Zone of Influence of Ground Potential Rise on Wire-Line Communication Installations in Urban Areas

Leonid Grcev and Velimir Filiposki
Elektrotehnicki fakultet, Univerzitet "Sv. Kiril & Metodij"
Karpos II bb, P. O. Box 574
Skopje, REPUBLIC OF MACEDONIA

Abstract: Wire-line communication installations serving telephone subscribers in the zone of influence of fault-produced ground potential rise (GPR) in an area surrounding the high voltage substations require special protection. In urban areas the substation grounding system may be connected to or located near to a large and complex network of conductors composed of metal sheaths of power and telecommunication cables, pipes for water, gas and heating, and rails of traffic systems, which in some cases might enlarge the GPR zone of influence. This paper presents analysis of the influence of such metal structures external to the substation grounding system on the GPR zone of influence.

INTRODUCTION

Faults to ground inside a high voltage substation or on a connected power line may cause a ground potential rise (GPR) with respect to remote ground [1]. The area surrounding the substation that is raised in potential is referred to as the zone of influence [2,3]. The CCITT directives [4] define 430 V (or 650 V) contours as a border of the zone of influence on the telecommunication lines. All wire-line telephone subscriber installations in the zone of influence are endangered and have to be protected [3,4,5,6]. This problem is of special interest in urban environments, where a large number of subscribes can be in the zone of influence [7].

As it is well known, metallic objects, connected to or located near to the substation grounding system, may distort the equipotential contours [8], which in some cases, may enlarge the zone of influence. This is typical for the urban environment, where a number of complex and spacious networks of conductors, are constructed for different purposes, such as: metal sheaths of power and telecommunication cables, neutral wires of power distribution lines, water pipes, pipelines for heating and gas, and rails of traffic systems.

Analytical modeling of the potential contours in the urban environment is a very difficult task, firstly, because of the complexity of the problem, and, secondly, because there are numerous unknown elements of the urban environment that cannot be included in any model. On the other side, measurement of the potential profiles in the urban environment is also difficult [9].

In spite of that, this problem is often greatly simplified. In some cases, all other buried metal structures are neglected, which may lead to underestimation of the zone of influence, as it is shown in [10]. In other cases, the problem is minimized by assuming nearly equipotential zone in the whole urban area [9,11].

Previous publications [12,13] presented analysis of the influence of the external metal structures on the GPR zone of influence in soil with different resistivity. This paper summarizes the main

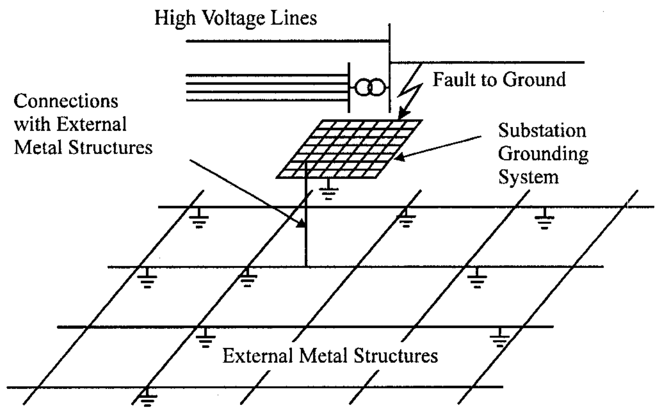

Figure 1. Grounding system of an urban high-voltage substation (adapted from [9]).

conclusions and extends the previous analysis in [12,13] investigating the influence of different external metal structures that might or might not be connected to the substation grounding system.

FORMULATION OF THE PROBLEM

Analyzed problem is illustrated in Fig. 1, where the upper grid represents an urban high voltage substation grounding system in case of a fault to ground. The lower grid, in Fig. 1, represents external metal structures in the urban environment built for different purposes, such as: power, telecommunications, water and gas supply, heating and transportation. The connections of these structures with each other and with the high-voltage substation grounding system usually are not completely known. As a first approximation, such structure may be modeled as a grid with square meshes [9].

