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MULTI LAYER GROUND STRUCTURE INFLUENCE ON THE LIGHTNING OVERVOLTAGE LEVEL IN HIGH VOLTAGE POWER SUBSTATION

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Abstract – In this paper a comparison between different ground structures was described with respect to lightning overvoltage level. The results of lightning overvoltage calculations for high voltage substation are presented. They were made for voltage signal lines as part of the HV substation control devices. Bases on the real object, calculations, for one, two and four layers ground models were considered.

1 - INTRODUCTION

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 center, depending on impedance factors, soil structure and other variables [5]. Lightning protection specialist should consider all situations in overvoltage analysis. Any malfunction can cause black-out.

During lightning strike grounding system take major part assuring safety for personnel and electronic devices. Ground resistivity is predominating grounding systems parameters. Grounding system arrangement is constant but ground resistivity depends on seasons, weather conditions and geological structure. Knowledge of the geological structure, the values of ground resistivity along with depth change can be useful to estimate overvoltages level and to improve substation reliability. To assure proper work of high voltage substation it is necessary to know appearing overvoltages hazard.

This paper presents influence of the ground resistivity change on the lightning overvoltages and overcurrents level. All analyzes were performed for telemechanics transmission lines during direct lightning strike into the high voltage substation. One, two and three layers ground model was considered. 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.

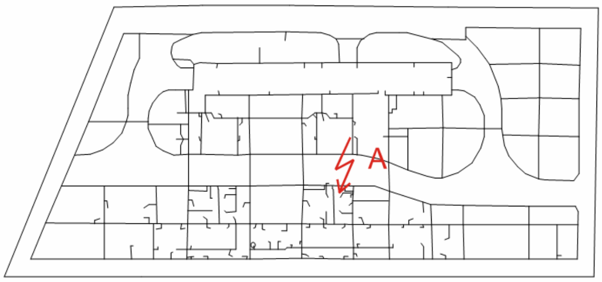

Figure 1 - Analyzed HV substation grounding gird – according the original documentation [2]

All steel conductors, with cross section 80 mm^2, were buried at 0,8m 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].

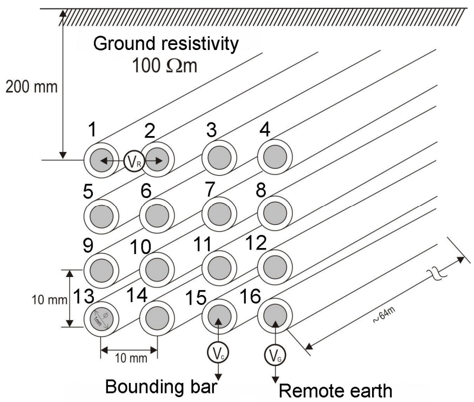

Figure 2 - Signal wires configurations in the telemechanics cable canal

3 - HV SUBSTATION COMPUTER MODEL

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

The numerical model includes an grounding 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.

The computation methodology assumes frequency decomposition of the time domain current surge [4].

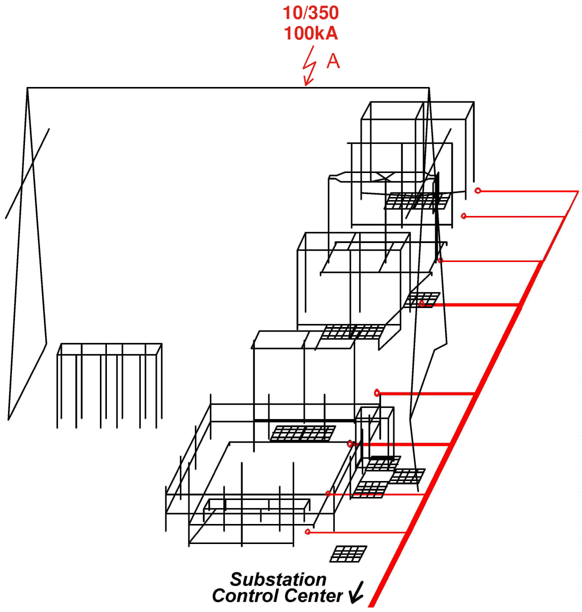

Figure 3 - HV substation line equipment field - 3D model

Next frequency domain computations for a single harmonic unit current energization were made. Superposition of the frequency domain computations modulated by the amplitude of the lightning current is performed in FFTSES Software [4].

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

where:
t - time, α - reciprocal of time constant, β - reciprocal of time constant, I - peak current, η - correcting factor

In calculations the lighting current (shape 10/350μs, peak value 100kA) was approximated by following values:
$\alpha = 2049{,}38$ s-1, $\beta = 563\ 768{,}3\ s^{-1}$, $I = 100kA$, $\eta = 0{,}976$

4 - CALCULATION RESULTS

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

- HV substation is disconnected from electric power system,
- Three types of environment model were considered (air with one, two or three layers 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.

