



## GROUND POTENTIAL RISE ON THE HIGH VOLTAGE SUBSTATION DURING LIGHTNING STRIKE MEASUREMENT AND SIMULATION RESULTS

Jarosław Wiater

Electrical Department, Białystok Technical University  
jaroslawwiater@we.pb.edu.pl  
Białystok Technical University  
ul. Wiejska 45D, 15-351 Białystok, Poland

**Abstract** - This paper will present a ground potential rise (GPR) measurement results. All measurements were made during normal work of the real high voltage substation and according a special procedure developed for this occasion. This procedure doesn't influence on the protection relays and ensures a proper work of the substation even for 6kV surges. During measurements current and voltage surges were produced by the impulse generator – UCS 500M6B. Measurement results are compared to simulation results performed in CDEGS software for the same initial conditions.

### 1 INTRODUCTION

Fast economic growth depends on the secure and reliable electric power supply. High voltage substations are very important for the electric power system stability. Any malfunction can cause blackout. General average lose will be crucial for electricity generating board and for ultimate consumer too.

Malfunction of the electric system feeding-points can be catastrophic for national economy. It can cause electric power system break-up.

High voltage substations are very often placed on the open area. They consist of many high metallic components such as overhead transmission pylons, busbar bridges ect. and are exposed to direct lightning strike.

During strike, grounding system will transfer lightning current to earth. Parameters of this system are changing dynamically during the lightning current flow. This effect causes a ground potential rise (GPR) during the lightning with respect to remote earth or other substation grounding system.

Electrical and electronic devices, as a part of high voltage substations are susceptible to disturbances or destruction by direct lightning strokes and by LEMP (lightning electromagnetic pulse). A lightning discharge current can cause disturbances to 1-3km from strike centre, depending on impedance factors, soil structure and other variables. Lightning protection specialist should consider all situations in overvoltage analysis.

### 2 ANALYZED HV SUBSTATION

Polish high voltage substations are projected and made according the structural design called KSU-3. All modifications concern required devices localisation for the specific relief. Analyzed HV substation 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,
- grounding system consists of steel conductors with cross section 80mm<sup>2</sup>.
- steel conductors were buried at 0,8m depth in homogeneous soil.



Fig. 1 – Ground potential rise measurement process on the high voltage substation

### 3 MEASUREMENTS

The lightning surges were produced by the high-voltage surge generator (SG) – type UCS 500M6B. The SG covers transient and power fail requirement according to international standards with voltage capability of up to 6.6kV, shape 1,2/50µs and current 3kA, 8/20µs. During the measurements process HV substation was working without failure. All measurements equipment was supplied from gasoline generator. Listed below equipment used for measurement purposes:

- digital oscilloscope Tektronix TDS3032B 300MHz, 2,5GS/s,
- high voltage probe with 100x attenuation. Tektronix P6009 4kV, 180MHz, input capacitance 2.5pF, input resistance 10MΩ, cable length 9ft,
- high voltage coaxial cable  $Z_0 = 50\Omega$ .

Figure 2 is a functional block diagram of the equipment used for the ground potential rise measurements – a surge generator and a frequency-selective voltmeter (i.e., digital oscilloscope). As shown in Figure 2, a current 0.1kA, 8/20µs is injected from a surge generator between the substation's lightning rod and a remote return electrode – figure 3.

A frequency-selective voltmeter measures the potential difference between the two potential probes. This latter is placed at a series of locations, beginning close to the grid and ending near the return electrode, moving from point to point on the substation area. GPR of few selected points are presented on figures 4,5,6. GPR rise up to 50V for the point no. 2. Points description as follow:

- Point no. 1 – transformer T1 grounding connection,
- Point no. 2 – busbar grounding connection,
- Point no. 3 – outgoing circuit breaker grounding connection (section 1).

