

Grounding and shielding in EMC problems of electric power substations

N.V.Korovkin, O.V.Frolov
JSC «STC UPS»
Saint-Petersburg, Russia
e-mail: Nikolay.Korovkin@gmail.com

S.L.Shishigin, D.S.Shishigin
Vologda State Technical University
Vologda, Russia
e-mail: ctod28@vologda.ru

Abstract— Galvanic and electromagnetic interference occurring at lightning stroke, short-circuit or equipment switching may result in damage or failure of microprocessor control systems of electric power stations and substations. The EMC problem is to limit interference; its solution starts with the design of grounding and shielding systems. To continue the works, [1,2] we would like to discuss impulse characteristics of grounding devices; to propose a multilayer ground model with boundaries of arbitrary shape; to show the procedure to design electromagnetic screen and grounding devices; to give an example of problem solution based on ZYM program developed by us.)

Keywords— grounding, shielding, multilayer ground, AutoCAD application

I. INTRODUCTION

In EMC problems of electric power stations and substations there is need to calculate galvanic and electromagnetic interference in cable power lines and microprocessor control systems and to undertake measures for its reduction. Grounding and shielding are the ways to solve this problem. The parts of the grounding device (GD) act also as screens, so the problems of grounding and screening are to be solved all together. We would like to call to our position regarding the selection of simulation models and calculation procedures [1, 2] and to show new possibilities.

II. SIMULATION MODELS OF THE GD

A. Main models

There are field, circuit and hybrid models of the GD. The field model is based on Maxwell's equations, whose numerical solution is usually done by applying finite-difference time domain method (FDTD method). But for the GD calculations (an open-form problem with system dimensions that are several orders greater than wire section) this way is likely to be inefficient or impossible due to cumbersome calculations.

The frequency range for the GD calculations is limited by several MHz that in most problems corresponds to the near-field region of the Hertzian wave. But there is another extreme – a circuit model of the GD which is essentially simpler, however it is impossible here to take into consideration inductive coupling between components and shielding.

Moreover, component voltages and currents other than electromagnetic field strengths for EMC problems will result from the calculations.

Antenna theory corresponds perfectly well to modern GD design problems. At a given external action there should be specified firstly the current distribution over antenna components (inner problem) and then the distribution of the electromagnetic field generated by currents (outer problem). This procedure where both electrical circuit and electromagnetic field theories are used is also efficient for GD analysis.

B. Circuit-field GD model

The problems of the GD design are circuit-field type and their solution requires two interrelated models - circuit and field models [1, 2]. A field model is required to calculate electromagnetic characteristics of the GD components which will be used afterwards in a circuit model to calculate component currents. Once currents are specified, the distribution of electromagnetic field strength shall be calculated again on a field model.

The nodal solution (NS) is applied for steady-state conditions. The discrete coordinate method (DCM) shall be used to calculate impact acceleration processes. Problems with frequency-dependent usually confine the scope of the use of DCM application (to solve them the frequency-domain method is usually applied). But due to the development of efficient methods of frequency-dependent components such a restriction has been lifted [1, 2].

III. RESISTANCE OF THE GD UNDER IMPULSE EXCITATION

Let us consider a grounding device as passive impedor. Voltage $u(t)$ and current $i(t)$ are specified. It is required to find an input impedance of the impedor.

This problem has a simple solution under the form of resistance R or vector impedance Z at direct or simple harmonic current. The resistance of switching-type grounding device is a function of time. Nevertheless, the impulse resistance of the grounding device is widespread and it is equal to the ratio of maximum voltage to maximum current $z=\max(u)/\max(i)=\text{const}$. The ratio is used to calculate high-voltage surges and to compare resistances of the GD if they

have been specified at equal current pulses. Many researchers consider critically this characteristic (actually, one takes and divides two values of pulse functions and also for different instants of time).