In this paper, the influence of the following parameters on the ground potential distribution are investigated:

- the quality of the connection between substation grounding system and the external metal structures,
- the influence of different mutually isolated external metal structures of which one is connected and the other is not connected to the substation grounding system, and
- the resistivity of the soil.

METHOD OF ANALYSIS

Usual models for power frequency analysis of grounding systems [8,14,15] assume equipotential electrodes. Such models are not applicable here, since the analyzed external metal structures (Fig.

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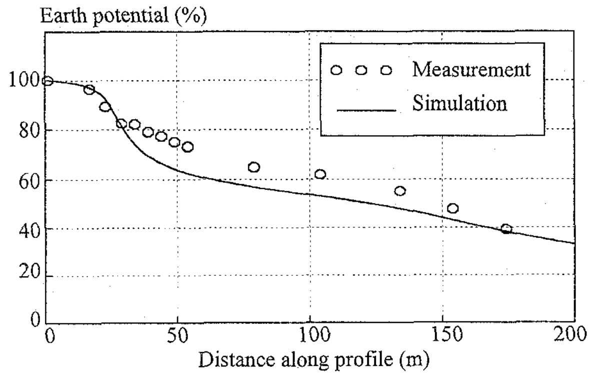

Figure 2. Comparison with field measurements.

1) may be very large, and consequently cannot be assumed equipotential.

In this paper a rigorous model based on formulation derived from the full set of the Maxwell's equations has been used. This rigorous approach is based on the recent advances in application of the electromagnetic field theory to grounding system analysis at both low and high frequencies [16,17]. The main advantage of this approach is in rigorous modeling of all mutual electromagnetic interactions between elements of complex structures. Therefore, speaking in circuit terms, both conductive and inductive effects are taken into account. Reader is referred to [16,17] for full details on the model and its validation by comparison with field measurement and with other authors' models [17].

VALIDATION OF THE COMPUTER MODEL

The validation of the results of computer analysis is based on the comparison with field measurements performed by the Electricite de France, Paris, France, in the period 1976-85. An extensive set of experiments had been performed for different grounding electrodes arrangements [18]. Some comparisons for low and high frequencies are documented in [17].

Figure 2 shows comparison between computation and field measurement of the potential distribution at the earth surface above irregular and complex arrangement of ground electrodes near power station Tikves [19].

The computer model was also compared for power frequencies with other authors' software [8], with excellent agreement of the results, Fig. 3. Results in Fig. 3 are magnitudes of the electric field component along profile A-A at earth's surface above the illustrated ground grid. The profile starts and ends at points 5 m away from the edge of the grid. Conductors are constructed of copper with radius 0.5 cm, and grid is buried in soil with $\rho = 100$ Ω·m at 0.5 m depth. Current of 1 kA at power frequency is injected at the central point.

DESCRIPTION OF THE CASES ADOPTED FOR ANALYSIS

Figure 4 illustrates the cases adopted for analysis. Substation grounding system is a 100 m × 100 m ground grid with 4 × 4 25 m square meshes buried at 0.8 m depth. This grounding system is surrounded by two mutually isolated external metal structures, the first one in a form of 1600 m × 1600 m grid with 100 m × 100 m square meshes in the inner part and with 200 m × 200 m square meshes in the outer part (in Fig. 4 depicted with full lines), and the second one in a form of 1500 m × 1500 m grid

