Lightning transients in control lines at the large urban area HV substation

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Abstract—**In the 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. Electronic devices are very sensitive for any transient state. 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. This current induces voltage and current in low-voltage cables, which can cause severe problems in control, measurement and secondary circuits.**

Keywords-HV substation; lightning transients; earthing

I. INTRODUCTION

In view of the growing number of factors with a disturbing influence on power systems and the ever-increasing sensitivity of the devices and installations on the consumer side, simple monitoring criteria such as undervoltage or overcurrent are usually inadequate nowadays. Reliable logging of all the relevant events within the electrical power system calls for the constant observation of a wide variety of derived parameters such as transients, harmonic content, system unbalance or interharmonics and the swift identification of the slightest deviation from the standard state.

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. Electronic devices are very sensitive for any transient state, which are generated by these sources. Additionally, there is simple relationship – more electric devices – lager damage risk.

In typical high voltage substation we have got many electronic devices such as all types of protection devices for example overcurrent, distance protection, ground-fault protection and many more. Disoperation one of the crucial HV substation or HV overhead transmission line can cause a blackout.

Circuit breakers are situated at the key points of electrical energy transmission and distribution systems. Their reliability has a decisive influence on the availability, safety and economic efficiency of electrical supply networks.

Although most electronic equipment has some limitations exist on the maximum voltage and maximum duration of the transient voltages that can be lead-in. Electronic components and equipment can have an immediate failure when subject to voltages larger than their maximum rated values. Transient voltages can also alter the characteristics of an electronic component without any immediate sign of damage. Unless there is a way to determine transient voltages is present, such anomalies can remain undetected and eventually lead to a premature and unexpected failure of a component.

Transient voltage recorders have been used for many years to monitor voltage spikes in cables. Common sources of transient voltages include large electric motors, switching operations in power equipment, direct and nearby lightning strikes.

In more cases, the transients generated by sources other than lightning tend to have frequency components well below 1 MHz, which most commercial transient recorders can detect and record. On the other hand, lightning-induced transients contain voltage peaks with amplitudes that rise from 10 to 90 percent in a fraction of a microsecond and can generate multiple transients within a few milliseconds of each other.

The problem with these lightning transients concerns also the digital devices in HV substations. 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 transients in control cables.

Most dangerous are 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 lightning transient which were induced in low voltage wiring in the case of lightning stroke to the area of substation.

II. ELECTRIC POWER SUBSYSTEM

The electric power subsystem being modeled consists with 3 HV substation and underground transmission HV lines between them (fig. 1).

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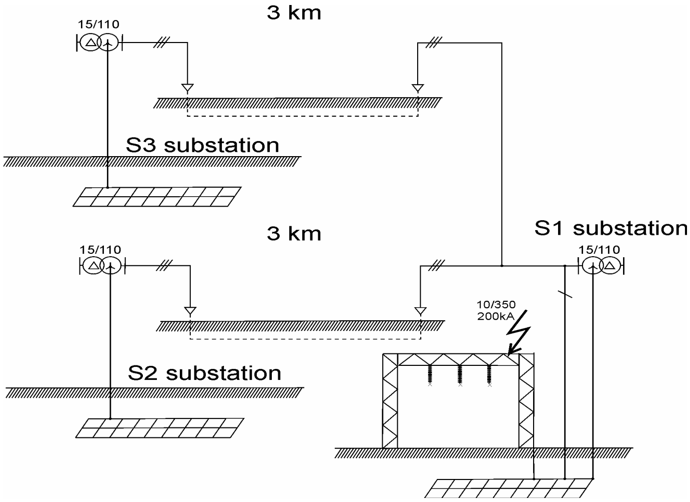

Figure 1. Analyzed electric power subsystem.

On each substation were the same arrangements of HV equipment and control cables.

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 0,8m depth in homogeneous soil (uniform ground model) with resistivity ρ=100$\Omega\cdot$m and relative permittivity ε_r=1.

The system of control cables, part of earthing system (fig.2) and the HV substation model are presented (fig. 3).