Let us now define the impulse resistance of grounding device relying on methods of theoretical electrical engineering. We shall replace current and voltage pulses by equivalent sine waves of $f=0.25/T_1$ frequency (equivalent frequency) at a constant amplitude and we shall restrict ourselves to the design range $t < T_1$. Then, the impedance of the grounding device is equal to $Z=U/I=|Z|e^{j\varphi}$, and the resistance modulus $|Z(T_1)|=U_m/I_m$ coincides completely with the grounding device impulse resistance $z_i=|Z(T_1)|$. So, the impulse resistance has the sense of resistance modulus on an equivalent impulse frequency and is in this case the function of pulse leading-edge time $z_i(T_1)$. The calculation of dependency $z_i(T_1)$ may be performed either for pulses with linear rise or upon the frequency response function of resistance modulus $|Z(f)|$ at $f=0.25/T_1$. Since the impulse resistance was found for equivalent frequency it should not be used within the range $t > T_1$.

Upon the authors' opinion, the most convenient (and theoretically grounded) pulse characteristic of the grounding device is the transition resistance $z(t)$. Numerically it is equal to transition resistance at circuit coupling to dc power supply. The value $z(t)$ may be used for the grounding device comparison. The resistance of the GD is $R=z(\infty)$. To calculate the GD voltage at given current and $z(t)$ we shall use the Duhamel integral. The transition resistance may be obtained by analytical or experimental methods at any current pulse shape [1, 2]. An equivalent circuit may be easily correlated with the function $z(t)$. Thus, there is every reason to use the transition resistance as a common characteristic of the grounding device at impulse currents.

IV. GROUND SIMULATION MODEL

Two-layer ground is a satisfactory compromise solution between computational accuracy and fast operation. The model is used up to date but the tendency has been revealed for choosing multilayer horizontal models. The next step for the development of ground model is conditioned by layers having dipping interfaces, non-homogeneity, cavities etc. The model may be performed by using the FDTD program; however the labor intensity will be huge due to a very awkward matrix. We shall show the procedure which is much more effective for simulation of boundaries of any shape by using the integral equation method [3].

The piecewise non-homogeneous medium is reduced to a uniform medium by placing at boundary interface S induced (secondary) currents satisfying the integral equation

$$\frac{J(P)}{2} - k \int_S J(Q) \frac{dG(P,Q)}{dn} dS_Q = 0,$$

where $G(P,Q)$ – is the equation kernel that has the sense of potential in a target point P on surface S from power supply

source in point Q ; $dG(P,Q)/dn$ – is the derivative of kernel normally toward the boundary in point P that has the sense of strength; J – is the flowing-off current density; k – is the reflection ratio. Or in matrix form

$$\mathbf{D}_{12}\mathbf{I}_1 + \mathbf{D}_{22}\mathbf{I}_2 = 0,$$

where the index 1 refers to the grounding device, while the index 2 – to ground surface S . It follows that the relationship between secondary and primary currents takes the form

$$\mathbf{I}_2 = -\mathbf{D}_{22}^{-1}\mathbf{D}_{12}\mathbf{I}_1.$$

The voltage potential of the GD components with account of secondary currents shall be

$$\varphi_1 = \mathbf{R}_{11}\mathbf{I}_1 + \mathbf{R}_{12}\mathbf{I}_2 = (\mathbf{R}_{11} + \Delta\mathbf{R})\mathbf{I}_1,$$

where \mathbf{R}_{11} – is the resistance matrix of the GD components, \mathbf{R}_{12} – is the matrix of the mutual resistances of the grounding device and ground surface S ,

$$\Delta\mathbf{R} = -\mathbf{R}_{12}\mathbf{D}_{22}^{-1}\mathbf{D}_{12}$$

– is the matrix of reflected resistance of the grounding device.

Thus, the action of induced currents on boundary interfaces is reduced to the reflected resistance of the grounding device. The above technique does not result in dimensionality increase of the geometric model. A multilayer ground with boundaries of arbitrary shapes is the next step to increase the adequacy of the ground simulation model.

We shall take as an example the resistance of a horizontal bar at non-level interface ground-air with variable projection height h (Fig. 1). At $h=0$ we shall have a homogeneous ground model, where the bar resistance is $R=12.9$ Ohms. The same result is obtained by using the proposed method. At another end-point $h \rightarrow \infty$ the bar is inside the continued angle that gives us an analytical solution of $R=17.1$ Ohms. The numerical value of $R=16.7$ Ohms, $h=100$ m differs by 2.5%.

