A Practical Method to Test the Safety of HV/MV Substation Grounding System

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Abstract. The adequacy of a Grounding System (GS) to the safety conditions has to be periodically tested by measurements. The test methods and techniques used to verify the electrical characteristics of the GS include the measurements of step and touch voltages. The goal of the test is to verify that touch voltage and step voltage remain below a safe value in all the zones of the installation. The measurements can present some operational difficulties. The purpose of this paper is to present the procedure, step-by-step, of a practical method of measuring touch/step voltages in grounding systems located in urban or industrial areas with reduced accessibility. The suggested method uses auxiliary current electrodes located at short distances. This paper demonstrates by test measurements done in a real case that the method provides conservative results.

Index terms: Electrical safety, grounding system, global grounding system, ground potential.

I - INTRODUCTION

A grounding system (GS), during its operation, has to assure that a person operating inside or near grounded facilities has not to be exposed to the hazard of critical electric shock. It is well known that under normal conditions, grounded electrical equipment operates at near zero ground potential. During a ground fault event, the flow of current into the ground causes potential gradients within and around the zone of influence of the GS. Protection against electric shock requires GSs must guarantee to keep touch voltage (Ut) and step voltage (Us) to a safe permissible value. In order to guarantee the adequacy of the GS, periodical measurements should be conducted.

Since the rigorous measure can result too much laborious or too much expensive, a simplified conservative testing method of the behavior of ground electrodes can be favorable.

The European EN 50522 and International IEC EN 61936-1 Standards [1,2] introduced, with reference to MV distribution systems, the concept of global grounding system (GGS), that is defined as "equivalent GS created by the interconnection of local GSs that ensures, by the proximity of the GS, that there are no dangerous touch voltages".

The Meterglob project, founded by the Italian CCSE (Cassa Conguaglio per il Settore Elettrico), is studying different aspects related to GGSs. At the Meterglob project is working a consortium of six partners: Enel Distribuzione, Politecnico di Torino, Sapienza Università di Roma, Politecnico di Bari, Università di Palermo and Istituto Italiano del Marchio di Qualita IMQ. In particular, the contribution of extraneous conductive parts and LV neutrals to the ground surface equipotentialization and the problem of periodic testing of safety conditions of Grounding Systems (GSs) have been studied. In addition to this, one of the outcomes of the Meterglob project will be a set of guidelines for the definition of GGSs [5-8]. This paper presents a practical method that can be used for measuring step and touch voltages in GSs associated with substations and electric Utility facilities. The method is particularly suitable for GSs of facilities and HV/MV substations located in urban or industrial areas where it could be very complicated to install the current electrode outside the influence zone as required by the Standards. The suggested method uses multiple auxiliary current electrodes at short distances. The paper demonstrates by test measurements done in real cases that it provides conservative results.

II – SAFETY ADEQUACY OF GROUNDING SYSTEMS GSS

The safety adequacy of a Grounding System (GS) can be verified by:

i) the measurement of the Ground Potential Rise (GPR)
ii) or if the GPR exceeds the admissible limit by the measurement of the Touch Voltages (Ut) and the Step Voltages (USs) .

In the second case, if the values of Ut and Us, measured in different locations, do not exceed the admissible limits fixed in the Standards, the GS is certainly adequate apart from the value of Ground Potential Rise (GPR).

The limits of the Ut and Us are fixed by the Standard that offers a curve of maximum values of voltages according to the tripping time of the protective device (Figure 1).

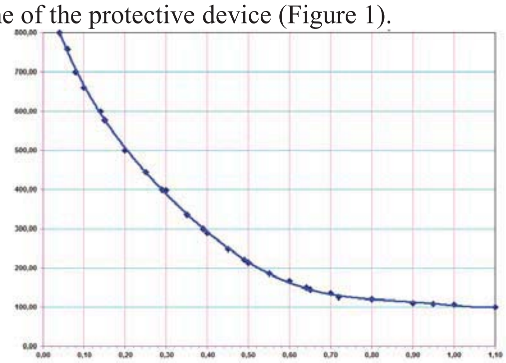

Figure 1. Maximum permissible values of voltages according to the tripping time of the protective device in HV-MV systems

This protective device is:

- the MV circuit interrupter for a grounding system of a facility with a MV Point of Connection;
- the HV circuit interrupter for a HV/MV substation.

The Ut values that appear on the system depend on the prospected fault current I_F. Generally, I_F can assume the following values:

- for MV systems, about 50 A in a system with a compensated connection of the neutral to the ground, about 100-300 A in a system with isolated neutral;
- for HV/MV substation more than 10 kA (HV ground fault in a system with the neutral solidly grounded).

