Safety and Emc Aspects of The Selection of Earthing Grid Material

József LADÁNYI*

Abstract

This paper deals with the effect of material quality, used for the installation of earthing grid, on electrical safety and EMC requirements. So, we compared technical performances of earthing grids made of thermally zinc coating laminated carbon steel with the earthing grids made of copper laminated profiles, and we particularly insisted on potential rises, step voltage evolution, as well as the EMC of the secondary wiring inside the dependent station.

Keywords: earthing grid, steel, copper, simulation, EMC, earth potential rise, step voltage

1. INTRODUCTION

During the last 6 decades, according to the Hungarian practice, the earthing grid of transformer stations was exclusively made of steel, or of any other steel-alloy. During the last few years, in Hungary, thanks to the adaptation of the other countries practice, the new transformer stations have been mostly established by using copper earthing grid. Many technical literatures and standards deal with earthing grid design and provide proposals for the grid materials. Unfortunately, the different material effect for the electrical safety (step and touch voltages, earth potential rise), and electromagnetic compatibility requirements (earth potential rise, potential differences inside the station affecting secondary wiring) are not considered in these literatures, thus the designers do not take into account these effects in their planning phase.

In this paper, comparisons are made between the features of earthing grids made of linear (copper) or nonlinear (steel) materials.

Steel earthing grids are generally built of cylindrical bar-steel. Strands are widely used in case of copper earthing grids rectangular copper tapes (e.g. size of 40 × 3 mm), or copper. Simulation study has been done to compare steel and copper characteristics of earthing grid. The analyses have been done for the 400/120 kV substation installed in Szombathely, Hungary. The designer, EROTERV Ltd., has given free run of the necessary input data (earthing grid design, fault current distribution, secondary wiring design) [1], [2].

Simulation study has been done for the following two cases:

- steel earthing grid built by cylindrical steel rods (bar-iron) of 20 mm diameter;
- copper earthing grid built by 40 × 3 mm rectangle zincked copper tape.

In both cases, the conditions (grid geometry, soil resistivity a.s.o.) were the same, except the grid material. The soil resistivity was 100 Ωm, and uniform. The study was made by CDEGS (Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis) software package [3]. The steel is a ferromagnetic material with nonlinearity internal impedance.

Therefore, in case of steel grid, this nonlinearity shell is taken into account. The nonlinearity means that, the internal impedance of bar-steel depends on the current magnitude flowing through the steel (on a given frequency). In addition, the internal impedance is frequency-dependent, as well. The internal impedance of the 20 mm diameter bar-steel has been measured by the use of a special laboratory measurement technique [4].

The Figure 1 shows the measured current depen-dence of internal impedance bar-steel for 50 Hz. In case of steel earthing grid, the current distribution has been determined by the iterative method considering the nonlinear measured internal impedance of bar-steel.

*József LADÁNYI Assistant Lecturer – Budapest University of Technology and Economics, Department of Electric Power Engineering, Budapest, Hungary.

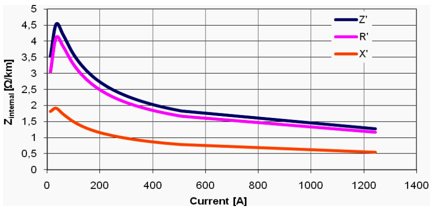

Figure 1. The resistive (R') and reactive (X') components of the measured internal impedance of bar-steel ($Z_{internal}$) for 50 Hz.

2. **E**ARTHING GRID RESISTANCE (R_E)

The resistance of an investigated earthing system has been calculated, by definition, as the ratio of the electrode potential rise (EPR) and the current causing it (Ohm's law). That's why, the current injection technique has been used. Thus, a test current has been injected into the grid, which caused a grid potential rise. The potential rise ratio to the remote earth, at the current injection point, and to the current value, give the grid resistance. The injected current is assumed in all cases to 10 kA with zero phase angle. The potential rises for copper grid and steel grid are shown in Figure 2 and Figure 3, respectively.