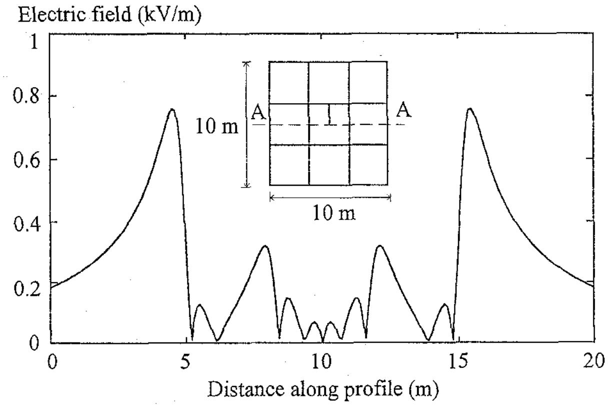

Figure 3. Comparison with other authors' model.

with 100 m × 100 m square meshes (in Fig. 4 depicted with dot lines). The first one is buried at 0.8 m depth, and the second one is buried at 0.5 m depth. The distance between the substation grounding systems and the first external metal structure is 50 m. As a first approximation all grids are assumed to be constructed of copper conductors with diameter 1.4 cm.

To investigate the influence of the quality of the connection between the substation grounding systems and the external metal structures, three cases were analyzed, Fig. 4. In all these three cases only the first external structure (depicted with full lines in Fig. 4) is considered.

- Case A – The substation grounding grid and the external metal structure are not connected.
- Case B – The substation grounding grid and the external metal structure are connected with one conductor.
- Case C – The substation grounding grid and the external metal structure are connected with four conductors.

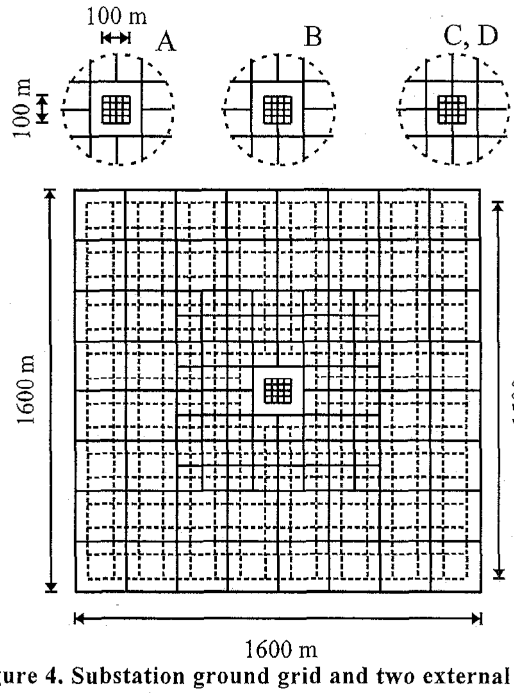

Figure 4. Substation ground grid and two external metal structures.

To investigate the influence of the additional external metal structure (depicted with dot lines in Fig. 4), that is isolated from the first external metal structure and not connected to the substation grounding grid, the following fourth case is included:

- Case D – The connection between the substation grounding grid and the first external metal structure (depicted with full lines in Fig. 4) is identical as in the Case C, except that here the second external metal structure (depicted with dot lines in Fig. 4) is present.

To investigate the influence of the soil resistivity, computations have been performed for three values of soil resistivity: 30 Ω·m, 100 Ω·m, and 500 Ω·m. The soil is supposed to be homogeneous. In all cases 1 kA current at power frequency is injected in the central point of the substation grounding system.

3D perspectives of the potential distribution at the earth's surface, normalized to the maximum value U_m, for all analyzed cases are illustrated in Figs. 5, 6 and 7. In these Figures, $0.2 \cdot U_m$, $0.4 \cdot U_m$, $0.6 \cdot U_m$, and $0.8 \cdot U_m$ equipotential contours are shown at the base.

Influence of the External Metal Structures and Soil Resistivity on the Ground Potential Distribution

Influence of Isolated External Metal Structures

Potential distributions for case A in all Figs. 5, 6 and 7, are very similar to the case when the substation grounding system is alone, that is, without any external metal structures. These examples show that the external metal structures might have small influence, when they are insulated from the substation grounding system. In the analyzed cases they are at a distance of 50 m and are without direct metal connections with the substation grounding system. This conclusion holds for both conductive and poorly conductive soil.