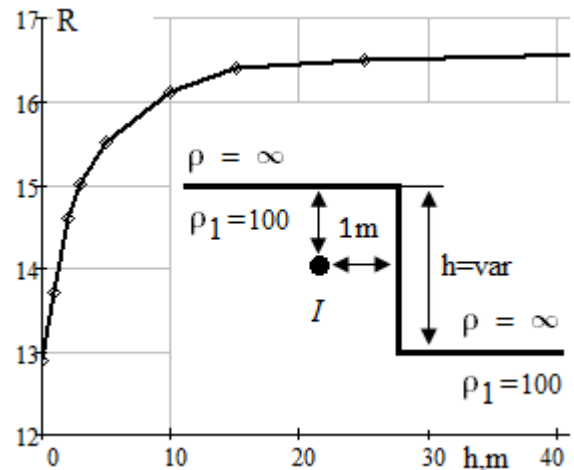


Fig. 1. Resistance of a horizontal bar of 10 m length and 20 mm in diameter.

V. ANALYSIS OF ELECTROMAGNETIC SCREENS

All steel structures of a substation serve as electromagnetic screens (grid and bulk) that contribute to damp interference caused by stroke and short-circuit currents. The design of a grid screen is similar to that one of ground grids; that is why the calculations of grid screens shall be performed together with the GD by using common programs. It is desirable to use a similar procedure for bulk screens by replacing them with grid models. Unfortunately they are not always correct as there is no Hertzian wave attenuation process in grid screens.

A real screen may be replaced by a curtain model (without wave attenuation) with equivalent conductivity found on the base of screening constant (plane wave) stability. Within the range of lightning frequencies (25 kHz and above) the model conductivity is taken as infinite (ideal screen), whose internal resistance is zero, we shall neglect capacitance currents. The screen shall be replaced by a bar grid. At selecting the bar diameter, the condition of invariable external inductance of a plate $d=0.36a$ should be met with the assumption that the plate current is constant where a – is the plate width (bar spacing). Thus, bulk screens may also be simulated by grids.

The screen exhibits screening constants of electric k_E and magnetic k_H fields. The electric field is efficiently attenuated by grounded structures. The analysis of k_H is of practical interest. For classic types of screens k_H is a constant value. In a general case k_H essentially differs inside the volume to be protected, so the analysis should be usually done in characteristic points, they should be away from the screen at 2-3 grid step distance in order to preclude the action of grid dimensional resolution on the results of the calculations. Using this procedure we always have a “dead” zone (where calculations are inaccurate), the dimensions of this zone are determined by grid step. The adjustment of a grid helps to expand operating conditions but does not solve the problem of k_H calculations near the screen.

The distribution of the screening constant over the screen surface contributes to exhibit the screen with more accuracy

$$k_H(s) = |H_0(s)/H_2(s)|,$$

where H_2 – is the strength in point s on the internal surface of the screen, H_0 – is the strength in the same point without screen. The distribution of k_H in 3D form gives a visual image of weak points on the screen. An average value of k_H features the screen as a whole. Under the influence of external field eddy currents appear in the screen, which weaken the field inside the screen and strengthen outside (Fig. 2).

When testing grid models (Fig. 2-4) there have been established the relationship between calculations accuracy and grid step. For example, an average screening constant of a spherical screen with grid (Fig. 3a) is equal to $k_H=33$ dB. It increases up to $k_H=37$ dB while the grid step reduces twice (Fig. 3a) and it increases up to $k_H=42$ dB if the grid step reduces twice once more (Fig. 3c). The screening constant slightly increases once the homogeneity of the external field becomes greater. For example (Fig. 3c), in the field of the two-wire transmission line $k_H=44$ dB. Certainly, analytical

calculations give us an arbitrary large value of k_H or $1/k_H=0$. But numerical results where $1/k_H < 1\%$ should be considered as ideal screening at a tolerable error of 1-5% for our problems.

For rectangular screens a considerable fall of screening constant in angles has been established. It should be found out how it is connected with calculations accuracy or screen properties. An average screening constant within the wire field is equal to $k_H=30$ dB. In a two-wire line $k_H=31.5$ dB and it increases up to 34 dB once the grid step is reduced twice. Thus, we observe once again that the results are affected by the grid step.