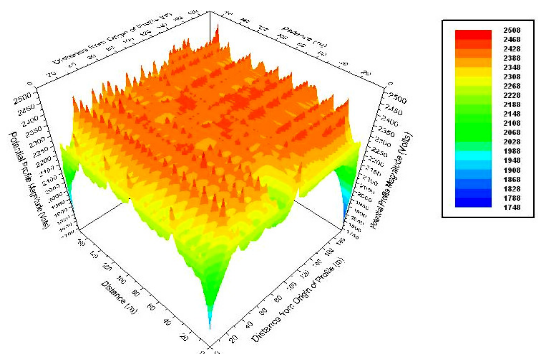

Figure 2. Potential rise of copper grid (calculated R_e is 0,2508 Ω)

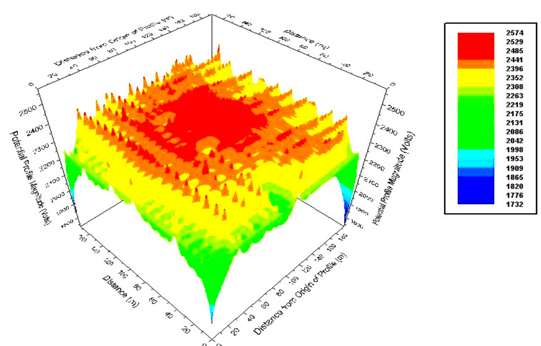

Figure 3. Potential rise of steel grid (calculated R_e is 0,2574 Ω

From these results, it is concluded that there is no considerable difference among the grid resistances of the copper and steel grids. The deviation is less than 3 %. That is clear, because the grid geometry and the total surface of grid elements, in contact with the soil, determine the grid resistance. In case of one injection point, the difference in the resistivity of steel and copper does not produce considerable difference in the potential distribution inside the grid, thus the grid resistances are practically the same in both cases.

3. **P**OTENTIAL DIFFERENCES IN THE GRID

As we explained above, the current injection in one grid point is only a theoretical model determining the grid resistance. The following current injection points should be considered during normal operation or under faulty conditions:

- the neutral of transformer(s),
- the earth connection points of the wires and/or cable sheaths,
- the point of earth fault inside the station.

The distribution of earth fault current is shown inside the station in Figure 4.

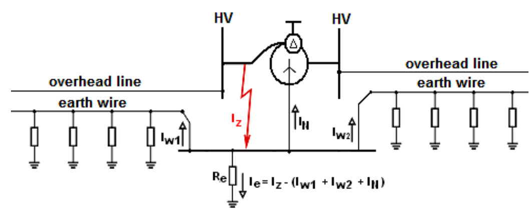

Figure 4. Grid current identification.

The different injection points of the investigated earthing grid are shown in Figure 5.

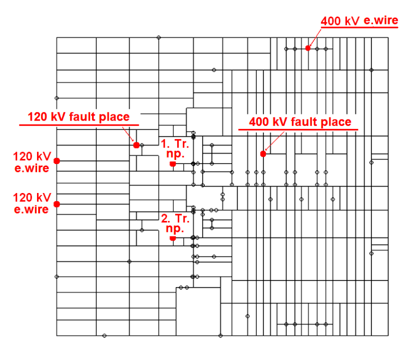

Figure 5. Grid geometry with injection points.

Calculation of the potential difference inside the station requires the followings:

- magnitude of the earth fault circuit current I_z;
- identification of the current I_e, actually flowing through the grid resistance.

In fact, this is the difference in the I_z and the following currents: I_{w1} and I_{w2} returning through the earth wires (no cable sheaths in this station), I_N returning through the neutral of the transformers.

The identification of fault current portion, that is conducted by the substation earthing grid into the earth, requires a detailed calculation of the current distribution. The distribution of zero-sequence earth fault current is given by network designer (EROTERV Ltd). The neutral current of the transformers is directly determined from the distribution of zero-sequence currents. The earth wire currents were calculated by the CDEGS software on the basis of overhead line parameters, tower's earth resistances and the grid resistances of connected substations (Szombathely itself, Györ, Szombathely-vépi). The overhead line parameters calculated by PLINE (Calculation of Power Line Parameters) software [5] on the bases of the conductor arrangement. Calculations have been done for two cases: the earth fault is on 120 kV or 400 kV level inside the station. The calculation results are contained in Table 1.