Influence of the Quality of the Connection

Results for cases B and C in Figs. 5, 6 and 7, show that the quality of the direct metal connections between the substation grounding system and the external conductor structure have exceptionally large influence on the earth potential distribution.

Influence of the Soil Conductivity

The influence of good connection between the substation grounding system and the external metal structures becomes greater in poorly conductive soil. The extreme case is for soil with ρ = 500 Ω·m and for good connections between the substation grounding system and the external metal structure, illustrated in Fig. 7c, where the whole area becomes nearly equipotential. This is in agreement with results published in [9] for Helsinki, where the soil is very resistive with resistivity of about 1000 Ω·m.

Influence on the GPR Zone of Influence

Results show that the GPR zone of influence may be significantly increased when the substation grounding system is in good contact with the external metal structures. This effect is emphasized in cases when the soil is poorly conductive.

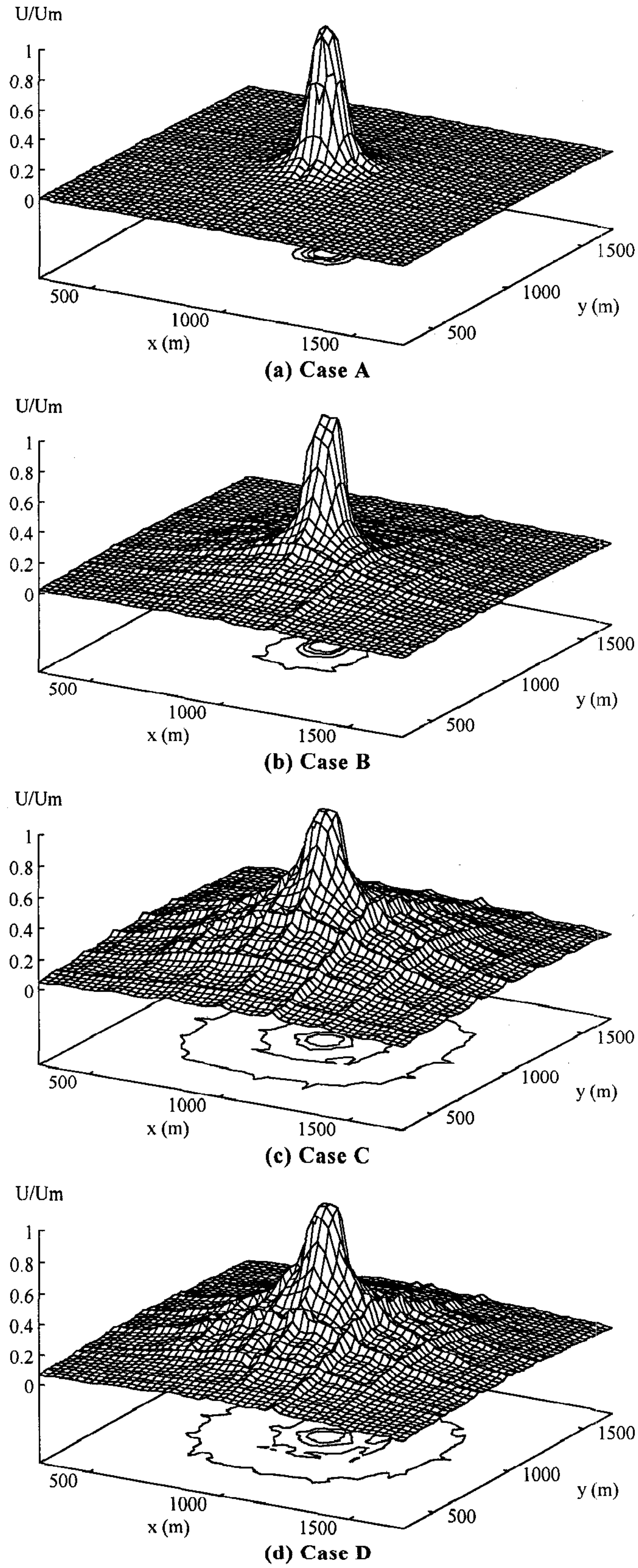

Figure 5. Earth potential distribution for very conductive soil (with ρ = 30 Ω·m).