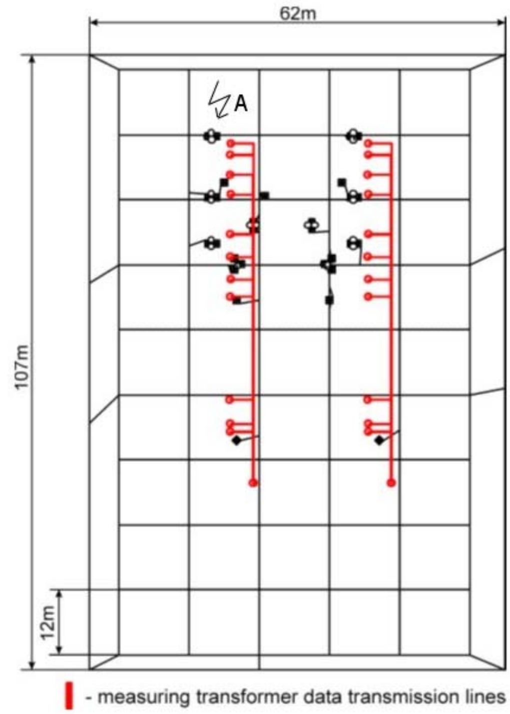

Figure 2. The part of substation model - substation earthing with control circuit wiring.

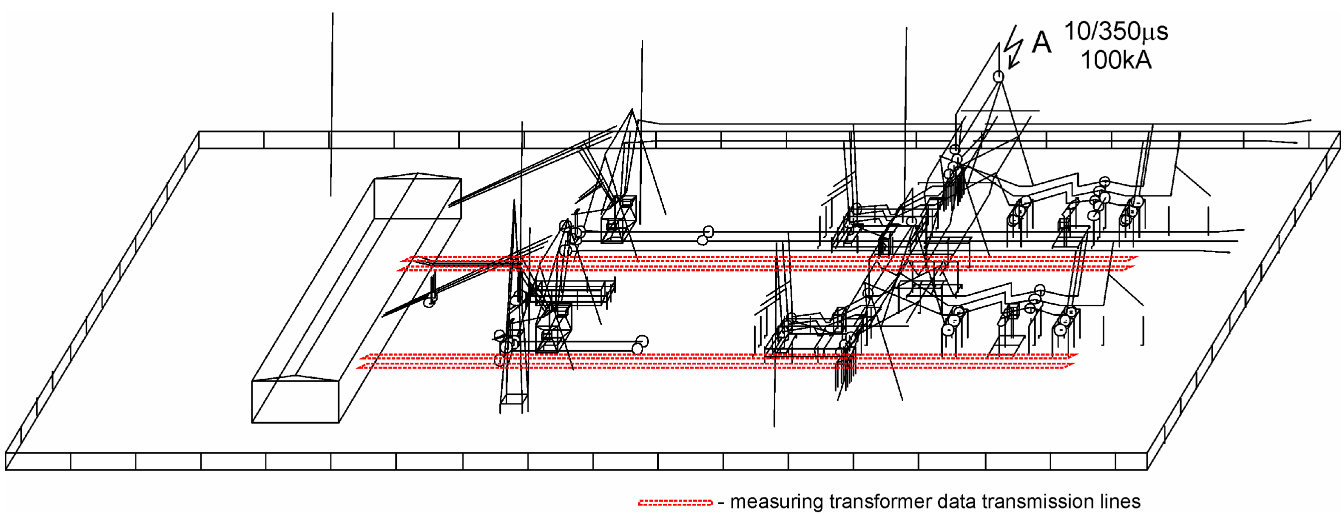

Figure 3. Configuration of HV substation S1 during the lightning strike.

Mathematical model was employed for the prediction of transients induced in control cables under the ground during a direct lightning stroke to the area of substation.

In model 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 computation methodology assumes the frequency domain analysis.

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 [6, 7].

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,
- shields or sheaths of HV cables,
- the earthing systems in station S2 and S3.

The lightning current has the following mathematical expression:

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

where:

I - peak current, t - time,

η - correction factor for the peak current

τ_1 and τ_2 - respectively front and tail time constants.

The parameters of the lightning current 100 kA, 10/350μs were taken according to the IEC 61312-1 [5] for the III-IV protection level.

