LEMP EFFECTS ON CONTROL CABLES IN HIGH-VOLTAGE SUBSTATIONS

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Abstract: This paper presents the numerical simulations of a direct lightning stroke into an open air HV (high-voltage) substation. Lightning current flowing through the conductive earthed structures over the ground and in grounding grids induced transients in low-voltage control cables. In calculation the different striking points, soil parameters and arrangements of cables have been taken into account.

Key words: Lightning stroke, lightning transients in wires, HV substations, LEMP.

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.

Some investigations have been made in the area, which concern the interferences caused by high voltage switchyard operations. However, little is known about the nature of lightning transients in control, measurement and secondary low-voltage circuits.

The problem with these transients 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.

Most dangerous are the surges induced in wires between the electric and electronic equipment located in control building inside the HV substation and other in different points on the substation area.

This paper presents a computer analysis of impulse voltages and currents which were induced in low voltage wiring in the case of lightning stroke to the area of substation. In investigation the influence of cables routing, parameters of earthing systems and location of striking points were taken into account.

2. High-voltage substations

The electric power system being modeled is not located in urban area and consists of the following components:

- substation S1,
- overhead transmission HV lines between substations,
- substations S2 and S3, which were connected with substations S1.

On each station were the same arrangements of HV equipment and control cables. Distances between stations S1 - S2 and S1 – S3 were 3 km (see fig.1.).

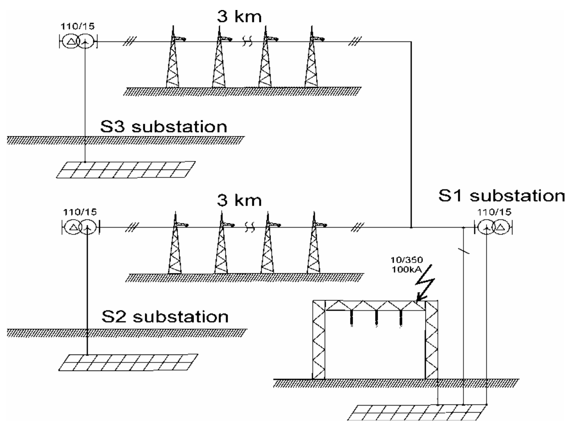

Fig.1. Typical distribution substations layout

A typical HV/MV substation, which was analyzed, consists of:

- 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,

The arrangements of control cables and same part of substation model are presented in Fig.2.Mathematical model was employed to determine the induced transients in control cables during a direct lightning stroke to the area of substation S1. The induced open circuit voltages and short circuit currents at the ends of cables in control building have been computed.

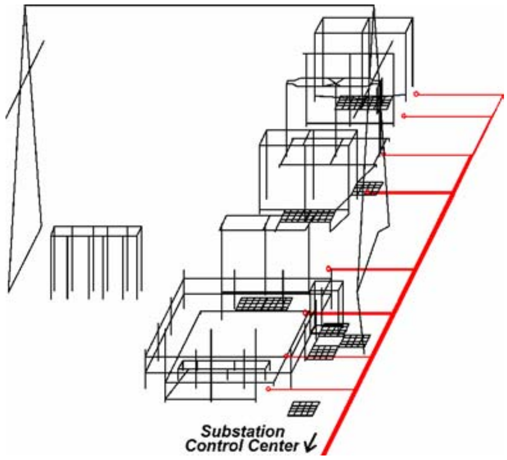

Fig.2. The part of substation model with control cables

2.1. Earthing grids

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. Fig.3. illustrates the earthing system adopted for analysis.

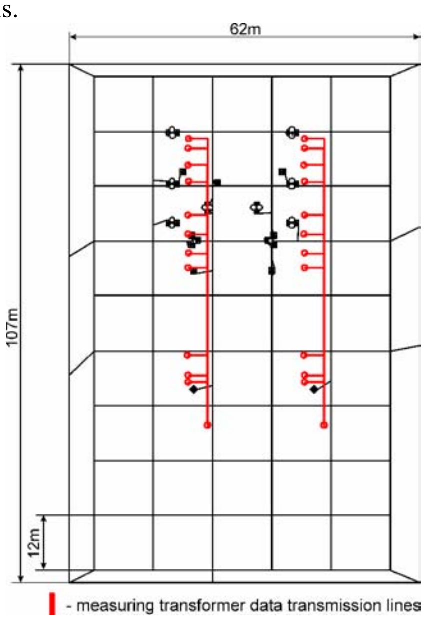

Fig.3. Substation earthing grid with the control cables

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,
- relative permittivity $\varepsilon_r = 1$.

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

2.2. The source of disturbances

A direct lightning stroke is simulated by an ideal current source injected the surge current in different points of station's area.