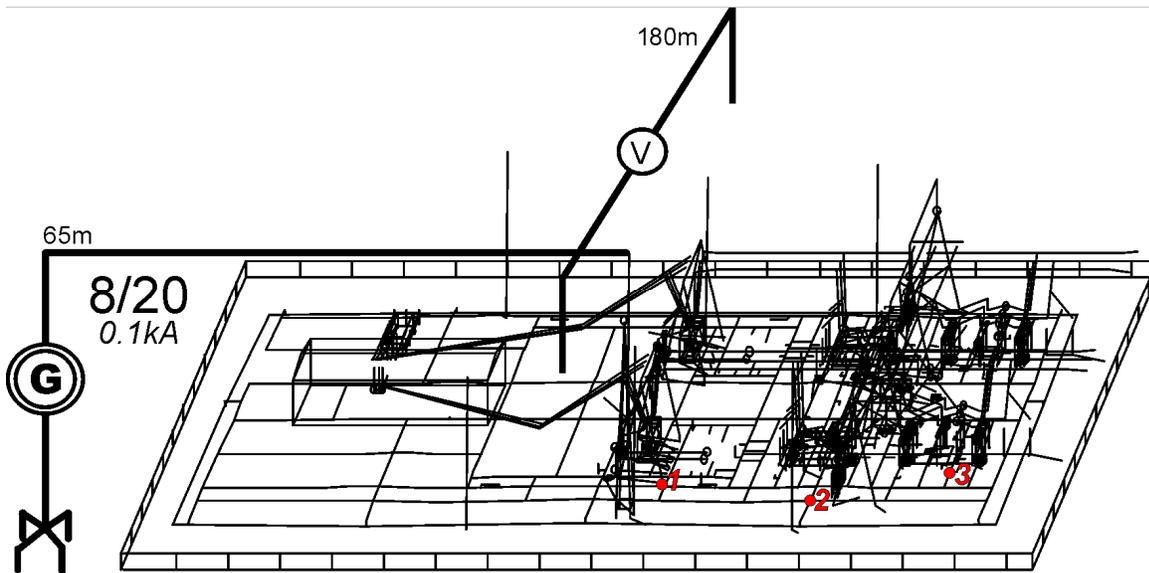


Fig. 2 – Functional block diagram of the equipment used for GPR measurements

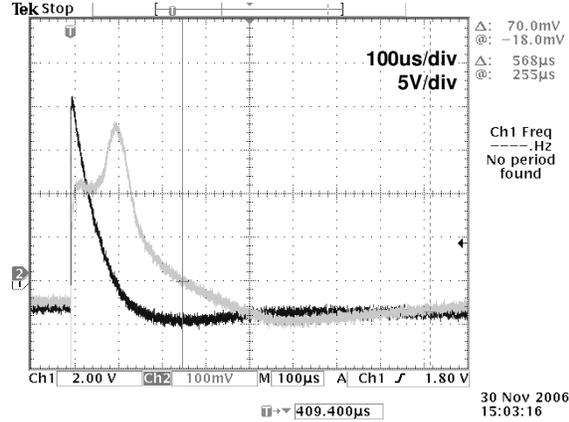


Fig. 3 – Voltage and current on the surge generator output (black curve –  $U_{max}=6kV$ , grey one –  $I_{max}=157A$ ).

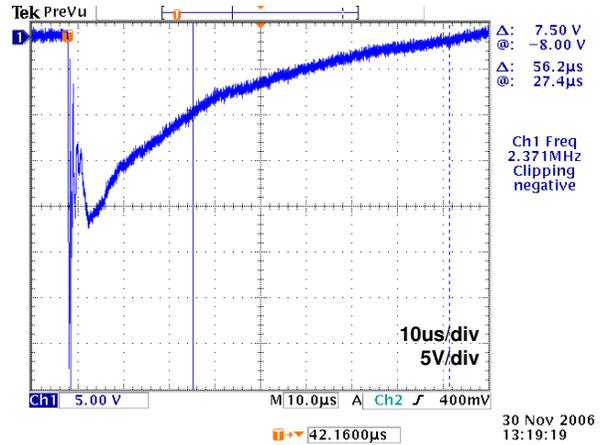


Fig. 4 – Ground potential rise on the high voltage substation – measurement point no. 1