In calculation, Fast Fourier Transform spread lightning current out into 32 frequencies. It has been done by FFTSES software [7].

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

- lengths 62 m,
- distance between layers – 10 mm and between cables in each layer – 10 mm.
- cables run under the ground on 200 mm depth.

The arrangements of control cables, which were the same in all substations, are presented in Fig.4.

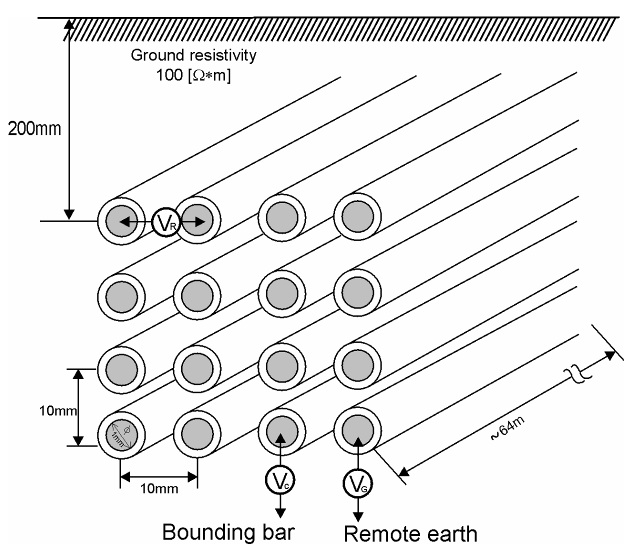

Figure 4. Arrangement of the control cables under the ground in HV substations

III. Computation Results

Below computation results are presented for HV substation S1 and S3 in the case of lightning stroke in point marked by the letter A on Fig. 2 and 3.

Direct lightning strike produce induced voltages in control cables. Those voltages are transferred from one conductor to another by capacitances and currents are transferred by mutual inductance.

For determining in signal cabling the open circuit voltages and short circuit currents the arrangements of isolated cables or two cables shorted at the ends have been assumed.

The transient voltages, which appeared in control building between:

- cables, which were in different places (V_R),
- cables and local bounding bar (V_C),
- cables and true earth (V_G)

were calculated for isolated cables under the ground.

Some results of lightning transient voltages, which appeared in control building in substations S1 and S3 are presented in Fig.5 - 9.

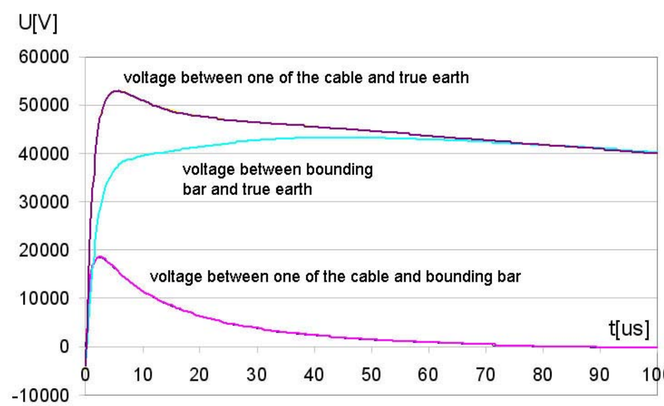

Figure 5. HV substation S1 – voltages between one of the cable and bounding bar or between true earth and voltage between bounding bar and true earth

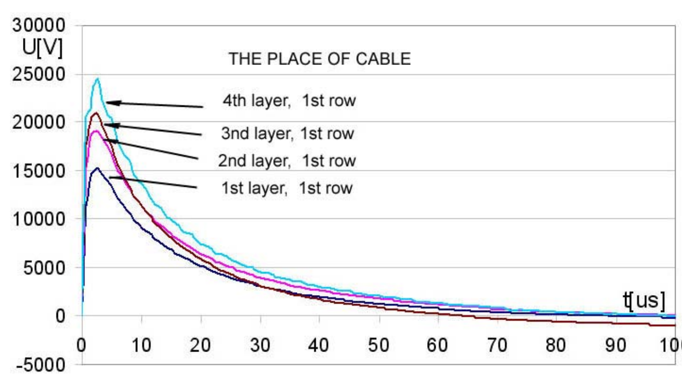

Figure 6. HV substation S1 – voltages between cables (V_C), which were in different layers and bounding bar