In analysis, the lightning current has the following mathematical expression:

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

where:

t - *time*
α - *reciprocal of time constant*
β - *reciprocal of time constant*
I - *peak current*
η - *correcting factor*

The parameters of the lightning current, for the first lightning stroke, were taken according to the IEC 61312-1 [5] 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=0,976, α= 2049,38 s^{-1}, β=563 768,3 s^{-1}.

In investigations the surge currents were injected to the different points of earthed structures in HV substation.

3. Numerical modelling

The analyses arrangements (fig.4) have been performed by the MultiFields [6,7] 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 [7].

4. Computation results

The impulse voltages and currents at equipment interfaces in control building have been computed for the following parameters of control cables:

- lengths 62 m,
- distances between cables10 mm.

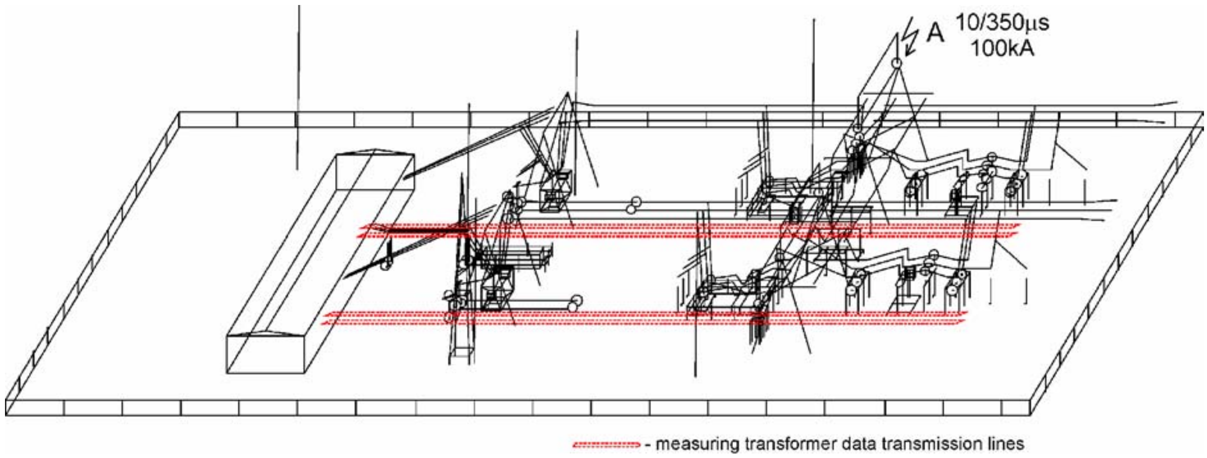

Fig.4. Configuration of HV substation S1 during the lightning stroke

The cables run above the ground on height 0,05m or under the ground on depth 0,23m or 0,25m (fig.5.).

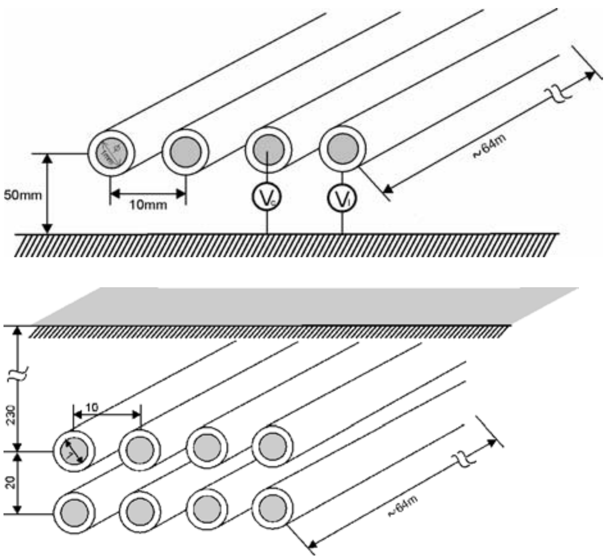

Fig.5. Configurations for computing the short circuit currents and open circuit voltages

During the stroke into the substation S1 the lightning 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 over the ground, two simple circuit configurations have been assumed:

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

Example of short circuit current in signal cabling in substation S1 is presented in fig. 6.

Fig.7 shows the short currents induced during this stroke in cables which were in substations S2 and S3. The arrangement of control cables in substation S2 and S3 were the same as in substation S1.

For the strokes into the area of substation S1 in all cases, which were calculated, the short currents did not exceed:

- 10 A in station S1,
- 0,07 A in substation S2 and S3.

