periodica polytechnica

Electrical Engineering
53/1-2 (2009) 73–77
doi: 10.3311/pp.ee.2009-1-2.09
web: http://www.pp.bme.hu/ee

RESEARCH ARTICLE

Analyses of the grid resistance measurement of an operating transformer station

József Ladányi / *György* Varjú

Received 2010-05-22

Abstract

This paper presents a non-conventionally installed HV/MV underground substation from the point of view grid resistance. The effects of the infeed high voltage (HV) cables and the connected medium voltage (MV) distribution cables on the resultant earthing resistance are studied. The grid resistance was calculated by the CDEGS software code in the design phase. Further more the grid resistance was measured both before and after the installation and jointing the connecting cable lines. The paper presents results on the frequency dependence of the grid resistance as well.

Keywords

Earthing · grid resistance · substation · simulation · measurement

József Ladányi
Department of Electric Power Engineering, Power Systems and Environment, BME, H-1521 Budapest,, Hungary
e-mail: ladanyi.jozsef@vet.bme.hu

György Varjú
Department of Electric Power Engineering, Power Systems and Environment, BME, H-1521 Budapest,, Hungary

1 Introduction

In case of simple grid arrangements, the grid resistance can be determined with analytical expressions given in the technical literatures [1, 2].

Nowadays the grid resistance of complex earthing systems with the consideration of the actual soil resistivity values and stratified soil structures can also be calculated by sophisticated computer codes based on numerical techniques [3].

Measuring the grid resistance of an already operating substation is difficult, due to the earth wires, cable sheaths, neutral of LV lines and other earthed structures connected to the grid.

This paper presents simulation study, measuring technique and measured grid resistance values of a substation immersed below the ground, called underground substation.

2 Problem identification

The earth potential rise (EPR) is the maximum electrical potential that a substation-earthing grid may attain relative to the distant earthing point due to the grid current, generally, caused by earth fault (Fig. 1).

Calculation of the potential rise of the earthing electrode covers the considerations:

- magnitude of the earth fault circuit current Isc,
- identification of the current Ie actually flowing though the grid resistance. In fact this is the difference in the Isc and the following currents: Iw and/or Ish returning through the earth wires and/or sheaths of the HV cables, respectively, I_N returning through the neutral of the transformers and finally I_{MVsh} flowing out from the grid through the sheaths of the connecting MV cables and other passive metallic structures,
- identification of the grid resistance R itself.

In fact, the EPR is equal to the maximum grid current I_e times the grid resistance R.

The identification of the portion of fault current that is conducted by the substation earthing grid into the earth requires a detailed calculation of the current distribution by specialised technique [4].

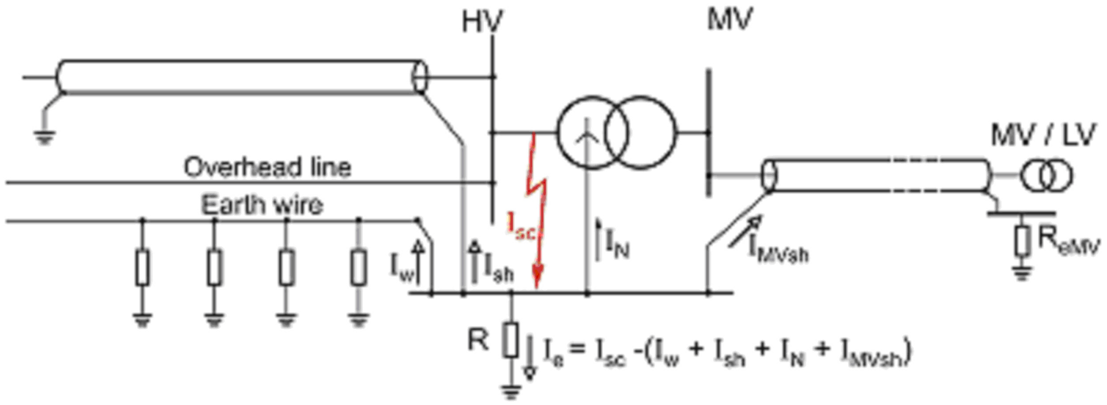

Fig. 1. Grid current identification

Measuring the grid resistance of a substation is simple only in that case when the substation is out of operation and the earth wires, the cable sheaths, the transformers star points and neutral conductors of LV lines, if present, are disconnected from the earthing grid. In practice, this can be realized in simple way only, during the installation phase of a new substation.

The paper provides methods and results of measurements performed in an operating substation.

3 Arrangement of the HV/MV substation

The allocation of the investigated HV/MV substation (called "Vermezö") is in a green park thus its installation required an environmental friendly way. Therefore, the only possibility was to install it as an underground substation.