Table 1. Injected current values in case of earth fault on 120 and 400 kV voltage levels (see Figure 4 for ref. directions)

Injection point	120 kV	400 kV
Earth fault point	15927/-87.94°	6982.9/-85.72°
I_{N1} neutral	4778.82/-90.22°	-948.48/-83.81°
I_{N2} neutral	4323.81/-88.93°	-948.48/-83.81°
I_{vv} to Györ	927.3/-93.69°	2106.5/-78°
I_{vv2} to Vépi	525.27/-43.78°	265/-49.26°
I_{vv1} to Vépi	454.65/-51.95°	265/-49.26°

The following values have been investigated by the simulation study:

- the maximum potential rise of the grid (EPR),
- the step voltages,
- the potential differences inside the station (affecting the secondary wiring inside the station)

Figure 6 and Figure 7 show the potential rise of copper and steel grid (U_e) in case of 120 kV earth fault.

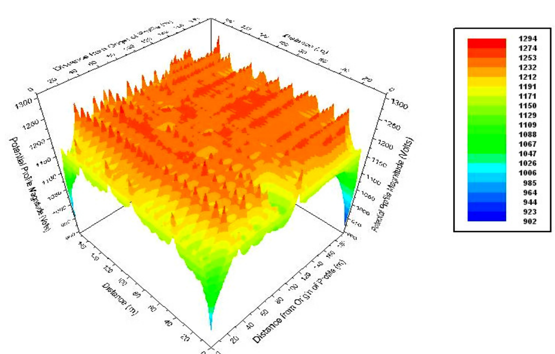

Figure 6. U_e for copper grid (U_{emax} = 1294 V).

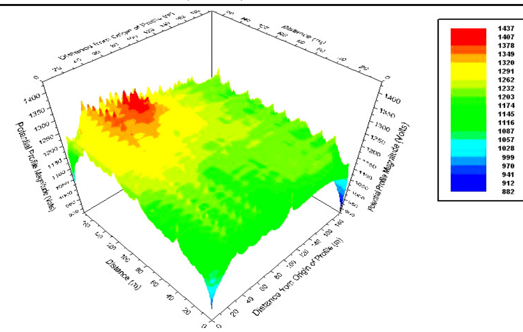

Figure 7. U_e for steel grid (U_{emax} = 1437 V).

It can be seen from the results, that the shapes of the 3D potential profiles significantly differ. These differences are due to the 2/3 part of the total earth fault current flows among the injection points (see Table 1.) causing potential drop on the grid elements. In case of steel, this potential drop is more significant due to the non-linearity and the higher difference of resistivity of grid material. In case of 400 kV earth fault, the differences in the potential values for copper and steel grids are less than in the previous case. That is predictable from Table 1. The maximum grid potentials and step voltages values are plotted in Table 2.

Table 2. Maximum grid potential (U_e) and step voltage (U_L) values in case of 120 kV and 400 kV earth fault

120 kV				400 kV			
$U_{e,max}$ [V]		$U_{L,max}$ [V]		$U_{e,max}$ [V]		$U_{L,max}$ [V]	
Copper	Steel	Copper	Steel	Copper	Steel	Copper	Steel
1294	1437	69,5	75,8	1602	1637	82,3	85,4

4. SECONDARY WIRING

The potential differences between points are appearing as common mode voltages in the secondary wiring between those points. These common mode voltages can be reduced, if needed, by the compensating effect of the cable sheath earthed at both ends. The compensating effect, characterised by the screening factor could be controlled by the appropriate design of the cross-section area of the wounded concentric screen. However, the screen should be checked in thermal stress point of view as well. Really cable tracks were considered with the worst case.

5. CONCLUSIONS

The following main conclusions are drawn from the simulation calculations:

- The grid material does not affect practically the grid resistance.
- Steel grid results higher step voltages, grid potentials and potential differences inside the station, but these values limited controlled accordingly to the limits by appropriate design.

- The establishment costs of the copper grid are significantly higher (1.6-1.8 times) than the steel grid.
- With adequate design (mesh size) the electrical safety and EMC requirements could be achieved by steel grid as well. The common mode voltages due to the potential differences inside the station can be reduced by improved screening of the wiring, i.e. with the increase of cable sheath cross-sections.
- Attention should be paid simultaneously to the electrical and corrosion effects in the planning phase of the earthing grid [5].

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József Ladányi
Assistant Lecturer,
Budapest University of Technology and Economics,
Department of Electric Power Engineering, Budapest, Hungary