 μs are: I=100kA, η=0,9761 , α= 2049,38 s^{-1}, β=563 768,3 s^{-1}.

4. Numerical modelling

The analyses of arrangements (fig.2) have been performed by the MultiFields [8, 9] software package, which is a part of CDEGS package. The computation methodology

assumes the frequency domain analysis, in which each conductor in the network is partitioned in small segments. The segments should be short enough so, that the current is assumed to vary linearly along with the segment for all analysed frequencies, but they should be also large enough to meet the thin wire approximation. Each such segment is represented by an electric dipole located at its centre and the electromagnetic quantities at an observation point are obtained by the sum of the contributions from all of the dipoles.
The field of a single dipole is expressed as the sum of the source term, the image term and the Sommerfeld integral. The Sommerfeld integrals have been computed by the Double-Integration method i.e. numerically, without any approximation [9].

5. Computation results

In control building, the lightning transients at the equipment interfaces have been computed for the shielded cables with following parametres:

- lengths 62 m,
- distances between cables10 mm,
- cables run above and under the ground (on height 50 mm or 200 mm depth).

The configuration of signal cables, which was the same for all substations, is presented in Fig.3.

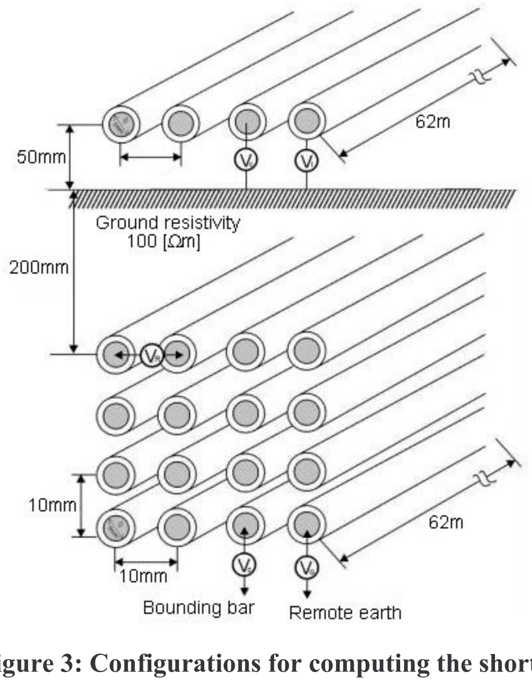

Figure 3: Configurations for computing the short circuit currents and open circuit voltages

In investigations the surge current was injected to the different points of earthed structures in HV substation 1. This current is divided into:

- earthing system of substation S1,
- grounding wires (also named shielded wires) of HV lines,
- the earthing systems in station S2 and S3.

For determining the open circuit voltages and short circuit currents in signal cabling two simple circuit configurations have been assumed:

- isolated cables,
- two cables shorted at the ends.

Below, results of calculations are presented in case of lightning stroke in point A (Fig.2b). Some examples of short circuit current in signal cables over the ground in substation S1, S2 ans S3 show fig. 4 and 5.
For strokes into the other points of substation S1 in all arrangements of cables over the ground, which were calculated, the short currents did not exceed 10 A in substation S1 and 0,07A in substations S2 and S3.

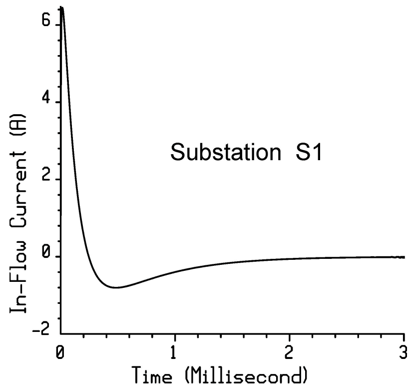

Figure 4: Short circuit current in control cables over the ground in substation S1.

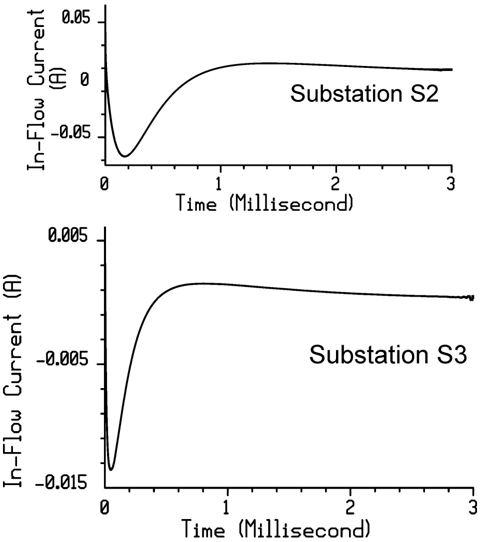

Figure 5: Short circuit currents in control cables over the ground in substations S2 and S3

Similar calculations were realized for cables under the ground. Results of calculations show, that the induced currents in arrangements of shorted cabled reached larger peak values compare to cable over the ground (Fig. 6).