The earthing system of such a not conventional underground 120/10 kV substation is investigated in the followings.

3.1 Arrangement of the earthing system

The basic arrangement of the earthing system of Vermezö substation is plotted in Fig. 2. On the top (-0.5 m) there is a frame which is connected to the vertical rods. The earthing grid itself is at the bottom (-18.5m) embedded into a 0.5 m thick backfill layer.

3.2 Feeding arrangement of the HV/MV substation

Each of the two HV/MV transformers (31.5 MVA each) of the "Vermezö" substation is fed by a double circuit 120 kV single core cable from the "Budaközep" substation (Fig. 3). The concentric copper wire screens of cables are directly connected to the earthing grids at the both ends. The distance between the substations is approximately 500 m.

There are 14 MV cables fed by "Vermezö" substation at 10 kV level. The cables are the mixture of old type lead sheathed steel armoured cables having continuous leakage to the earth, and plastic insulated cables with insulated outer jacket.

4 Calculation of the grid resistance

The resistance of an investigated earthing system has been calculated, by definition, as the ratio of the earth potential rise and the current causing it (Ohm's law). During the simulation calculation, 1 kA current was injected into the grid with zero reference phase angle.

For the simulation the real soil resistivity and stratification was considered obtained from preliminary measurement. These

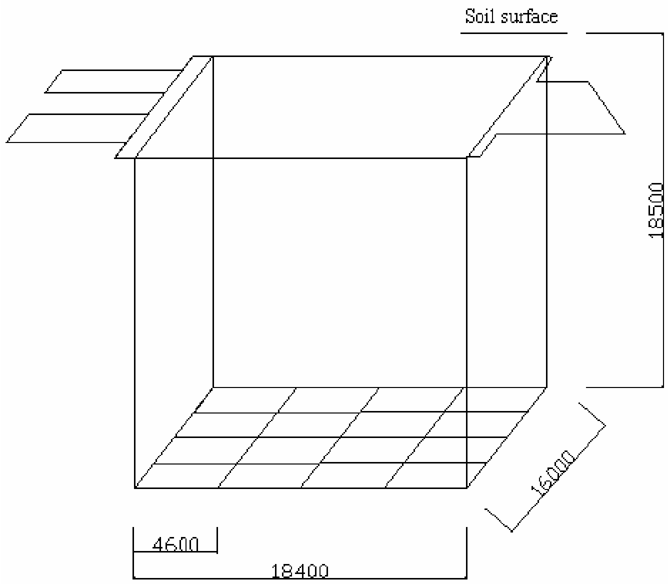

Fig. 2. Arrangement of the earthing system.

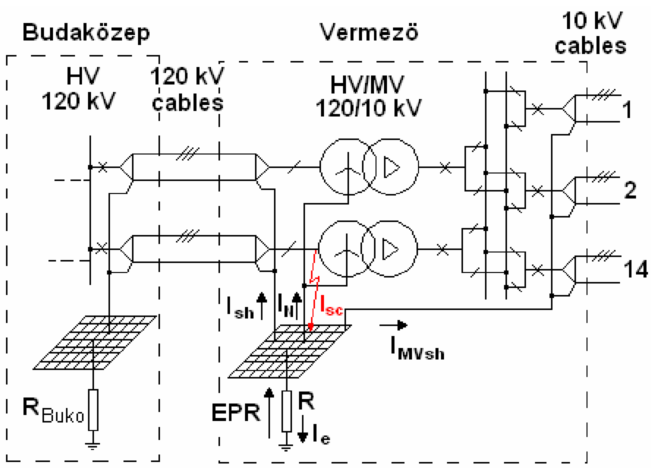

Fig. 3. Feeding arrangement of the substation

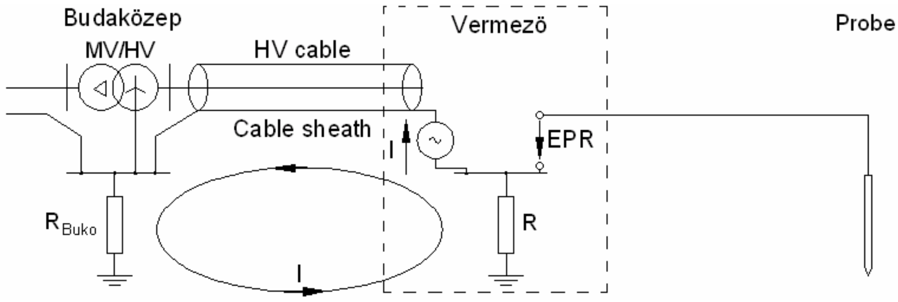

Fig. 4. Measurement scheme

values are shown in Table 1.