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 layers ground structure with variable first layer resistivity (10, 500, 1000 Ω•m),
- double layers ground structure with variable first layer width (from the 1m to the 30m),
- triple layers ground structure – real ground measurements results.

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.

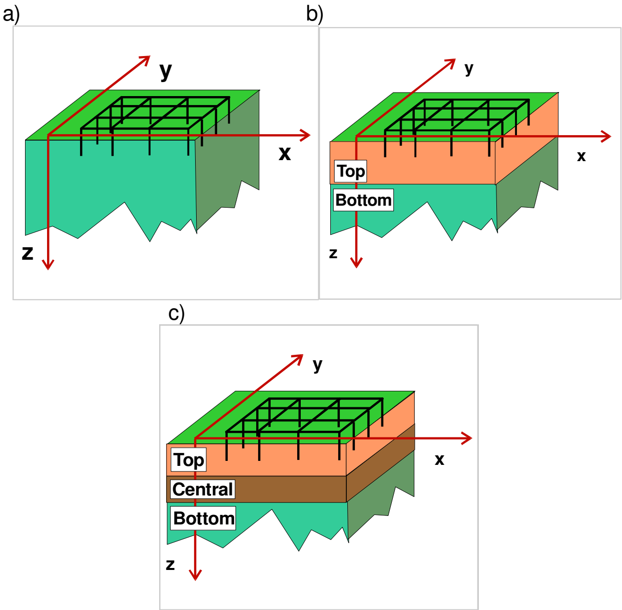

Figure 4 - Ground structure model – a) one layer one, b) two layers one, c) three layers one [4].

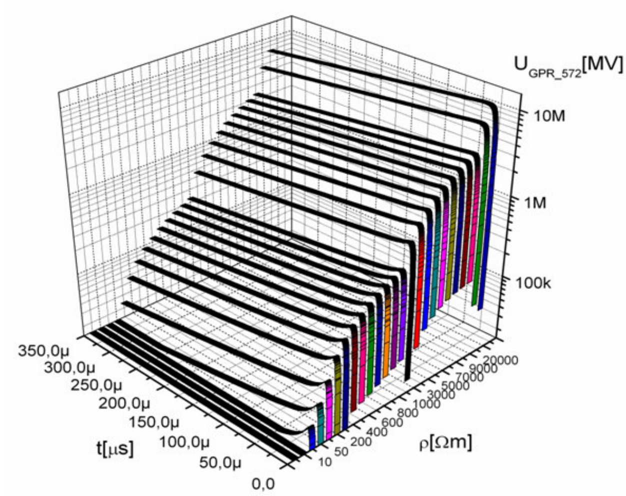

Figure 5 - Ground resistivity influence on the GPR level rise

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.
Figure 6 presents one layer ground resistivity influence on the inducted current.
Current was 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. 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).

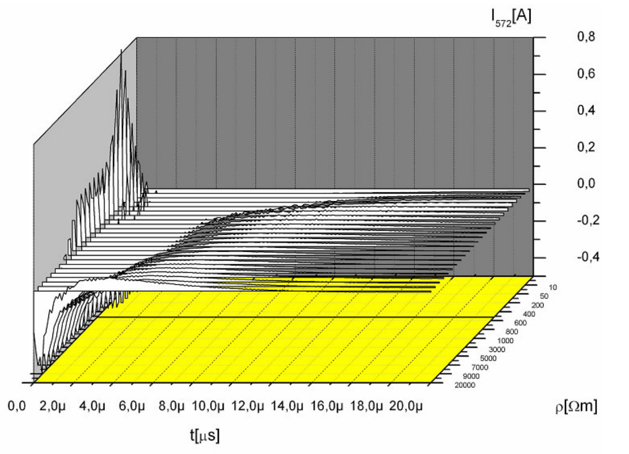

Figure 6 - Ground resistivity influence on the inducted current level

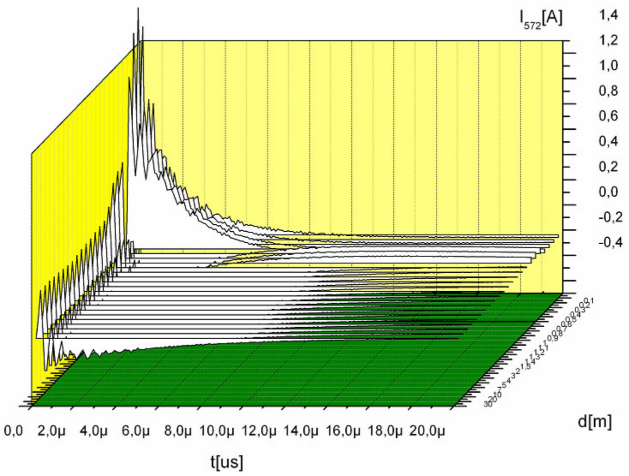

Figure 7 - Ground structure influence on the inducted current level. Two layer ground model. First layer - 10 Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞