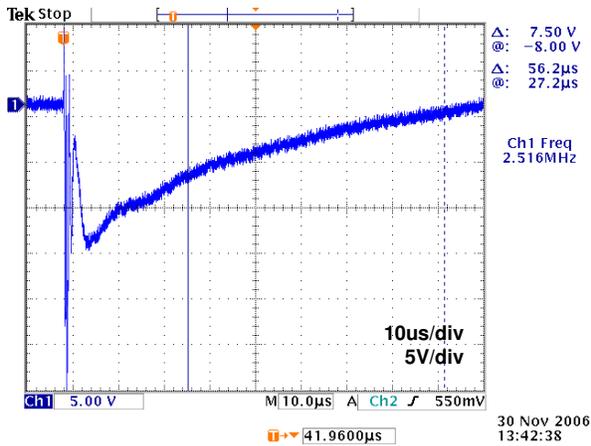


Fig. 5 – Ground potential rise on the high voltage substation – measurement point no. 2

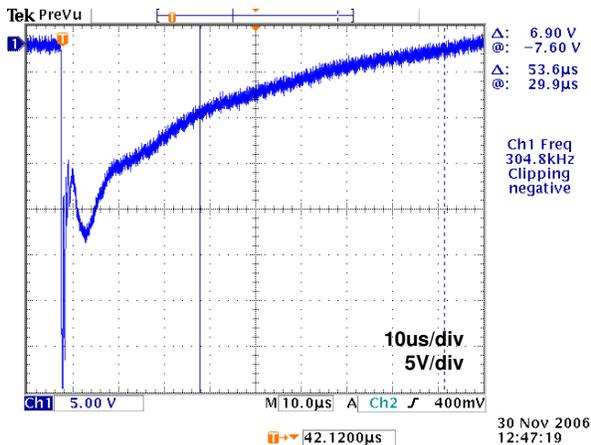


Fig. 6 – Ground potential rise on the high voltage substation – measurement point no. 3

#### 4 SIMULATION

Numerical simulations were performed by MultiFields software package, which is a part of CDEGS package [4]. The numerical model includes an earthing network as well as simplified models of aboveground elements such as flag pole structure and bonding network. Quick view on the substation 3D model shows figure 2. The computation methodology assumes:

- frequency decomposition (24 selected frequencies up to 160Mhz) of the time domain current surge by FFT,
- frequency domain computations for a single harmonic unit current,
- superposition of the frequency domain computations modulated by the amplitude of the lightning current (IFFT).

As input current for simulation purposes a output from surge generator was taken (peak value 0.157kA, shape 8/20µs). Simulations were performed for different ground

structure – according the measurement results. Ground resistivity is the most important factor for GPR level. Simulation results compared to measurement result are presented on figure 7. Shape and the peak values was almost the same.

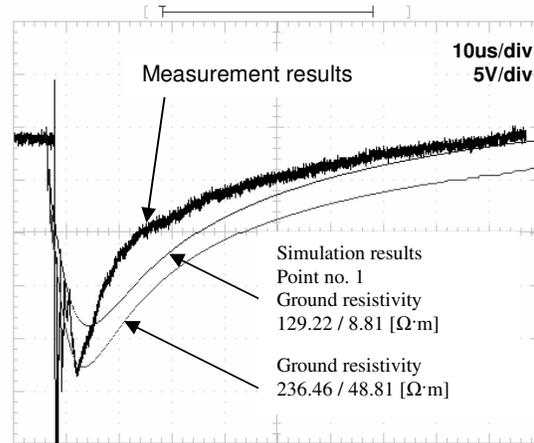


Fig. 7 – Ground potential rise on the high voltage substation – measurement and simulation for point no. 3

#### 5 CONCLUSION

Direct lightning strike to the earthed components of HV substation can cause severe interference problems in electronic equipment and systems. In article, a method for computer analysis of GPR rise in the HV substations was 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 stroke to the substation's area can be represented in theoretical model,
- impulse voltages and currents in cables under the grounds can be analyzed.

Provided analyzes proves that created model is accurate. It is possible to approximate ground potential rise during the lightning by the numerical calculations. Future calculations made for real lightning current allows proper surge protection device choose and cable traverse optimization on the HV substation area. Proper cable arrangement could minimize lightning overvoltages level with respect air-termination rods and other high structures.

#### 6 REFERENCES

- [1] Energoprojekt Kraków S.A., The HV Voltage Substation Technical Data - type KSU-3/ 110/15kV.
- [2] Energoprojekt Kraków S.A., Zestawienie wyników obliczeń do uziemienia stacji 110/15kV.
- [3] PN-E-05115, Power installations exceeding 1kV a.c., p.78.
- [4] Ses Software Canada, HIFREQ Theory, p.7-12.