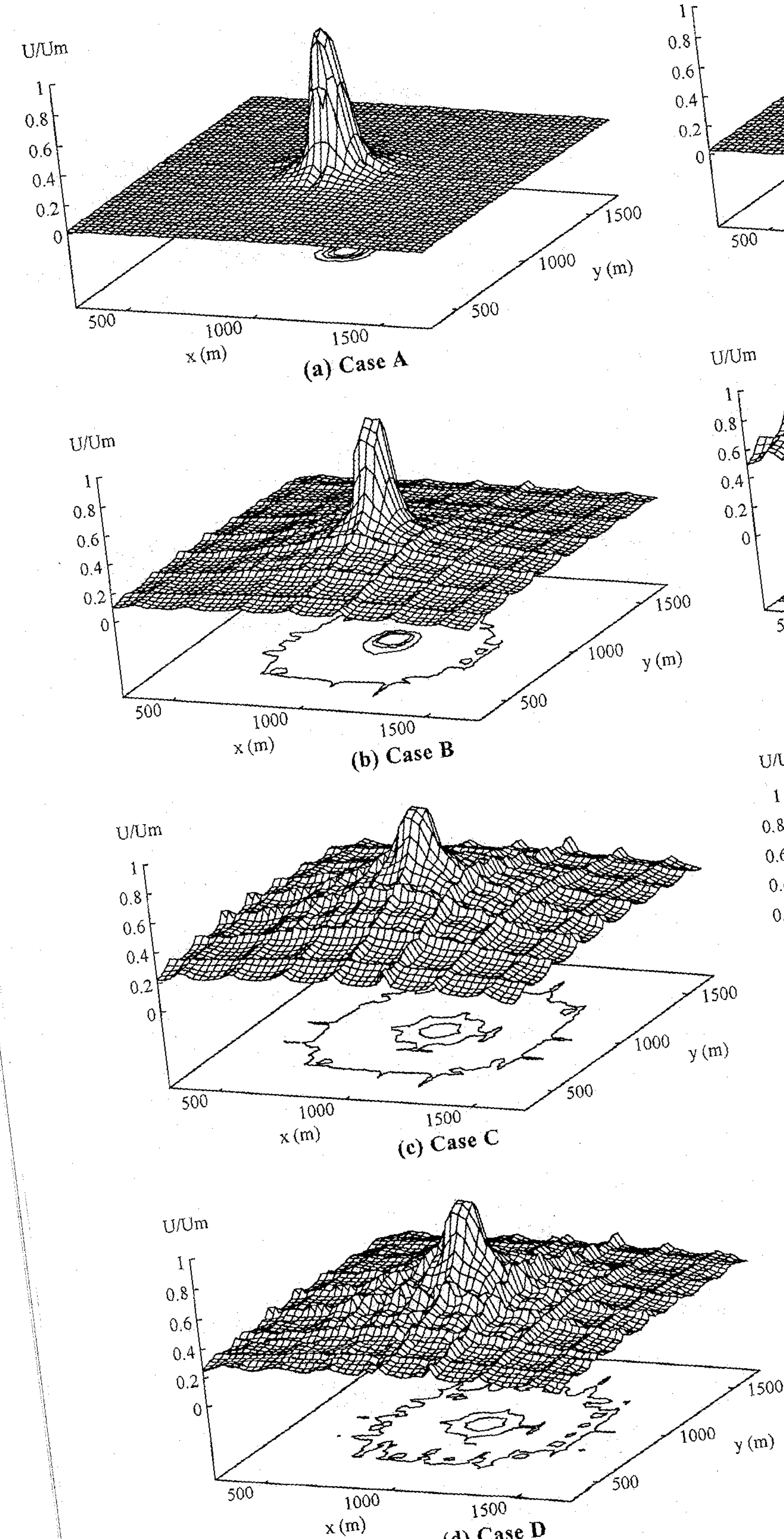

Figure 6. Earth potential distribution for conductive soil (with $\rho = 100\ \Omega{\cdot}m$).