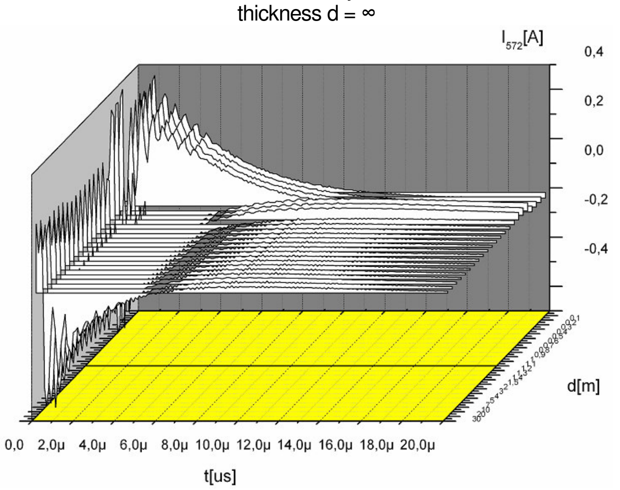

Figure 8 - Ground structure influence on the inducted current level. Two layer ground model. First layer - 500 Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞

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.

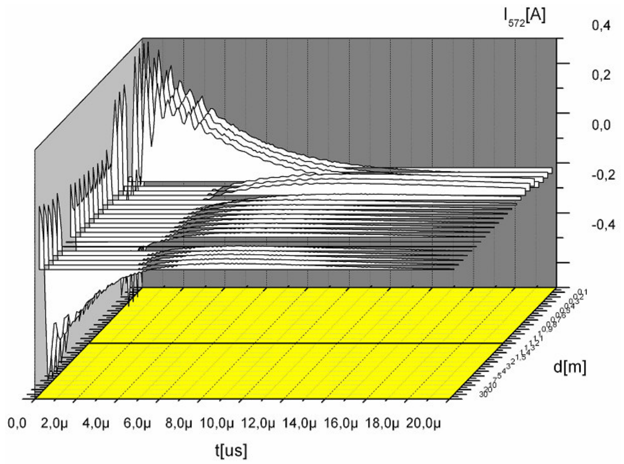

Figure 9 - Ground structure influence on the inducted current level. Two layer ground model. First layer - 1000Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞

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

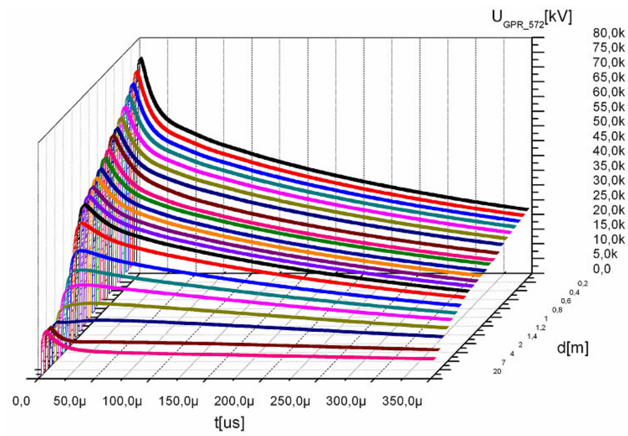

Figure 10 - Ground structure influence on the GPR level rise. Two layer ground model. First layer - 10 Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞

Figure 11 and 12 show relationship between exsiccations and GPR. With growing thickness of dry layer grows GPR level. Relationship is nonlinear.
For full comparison of different ground structure it's necessary to take into account real measurements results. As the real measurements results three layer ground structure were taken - 1st layer 1168 Ω·m , 2nd layer 219 Ω·m, 3rd layer 203 Ω·m (thickness as follow d_1=1.73m, d_2=14.09m, d_3=∞).
Figure 13 shows relationship between different ground structures. Parameters of other compared ground structures is weighted mean of thickness and ground resistivity except first case on figure 13 and fifth case assumed above.

