XVI International Conference on
ELECTROMAGNETIC DISTURBANCES

EMD 2006

27-29 September 2006 Kaunas, Lithuania

GROUND RESISTIVITY INFLUENCE ON THE LIGHTNING OVERVOLTAGE LEVEL IN HIGH VOLTAGE POWER SUBSTATION

Jarosław M. WIATER
Białystok Technical University, Poland

Summary: In the high voltage substation damages or malfunctions of the electric and electronic equipment can be caused by lightning. Those devices are very sensitive for any transient state. In this paper a lighting overvoltages on the open air high-voltage substation is considered with respect to different ground resistivity. This transient state induces voltage and current in low-voltage cables, which can cause severe problems in control, measurement and secondary circuits.

Keywords: ground resistivity, lightning, control circuits, HV/MV substation, 3D modelling.

1. Introduction

Overvoltages problem in high voltage substation telemechanic circuits appears simultaneous with electronic equipment. In present large number of electronic devices controlled by computers are steering substations. Any malfunction can cause black-out.
To assure proper work of high voltage substation it is necessary to know appearing overvoltages hazard.
Direct and indirect lighting strike could have negative influence on the substation electronic devices. During lightning grounding system take major part assuring safety for personnel and electronic devices. Ground resistivity is predominating grounding systems parameters. Grounding extensiveness is constant but ground resistivity depends on seasons, weather conditions and geological structure. Knowledge of the geological structure, ground resistivity change along with depth change can be useful to estimate overvoltages level and to improve substation reliability.
This paper will present influence of the ground resistivity change on the lightning overvoltages and overcurrents level. All analyzes will be performed for the high voltage substation telemechanics transmission lines during direct lightning strike. There will be also considered ground structure influence on the two layer ground model example. All the results can provide better cable routing with respect to lightning.

2. Analyzed HV substation

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.

For calculation purposes mathematical model was performed according the original substation documentation [1,2]. Substation grounding gird is presented on figure 1.

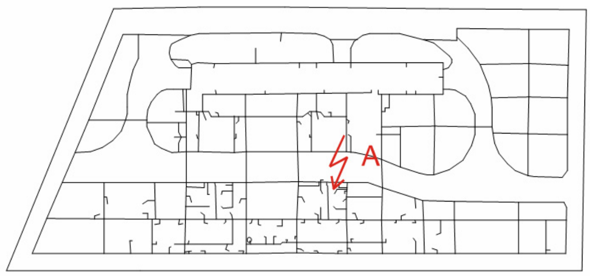

Fig. 1. Analyzed HV substation grounding gird – according the original documentation [2].

All steel conductors, with cross section 80 mm^2, were buried at 0,8 m depth in homogeneous soil (for one and two layer ground model). Signal wires were buried at 0,2m depth and they configuration is presented on fig.2 [3].

3. HV substation computer model

Numerical simulations were performed by MultiFields software package, which is a part of CDEGS package [4].

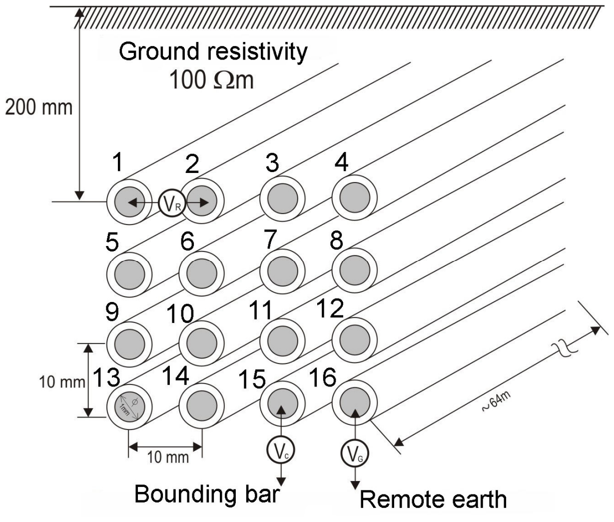

Fig.2. Signal wires configurations in the telemechanics cable canal.

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 3.