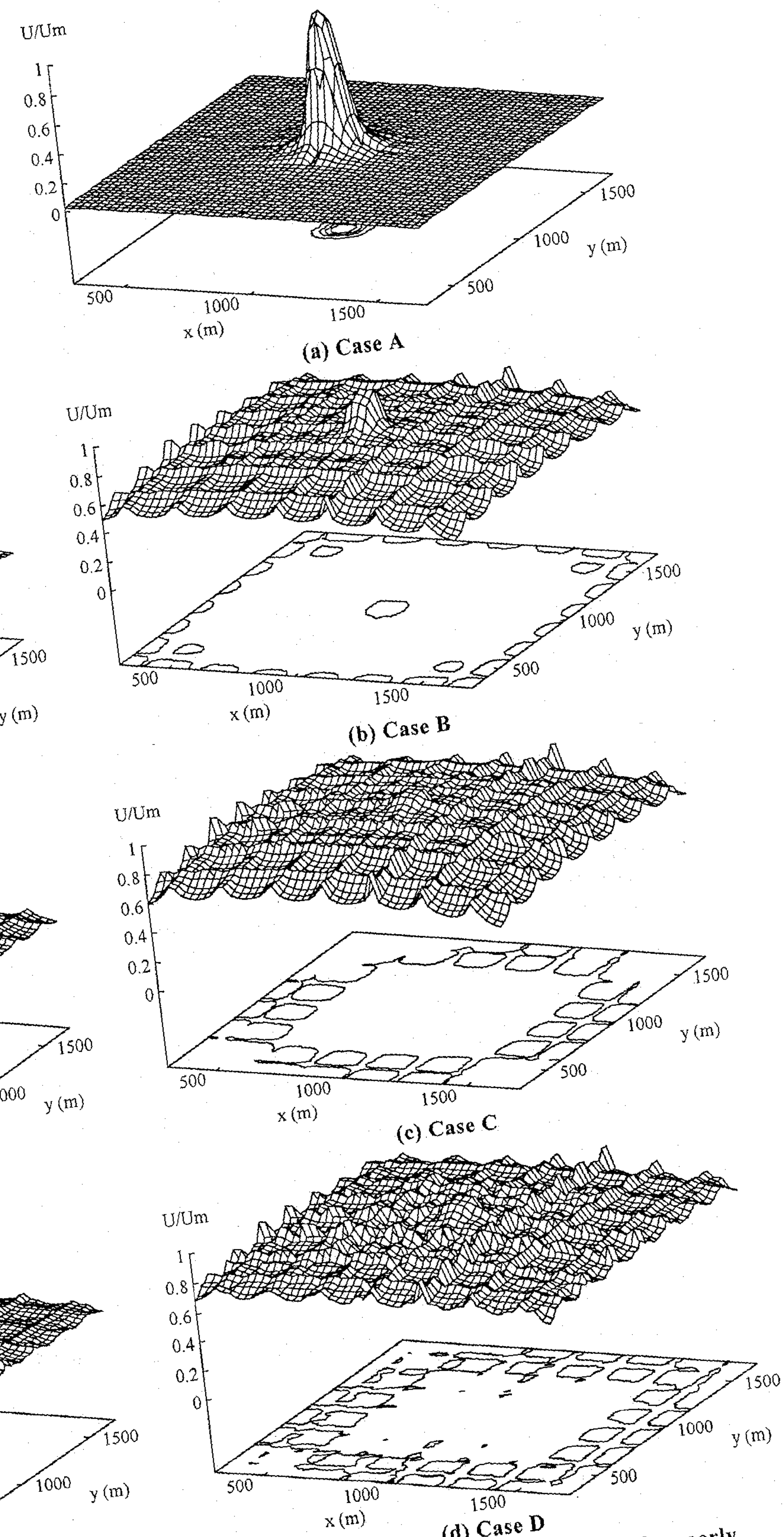

Figure 7. Earth potential distribution for poorly conductive soil (with $\rho = 500\ \Omega{\cdot}m$).