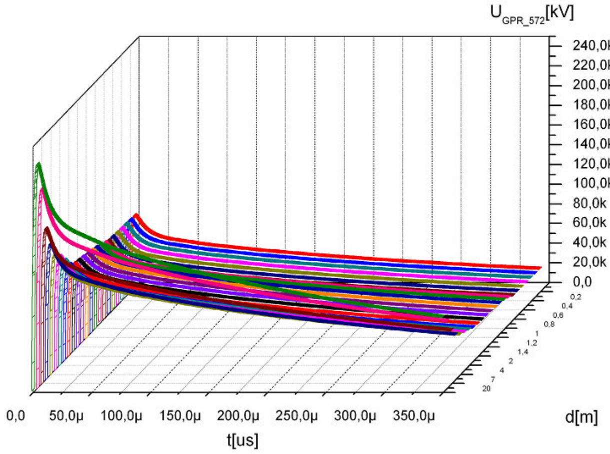

Figure 11 - Ground structure influence on the GPR level rise. Two layer ground model. First layer - 500 Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞

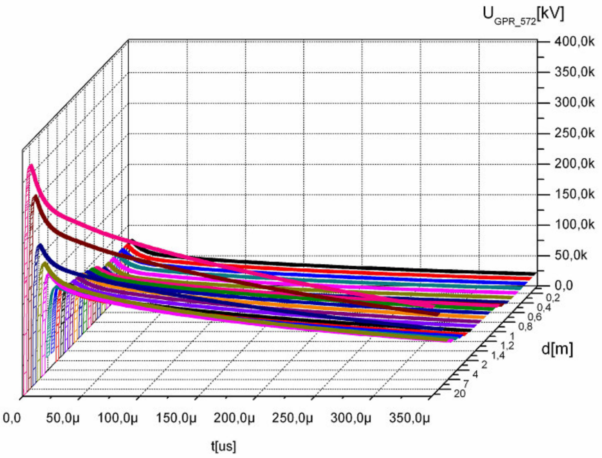

Figure 12 - Ground structure influence on the GPR level rise. Two layer ground model. First layer - 1000 Ω·m with variable thickness from d=0,1m to d=30m. Second layer - 100 Ω·m with infinite thickness d = ∞

GPR waveform shape seems to be same in all cases. Only the peak vale is changing for different cases presented below. Figure 13 proofs that proper ground structure measurement is crucial for precise GPR calculation results. Even small difference in ground structure can cause large difference in calculation results – see case 5 and 1st layer thickness.

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.

Presented analyzes proves that numerical calculations can approximate overvoltages and overcurrent level in low-voltage control systems. It allows choose the proper surge protection devices and also provide 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.

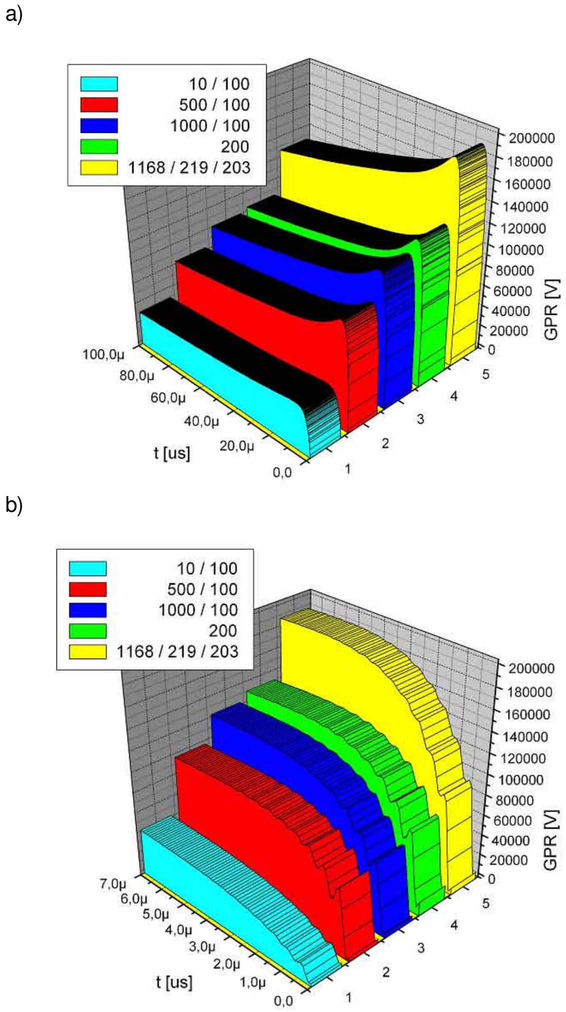

Figure 13 - Ground structure influence on the GPR level rise. One, two and three layers ground model for different observation time (“a” for long one, “b” for short one) : 1) Two layers one – 1st layer 10 Ω·m, 2nd layer 100 Ω·m. 2) Two layers one – 1st layer 500 Ω·m, 2nd layer 100 Ω·m. 3) Two layers one – 1st layer 1000 Ω·m, 2nd layer 100 Ω·m. 4) Single layer one – 200 Ω·m. 5) 3) Three layers one – 1st layer 1168 Ω·m, 2nd layer 219 Ω·m, 3rd layer 203 Ω·m.

6 - REFERENCES

[1] Energoprojekt Kraków S.A., “The HV Voltage Substation Technical Data - type KSU-3/ 110/15kV”.
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