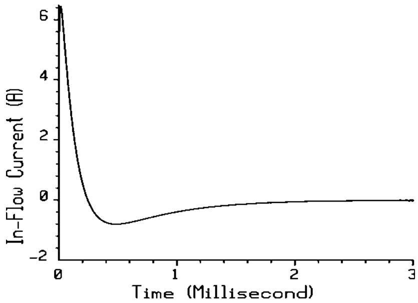

Fig.6. Short circuit current in control cable in substation S1

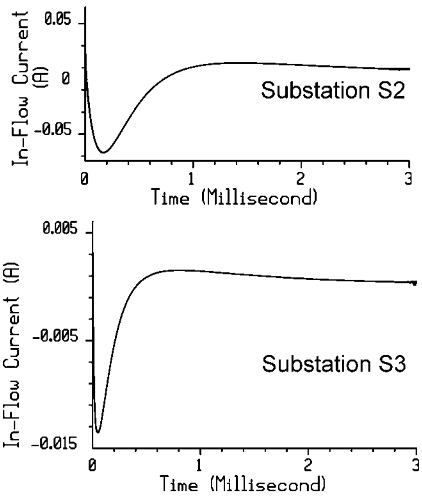

Fig.7. Short circuit currents in control cables above the ground in substations S2 and S3

For isolated cables the impulse voltages which appeared in control building between the wires and local (V_C) or true (V_G) earth were calculated. In analysed arrangements the impulse voltages V_G were much greater than V_C. Some examples of impulse voltages V_G in substation S1, S2 and S3 are presented in fig. 8 and 9.

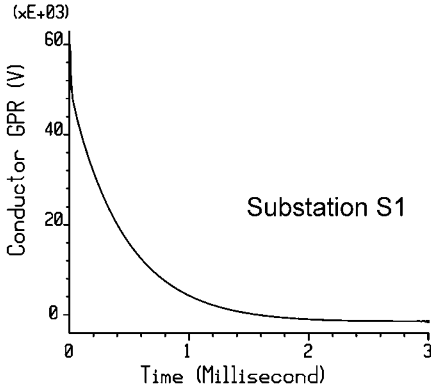

Fig.8. Impulse voltage between the wire of cable and true earth (Substation S1)

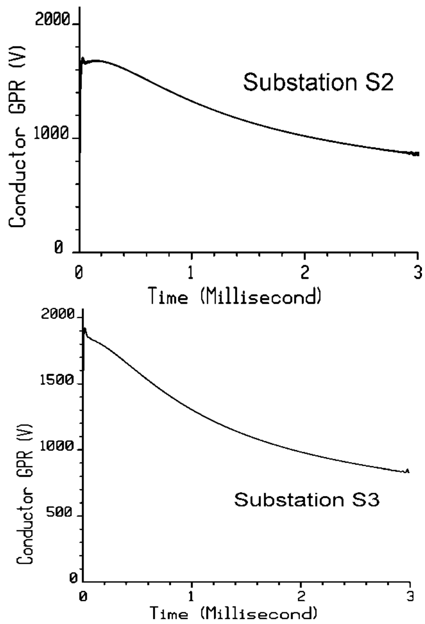

Fig.9. Impulse voltages between the wires of cables and true earth (Substation S2 and S3)

In worst cases the voltage V_G reached the values 50-80 kV in substation S1 and 2 - 2,5 kV in substations S2 and S3.

Similar calculations were realized for control cables under the ground. Some representations of currents induced in cables are given in fig. 10.

Results of calculations show, that the induced currents in arrangements of shorted cabled reached larger peak values compare to cable over the ground. In substation S1, for all arrangements of cables which were calculated, the maximum values of short currents reached 12A - 15A.

In substations S2 and S3 the values of currents did not exceed 0.08 A.

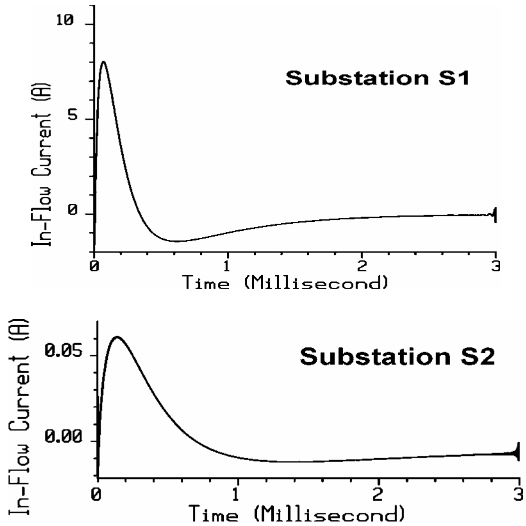

Fig.10. Short circuit currents induced in control cables under the ground

5. CONCLUSIONS

In article a method for computer analysis of lightning impulse currents and voltages in control cables is presented. The advantages of the proposal calculation of the HV substation are the following:

- all possible configurations of conductive elements on the station and different points of lightning stoke to the station's area can be represented in theoretical model,
- transients in conductors over and under the ground can be analyzed.

The study shown that, the magnitudes of surges can reach the values, which are dangerous for control electronic equipments in HV substation. It can also cause a black-out by the uncontrolled circuit breaker switch off or switch on.

References

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