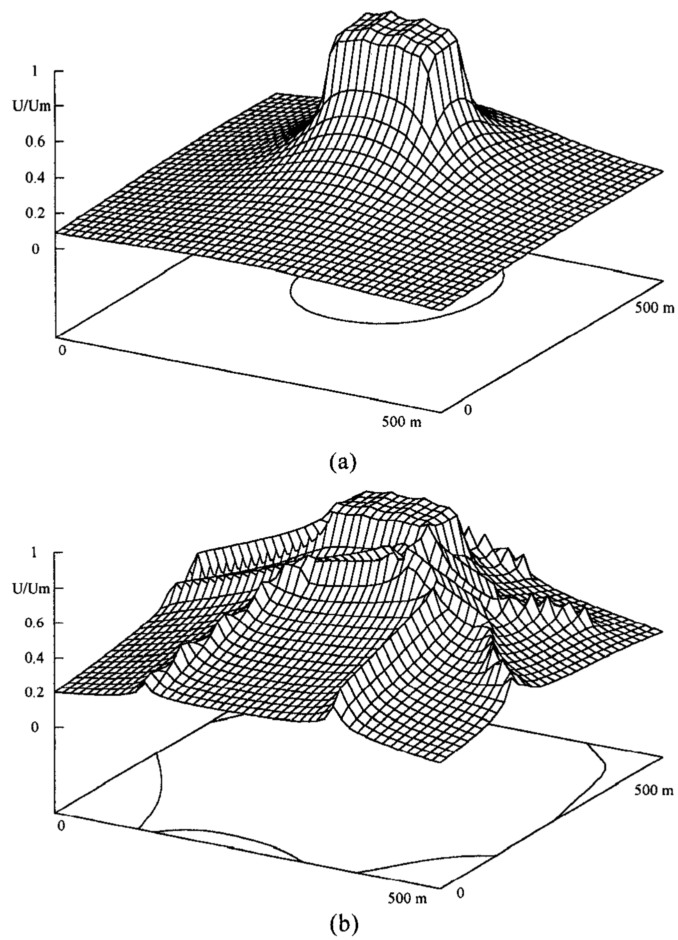

Figure 8. Potential distribution on the ground surface around 110 kV substation. (a) Ground grid only. (b) Ground grid with cable sheaths.

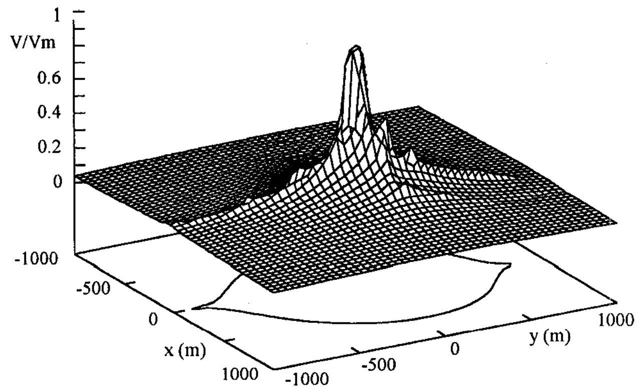

Figure 9: Earth potential distribution around 110/35 kV transformer station with grounding system connected to uncoated metallic sheathed high-voltage underground cables.