Tab. 1. Stratified soil with 7 layers

Layer number	Soil resistivity [Ωm]	Thickness (m)	
1	infinite	infinite	air
2	111	0.3	
3	103	1.2	
4	30	7.2	
5	3	9.5	soil
6	10 (backfill)	0.5	
7	3	infinite	

When the grid is assumed to be embedded into the concrete at the bottom the layers no. 5, 6 and 7 are merged into one layer which is identical with the layer 7.

Basic parameters are the followings:

- Stratified soil (see Table 1).
- Resistivity of the concrete is 60 Ωm (value given in [2]).
- Injected current is 1 kA into the centre of the grid.
- Air resistivity is 1E+18 Ωm (homogenous).
- Material of earthing system is Ø25 mm cylindrical stainless steel.

The grid resistance has been compared for conductors having diameters of 20, 25 or 30 mm (Table 2) The calculation results do not show significant differences between the resistance values. Finally, Ø25 mm stainless steel conductor has been selected on the bases of different practical considerations. It is worth mentioning, that the material of the grid is not affecting the grid resistance [5].

Tab. 2. Effect of the conductor diameter

Conductor diameter	R [Ω]
Ø 30mm	0.296
Ø 25mm	0.299
Ø 20mm	0.305

In the CDEGS software by hard adventure there is no possibility to consider embedded conductors and stratified soil simultaneously. Mind this fact the options given in Table 3 were examined.

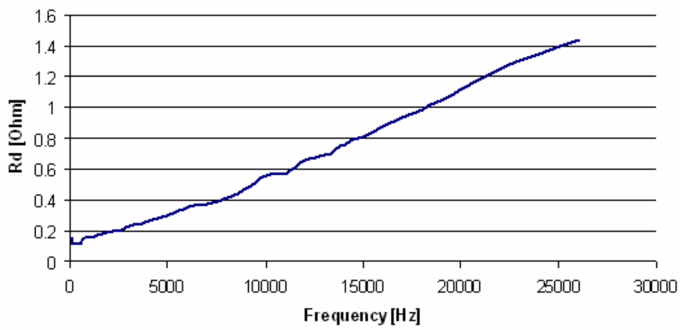

Fig. 5. Measured grid resistance vs. freuency

Tab. 3. Investigated cases

Case no.	Embedding of vertical rods	Embedding of bottom grid	Filling of inside area	Soil structure	R [Ω]
1	Embedded		Soil		0.31
2			Air	Uniform 20 Ωm	0.30
3	Emb.	Non			0.27
4	Emb.	10 Ωm	Soil		0.248
5	Non			5 layer	0.056
6	Non	10 Ωm	Soil	7 layer	0.064
7	Embedded			Uniform 10 Ωm	0.159
8	Emb.	Non			0.133

In the planning period the grid resistance has been calculated for the following conditions:

1 both the vertical and the bottom grid conductors are embedded in concrete (cases 1, 2 and 7);

2 only the vertical rods are embedded in concrete (cases 3, 4 and 8);

3 non of them are embedded in concrete (case 5);

4 non of them are embedded in concrete but the bottom grid is laid in backfill (case 6).

The calculations have been performed both for 20 and 10 Ωm in case of uniform soil structure. For these two resistance values, the grid resistance changes also correspondingly to 2:1 ratio (compare cases no. 1 and 3 with cases no 7 and 8, respectively).

Embedding of the conductors, especially the grid in concrete, increases the resistance remarkably (cf. cases no 1 and 4 or 7 and 8).

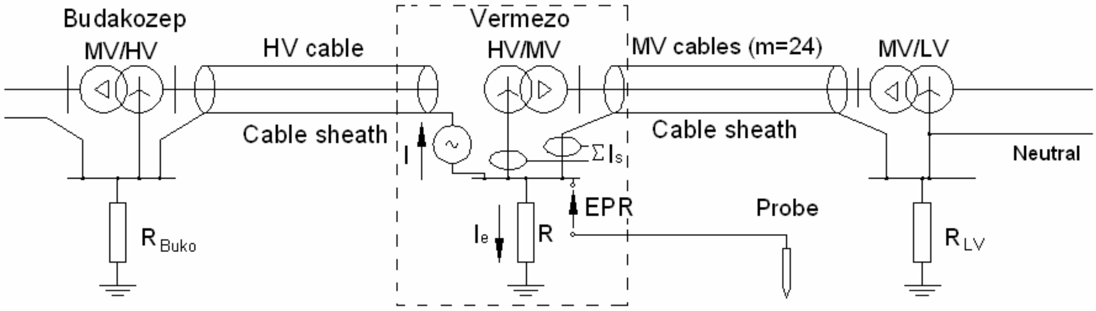

Fig. 6. Measurement scheme after completion.