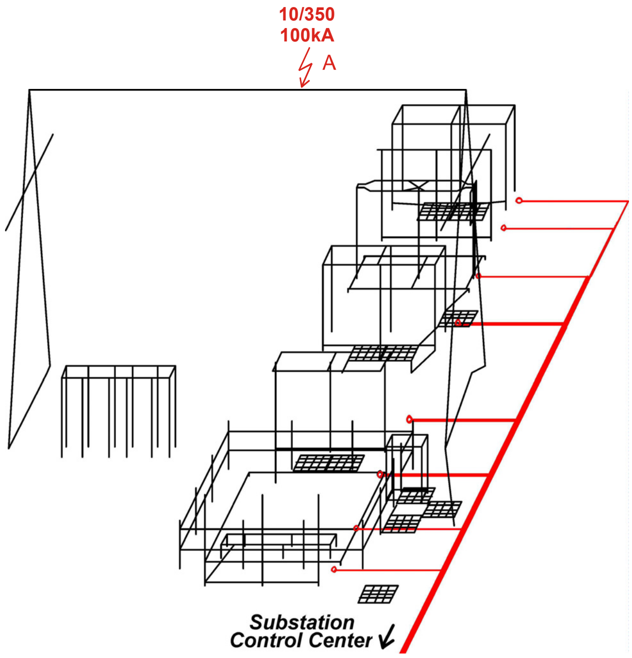

Fig.3. HV substation line equipment field - 3D model.

The computation methodology assumes frequency decomposition of the time domain current surge [4], frequency domain computations for a single harmonic unit current energization and superposition of the frequency domain computations modulated by the amplitude of the lightning current – shape 10/350µs, peak value 100kA [4].

$$i(t) = \frac{I}{\eta}\left(e^{-\alpha t} - e^{-\beta t}\right) \qquad (1)$$

where:

t - time, a - reciprocal of time constant, b - reciprocal of time constant, I - peak current, η - correcting factor

In calculation the following values of constants were used:

$\alpha = 2049{,}38\ s^{-1}$, $\beta = 563\ 768{,}3\ s^{-1}$, $I = 100kA$, $\eta = 0{,}976$

4. Calculation results

In order to simplify calculation problem and define computation range some assumptions were made:

- HV substation is disconnected from electric power system,
- Two types of environment model were considered (air with one or two layer ground structure – fig. 4),
- Datum point were single layer ground structure with resistivity 100 Ω•m and relative permittivity εr=1.
- Lightning current were injected in "A" point shown on figure 1 and 3.

a)

b)

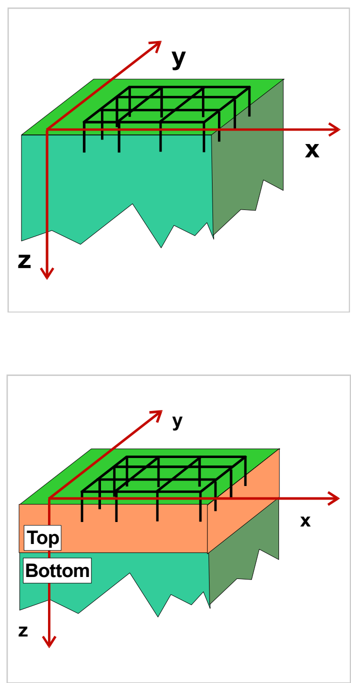

Fig.4. Ground structure model – a) one layer one, b) two layer one.

Established ground structures:

- single layer ground structure with variable resistivity (from the 1 Ω•m to the 30000 Ω•m) – for different ground structures from the wet one to the rocky one,
- double layer ground structure with variable first layer resistivity (10, 500, 1000 Ω•m),
- double layer ground structure with variable first layer width (from the 1m to the 30m).

On the figure 5 is shown one layer ground resistivity influence on the ground potential rise (GPR) in time domain. Specific transmission line no. 572 was analyzed.
Numeration was adopted from original substation documentation. This is a line which connects voltage measurement transformer with substation control center. Function shows growing logarithmic character.

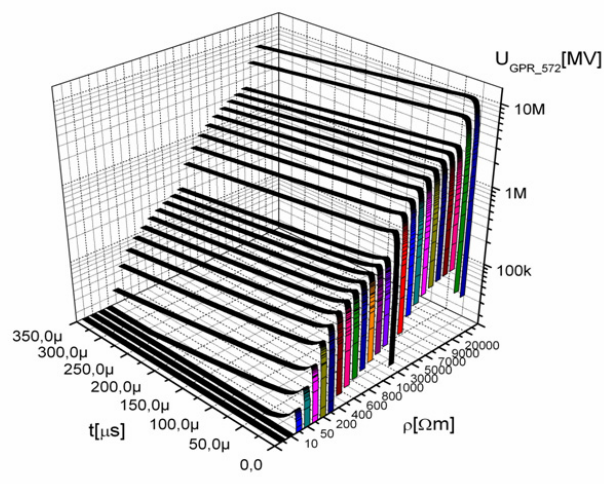

Fig.5. Ground resistivity influence on the GPR level rise.