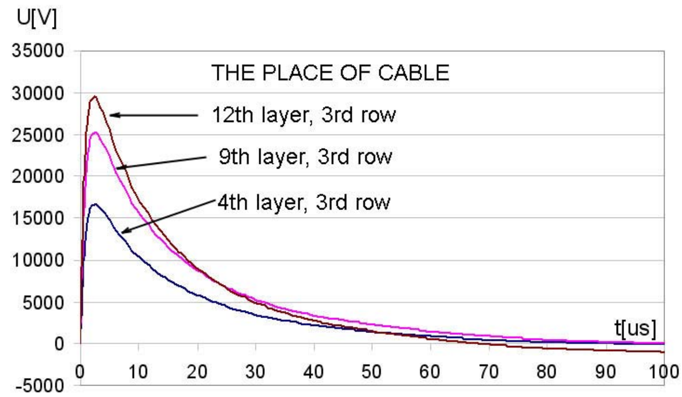

Figure 7. HV substation S1 – voltages (V_C) between cables in different layers and bounding bar

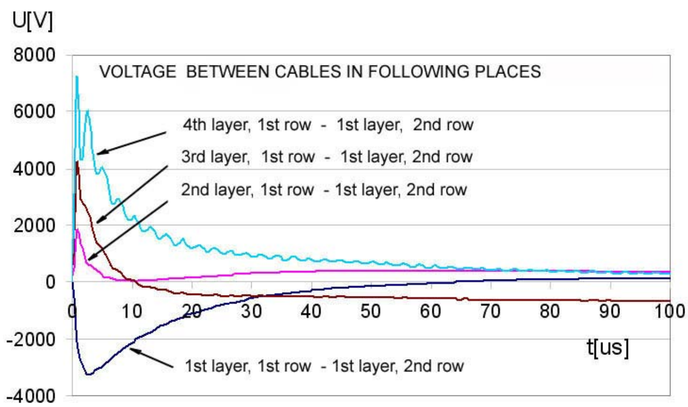

Figure 8. HV substation S1 – voltages (V_R) between cables in differnet places.

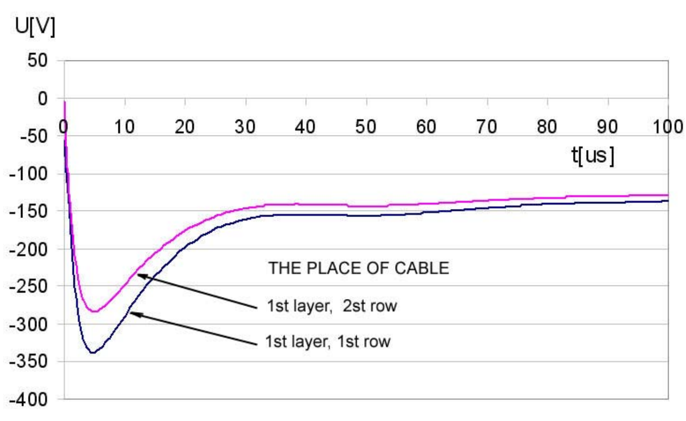

Figure 9. HV substation S3 – voltages (V_C) between cables in differnet places and bounding bar.

In worst cases in analysed arrangements the surge voltages V_G between cables and true earth reach reached the values 50 - 60 kV in substation S1 and 500 – 700 V in substations S2 or S3.

In HV substation 1 the voltages between cables (V_R) reached the values of some kV.

This can be serious dangerous for equipment in HV substation 1. Vicinal substations practically aren't in danger.

IV. Conclusions

Direct lightning strike to the earthed components of HV substation can cause severe interference problems in electronic equipment and systems. These problems have been observed in control buildings with electronic devices inside HV substation.

In article a method for computer analysis of lightning transients in control cables in HV substations is presented. The advantages of the proposal calculation are the following:

- 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 cables under the grounds can be analyzed.

The study shown that, without the surge protective devices or circuits, the magnitudes of lightning transients in control systems can reach the values, which are dangerous for electronic equipment.

Acknowledgment

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