In substation S1, for all arrangements of cables which were calculated, the maximum values of short currents did not exceed 12 A nad 0,08 A in substations S2 and S3.

For isolated cables over the ground the transient voltages which appeared in control building between the wires and local bounding bar (V_C) or true earth (V_G) were calculated.

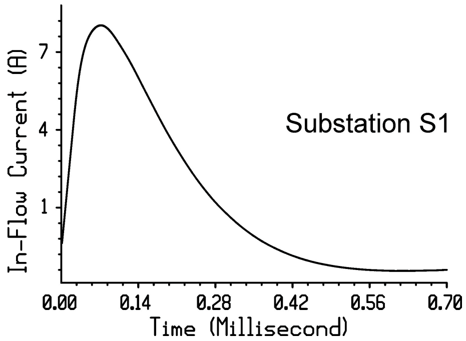

Figure 6: Short circuit currents in control cables under the ground in substations S1

In analysed arrangements the impulse voltages V_G were much greater than V_C. Some examples of transient voltages V_G in substation S1, S2 and S3 are presented in fig. 7.

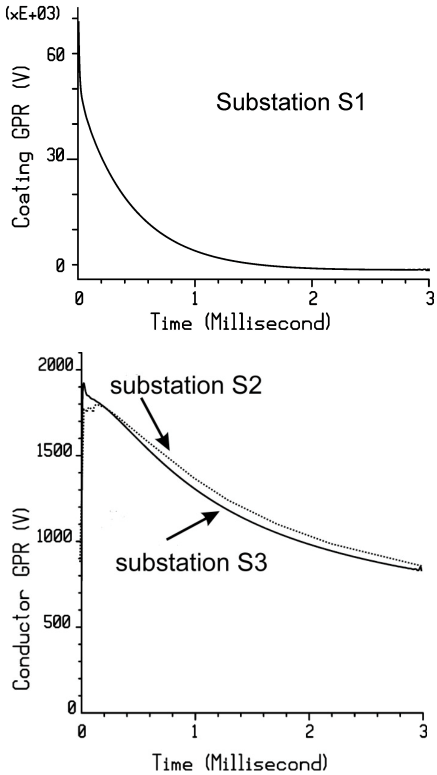

Figure 7: Impulse voltages between the wires of cables and true earth (Substation S1,S2 and S3)

In worst cases the voltage V_G reached the values 50-70 kV in substation S1 and 1,8 - 2,2 kV in substations S2 and S3.

Additionally, the voltages V_C and V_G were determined for control cables under the ground. Some representations of induced voltages are given in fig. 8.

6. Conclusion

In article a method for computer analysis of lightning transients in control cables in HV substations is presented. The information about these impulses is very important when electronic digital devices are used in these substations.

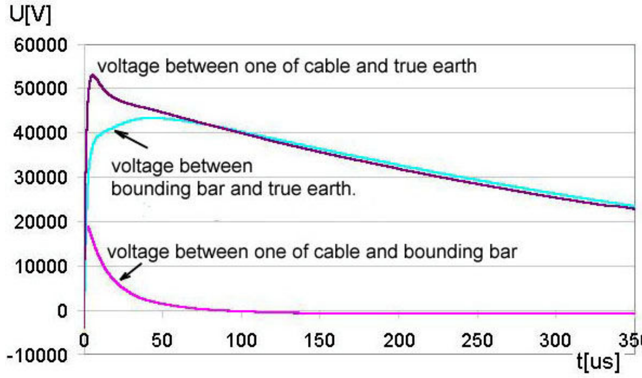

Figure 8: Impulse voltages between the wires of cables under the ground in substation S1

The advantages of the proposal calculation of lightning transients in control cables are:

- all possible configurations of conductive elements on the HV substation and different points of lightning stoke to the substation's area can be represented in theoretical model,
- impulse voltages and currents in conductors over and under the grounds can be analyzed.

The study shown that, the magnitudes of surges can reach the values, which are dangerous for equipments.

7. Acknowledgment

The work was partialy supported by the Białystok Technical University, Rector 's Project No W/WE/3 /03.

8. References

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