Figure 6 presents one layer ground resistivity influence on the inducted current. Current were observed in loop connecting voltage measurement transformer with relays. Line had 100 Ω loads on the relays side. For 400Ω•m ground resistivity level presented function had current extreme.

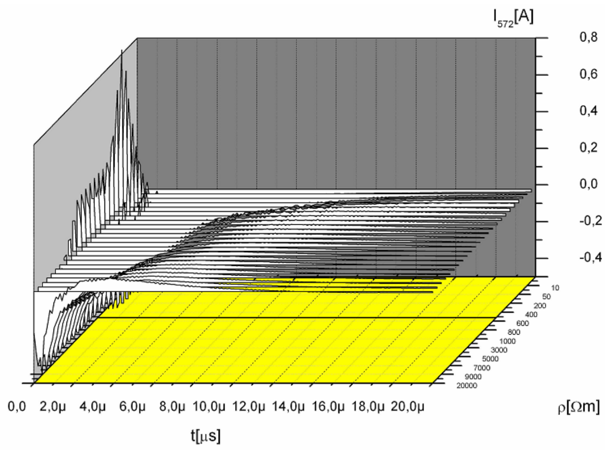

Fig.6. Ground resistivity influence on the inducted current level.

Next six figures from 7 to 12 show computation results for simulated seasonal ground resistivity changing. On figure 7 is presented first layer sogginess influence of on the inducted current described above. As the sogginess level first layer thickness were established. Wet ground resistivity were established on the 10Ω•m level. Larger first layer thickness matches heaviest sogginess level. Analysis was performed for little sogginess level (0,1m first layer thickness) to the extremely high level (30m first layer thickness). Received results show rapid current growing for first layer thickness larger than half grounding gird buried depth. Analyzed relationship has got extreme for 0,4m first layer thickens. After crossing 0,8m depth appears saturation effect – grounding grid buried depth. Current stays approximately on the same level.

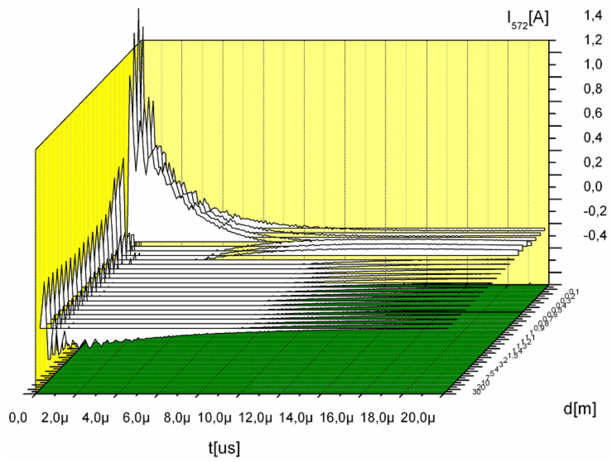

Fig.7. Ground structure influence on the inducted current level. Two layer ground model. First layer - 10 Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞.

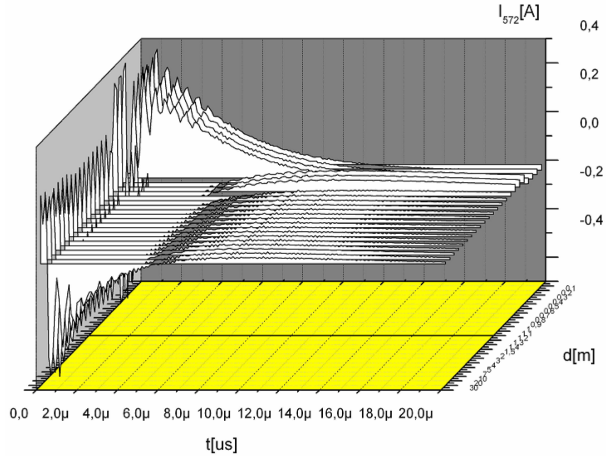

Fig.8. Ground structure influence on the inducted current level. Two layer ground model. First layer - 500 Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞.