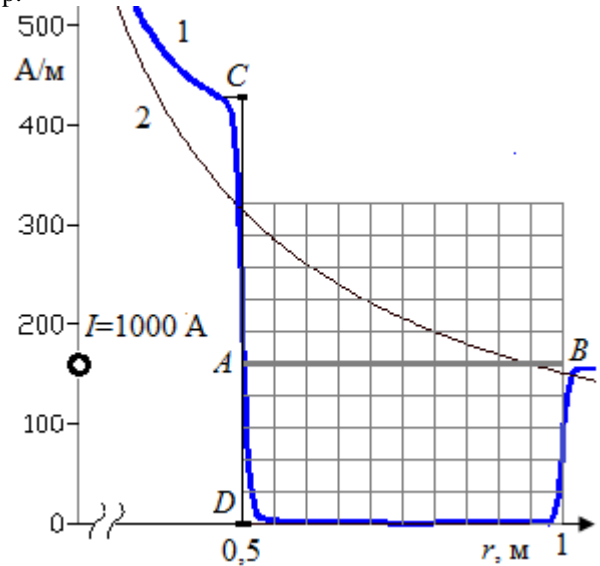


Fig. 2a A wire magnetic field with (1) and without (2) a cubical screen

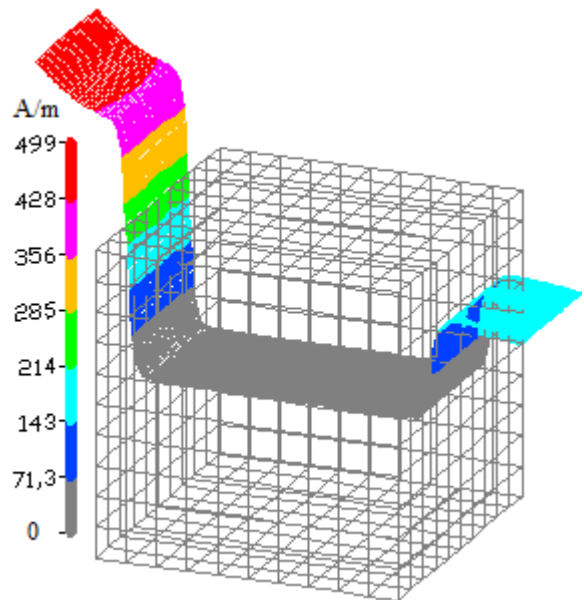


Fig. 2b A wire magnetic field with a cubical screen

We examined the solid screens but it should not be difficult to “cut windows” in grid models and to solve problems with the windows.

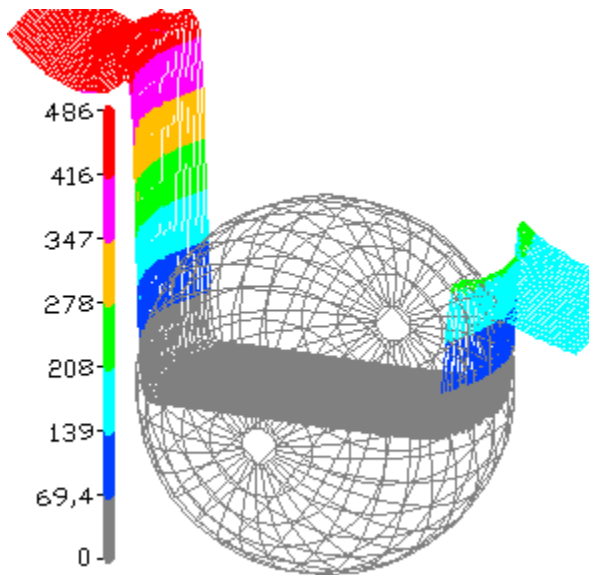


Fig. 3a A wire magnetic field with a spherical screen (0.5 m in diameter)