5 Measuring technique

Current injection technique and fall-of-potential (FOP) method [6] was used during the measurement. The measuring current has been injected into one of the sheath of HV cable via the earthing of the Budaközep substation (see the loop I in Fig. 4). The other sheaths of the HV cables were disconnected from the earthing grid of Vermezö.

The EPR occurring in Vermezö has been measured against a voltage probe, placed 200 m away from the Vermezö in opposite direction to Budaközep.

The grid resistance could be calculated as a ratio of the EPR and the injected current causing that EPR.

6 Measured grid resistance

The grid resistance of the Vermezö HV/MV substation was checked by site measurement after the completion of the earthing system but before the connection of the MV cables. During that installation phase, the "Vermezö" substation was out of operation and the screens of the 120 kV cables could be disconnected from the Vermezö grid.

The grid resistance was measured by:

1 injected current at 50 Hz;

2 injected current varying from 35 Hz – 26 kHz.

The grid resistance values measured at 50 Hz is given in Table 4.

Tab. 4. Grid resistance values (frequency 50 Hz)

I[A]	U_{probe}[V]	$R[\Omega]$
9.94	1.381	0.139
20.00	3.023	0.151
30.00	4.390	0.146
40.00	5.810	0.145
50.00	7.201	0.144
	Average	0.145

The measured average value of the grid resistance of 0.145 Ω is in a good agreement with that obtained from the simulation calculation for the cases of 7 and 8 given in Table 3.

In fact the cases 4 and 8 correspond to the actual installation of the grid, i.e, the vertical conductors are embedded in the concrete and the bottom grid is laid in the backfill. The uniform soil resistance of 20 Ωm (case no 4) seems to be an overestimated value for the representation of the stratified soil.

On the other hand, soil resistance of 10 Ωm (case no 8) results in a grid resistance, which is very close to the measured value. This is reasonable due to the very law specific resistance of the deeper layers.

In the second case, the grid resistance was measured vs. the frequency. For this purpose, the frequency of the injected current was varied between 35 Hz and 26 kHz while the EPR was measured by selective meter (a narrow band analyzer).

The measured grid resistance values are shown vs. the frequency in Fig. 5.

It can be seen, that the grid resistance is approximately linearly increased with the frequency.

7 Scheduled future measurement

The "Vermezö" substation has recently been taken into operation, i.e. the neutrals of the feeding HV/MV transformers; all cable sheaths are bonded to the earthing grid.

The measurement scheme applicable in the operating substation is presented in the Fig. 6.

The measurement of the grid resistance requires the identification of the current I_e flowing through the grid resistance itself.

The current I_e, which causes EPR can be determined as:

$$I_e = I - \Sigma I_s \tag{1}$$

where I is known (injected current), $\Sigma I_s$is the vector sum of the currents measured in the sheaths and neutral points of the transformer.

The determination ofI_e needs the measurement of the current distribution as shown in Fig. 6.

To appoint frequency dependency of the grid resistance, the current distribution should also be measured as a function of the frequency. Thus, the grid resistance can be separated from of the over all resistance of the substation earthing system.

8 Conclusion

The grid resistance can be determined with analytical expressions given in the technical literature in case of simply grid arrangements for homogenous soil structure [1, 2]. In the planning period sophisticated computer codes based on numerical techniques [3] were applied for the investigation of the grid resistance of complex earthing system with the consideration of the soil resistivity values and stratified earth. In this paper, the study of a not conventional, underground substation is presented from the point of view of grid resistance measurement.

Grid resistance measurement is a difficult task when the cable sheaths, transformer neutral-points of the feeding transformers, are already connected to the earthing grid.

The grid resistance is checked by site measurement after the completion of the earthing system. In addition, the grid resistance has been investigated as a function of frequency.

References

1 **Tagg G F**, *Earth resistances*, George Newnes Limited, London, 1964.

2 *IEEE Standard 80-2000*, 2000. IEEE Guide for Safety in AC Substation Grounding.

3 *Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis (CDEGS) Software package manuals*, Safe Engineering Services & Technologies Ltd., Montreal, Quebec, Canada. Application Version 13.

4 **Sollerkvist F J, Varju Gy**, *A general model and numerical method for multiconductor systems in frequency domain*, Proceedings of the IEEE/KTH Stockholm Power Tech Conference, Unknown Month June 18, pp. 227-232.

5 **Ladányi J**, *Examination of the effect of the earthing grid material in high voltage substations*, Budapest, 2006. M. Sc. thesis, (in Hungarian).

6 **Dawalibi F P, Mukhedkar D**, *Ground electrode resistance measurement in nonuniform soils*, IEEE Trans. **PAS 93** (Jan. 1974), no. 1, 109-116.