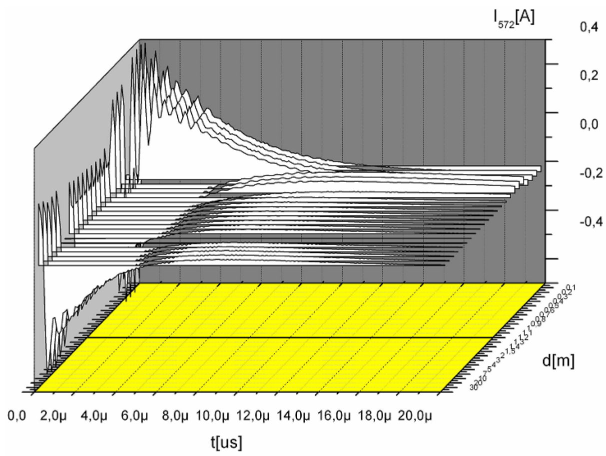

Fig.9. Ground structure influence on the inducted current level. Two layer ground model. First layer - 1000Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞.

Figure 10 shows relationship between sogginess and GPR. With growing thickness of wet layer linearly drops GPR level.

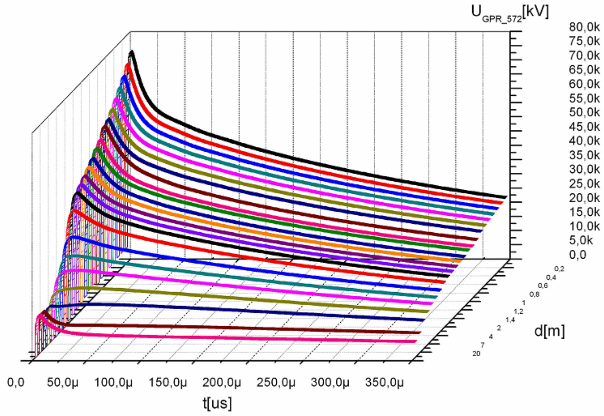

Fig.10. Ground structure influence on the GPR level rise. Two layer ground model. First layer - 10 Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞.

In the next case ground exsiccation effect was analyzed. Two different exsiccation levels were considered for to different first layer resistivity – 500 Ω•m and 1000Ω•m. Details are presented on figure 8 and 9. Like above different exsiccation level corresponds to the larger first layer thickness. Also like above saturation effect appears for the identical layer thickness.

Figure 11 and 12 show relationship between exsiccations and GPR. With growing thickness of dry layer grows GPR level. Relationship is nonlinear.

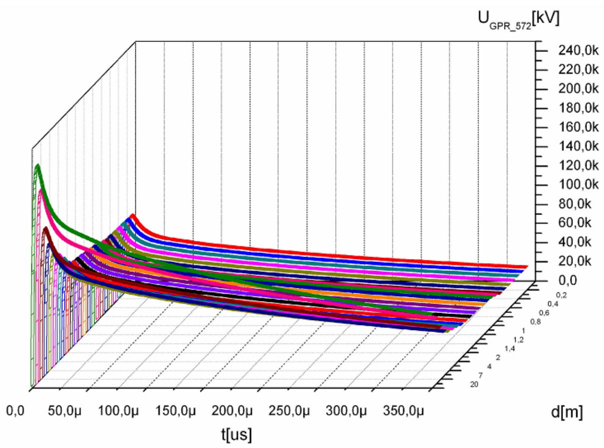

Fig.11. Ground structure influence on the GPR level rise. Two layer ground model. First layer - 500 Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞.

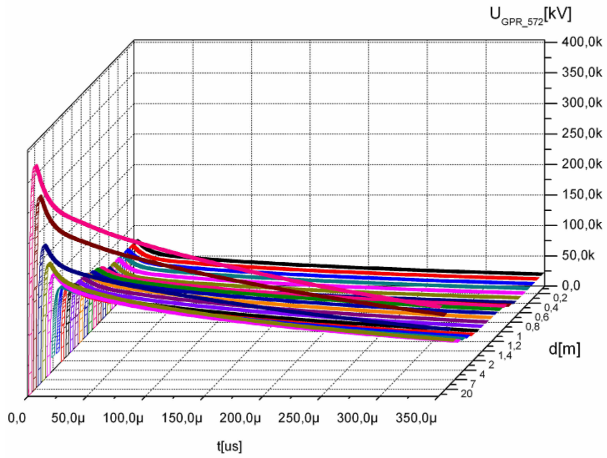

Fig.12. Ground structure influence on the GPR level rise. Two layer ground model. First layer - 1000 Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞.

5. Conclusions

Calculation results shows that GPR in HV substation is most important factor for lightning overvoltages level. It proves that real danger provided by lightning exists. Results show nonlinear relationship between ground resistivity and overvoltages level. Current function has got extreme.

Provided analyzes proves that numerical calculations can approximate overvoltages and overcurrent level in low-voltage control systems. It allows proper surge protection device choose and also 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. Presented above calculation method could estimate HV substation lightning hazard especially from signal lines.

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.