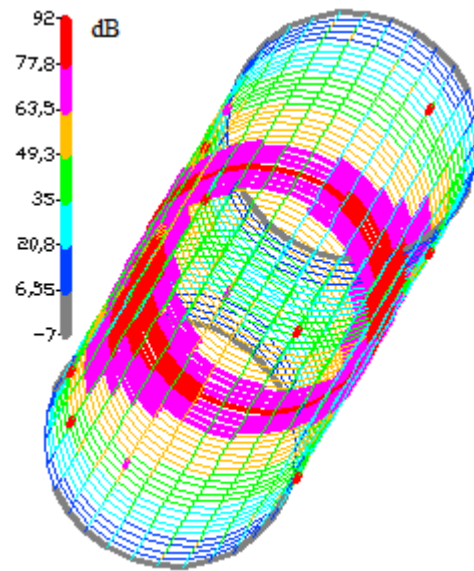


Fig 4 Screening coefficient k_H of a cylindrical screen of 0.5 m in diameter and 4 m long in magnetic field of a wire line

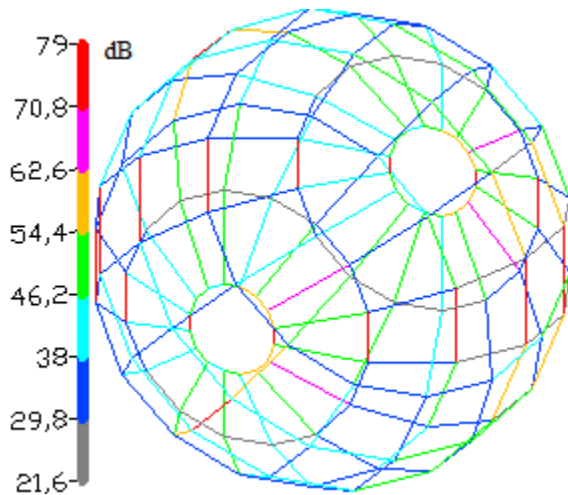


Fig.3b Screening coefficient k_H of a spherical screen

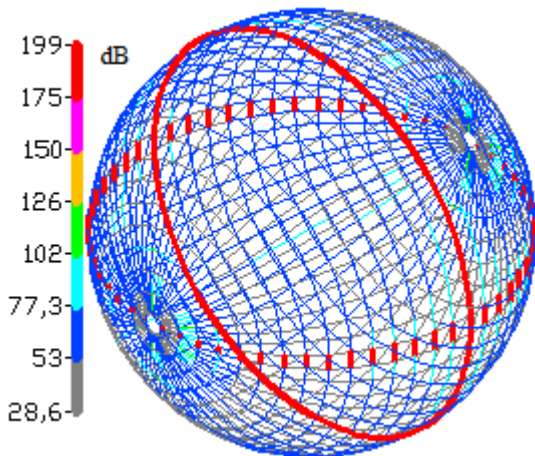


Fig.3c Screening coefficient k_H of a spherical screen

Thus, the calculations of grid and bulk screens are performed according to general procedures and programs together with the GD calculations. The problems of galvanic interference screening by using cable shields are solved by a similar way.

VI. COMPUTER PROGRAM

Computer program ZYM has been developed as an application to AutoCAD for the solution of problems of grounding, lightning protection, EMC and electromagnetic ecology. The application of the AutoCAD program is one of the main requirements of design engineers to the program. We have developed the user interface to be linked to AutoCAD through COM-technology. A high rate of analysis may be obtained due to Intel MKL use. Certainly, AutoCAD is not designed to make scientific analysis, it has not got standard tools for visualization and animation of scientific graphic charts MathCAD application has. These tools have been developed and they make the results visual (Fig. 2-4, [2]) and facilitate the chart control by AutoCAD tools. The main difficulty was to increase the rate of array data processing. We were to refuse the standard procedure of constructing a line (chart is a multitude of lines) AddLine. Charts are quickly plotted in dxf-files which are imported by AutoCAD.

REFERENCES

- [1] S.L. Shishigin, "Simulation models and calculation procedure of grounding devices," *Elektrichestvo, Russia*, 2010, vol 1, pp. 16 – 23.
- [2] N.V. Korovkin, O.V. Frolov, E.A. Ivanova and S.L. Shishigin, "Computing methods for building earthing devices in problems related to EMC of substations," *EMC Europe* 2012.
- [3] S.L. Shishigin, "Grounding resistance in multilayer soil with boundaries of arbitrary shape," *Elektrichestvo, Russia*, 2013, vol 4, pp. 18 – 23.