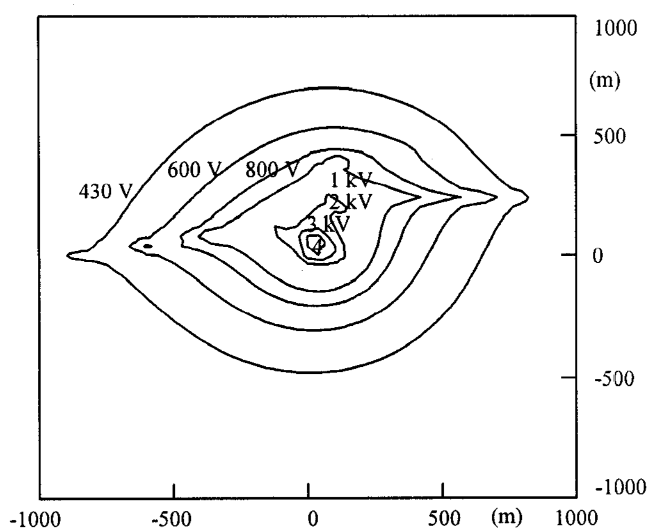

Figure 10: Potential contours and zone of dangerous influence on telecommunication installations around 110/35 kV transformer station.

PRACTICAL EXAMPLES OF THE INFLUENCE OF UNCOATED METALLIC SHEATHED HIGH-VOLTAGE CABLES

The uncoated metallic sheathed high-voltage cables have considerable effect on the performance of substation grounding systems [20]. These cables might considerably reduce the grounding system potential, but also they might transfer high potentials far away from the substation. Such cables are no longer manufactured in many countries, but many of them are still in operation.

Fig. 8 illustrates earth potential distribution on the ground surface around 110/35 kV substation with 110 x 55 m^2 ground grid. The soil is assumed homogeneous with measured resistivity around 100 Ωm. Fig. 6(a) illustrates imaginary case where the ground grid is alone, without any external metal structures. The zone of influence, with a border at the 430 V contour, is nearly circular (shown as contour at the base of graphs in Fig. 6). Fig. 6(b) shows the potential distribution when the existing uncoated metallic sheathed high-voltage cables are connected to the substation ground grid. It can be seen in Fig. 6(b) that cable sheaths help to equalize the potential distribution around the substation, but greatly widen the zone of influence.

Fig. 9 shows earth potential distribution around existing 100/35 kV substation, where maximum GPR is estimated to 4.45 kV. The grounding system is connected to uncoated metallic sheathed high-voltage cables that are routed in three main directions. They distort equipotential contours, and greatly enlarge the GPR influence zone. This is illustrated in Fig. 10 where potential contours are presented.

CONCLUSIONS

1. Wire-line communication installations serving telephone subscribers in the zone of influence of fault-produced GPR in an area surrounding the high voltage substations require special protection. The GPR zone of influence, limited by the 430 V (or 650 V) contours, might be distorted by an external metal structures composed of uncoated metallic sheathed cables for power and telecommunications, metal pipes for water, heating and gas and rails for transportation systems.

2. Although many details of the underground metal structures in urban environment are not usually known, simplified parametric analysis is possible that reveals parameters that have largest influence on the shape of the zone of influence.
3. Results of the presented parametric analysis reveals that external metallic structures that are not directly connected to the substation grounding system, might have small influence on the shape of the zone of influence.
4. External metallic structures that are directly connected to the substation grounding system, might have large influence on the shape of the zone of influence. This influence is increased with better connections between the substation grounding system and the external metal structures and in less conductive soil. In such cases the zone of influence might be considerably enlarged.
5. The uncoated metallic sheathed high- or medium-voltage cables are usually connected to the substation grounding system. They might considerably reduce the grounding system potential, but they also might transfer high potentials far away from the substation, enlarging the zone of influence on nearby telephone subscriber lines.

ACKNOWLEDGMENT

The work was partially supported by the Ministry of Science of the Republic of Macedonia, under Research Project no. 40224495.

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