In the second case, typical of the HV/MV substations, normally the GPR measured is more than the limit, so that, it is necessary to measure the Ut and the Us in several points of the installation.

In installation tests, GPR, Ut and Us are measured by the fall-of-potential FoP method. This method requires circulating a test current I_F between the GS under investigation and a remote current probe A (Figure 2).

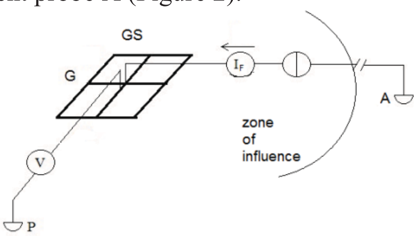

Figure 2. FoP method. A test current I_F is circulated between the GS and A. The voltage V between the GS and P is measured.

The accuracy of the voltage measurements depends on the actual location of the probe A.

The probe has to be located outside of the zone of influence, at a distance from the border of the GS at least equal 4 times its maximum length [2].

For the GPR measurement, the operator has to locate the voltage probe (P in Figure 2) in the inflection point of the potential profile (Figure 3). At this aim the operator has to move the probe P looking for the flat slope.

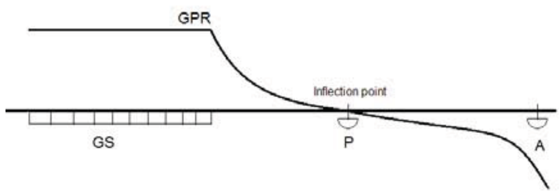

Figure 3. GPR profile and the flat slope useful for the GPR measurement.

III - Practical method with probes at short distance

Previous papers proposed a conservative practical method to verify the safety adequacy of a GS by locating one or multi auxiliary probes at short distance (Parise method) [9, 10].

Placing the current auxiliary probe A at a short distance, the potential profile U is modified in U' as shown in Figure 4.

If the current probe A is located too close to the GS the potential profile is influenced and distorted by a "cut" effect on the GPR measurement and a "gradient" effect on the U(x) measurement [9]. In this case the operator doesn't find a flat slope.

If the GS under investigation is situated in a zone characterized by the presence of obstacles or other facilities that don't allow to place the auxiliary electrode at the required distance, it becomes impossible to execute a correct measurement.

The voltage between the GS system and a generic point P on the earth surface, may be defined as:

$U_{GS\text{-}P}$=GPR-U(P), if referred to an auxiliary probe located at remote point,

$U'_{GS\text{-}P}$=GPR'-U'(P), if referred to an auxiliary probe a short distance.

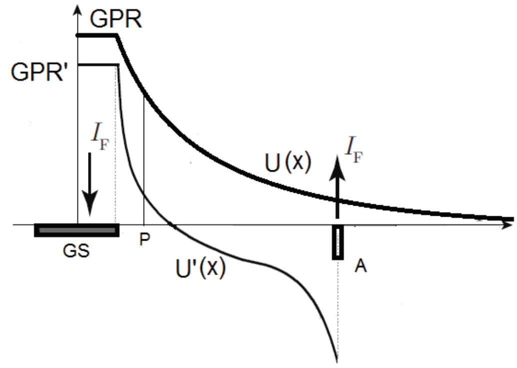

Figure 4 Distorting effects with probe A close to GS: a "cut" effect on the GPR and a "gradient" effect on the U(x)

The relative error is:

$$\varepsilon = (U'_{GS\text{-}P} - U_{GS\text{-}P}) / U_{GS\text{-}P} \quad \text{[p.u.]}$$

The suggested method [9] offers conservative results with an error depending on the number of the current probes n, their distance by the border and their position α around the GS under test (Figure 4).

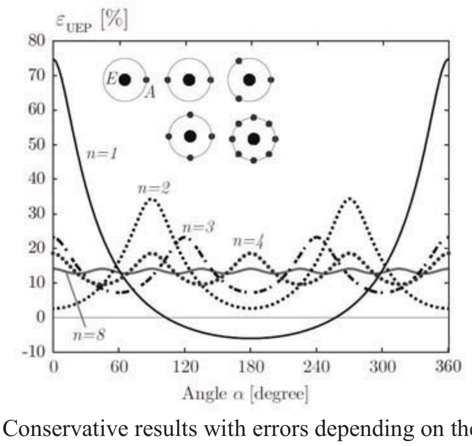

Figure 5. Conservative results with errors depending on the number n of the current probes A, their distance by the border and their position α around the GS under test

The use of n auxiliary probes influences the results with the following characteristic behavior (Figure 5):

- the absolute value of the relative error ε rapidly decreases with the increase of the number of the probes n;
- the fluctuations of the relative error reduce with the increase of the n;
- increasing n the relative error reduces but it does not reach zero.
- in order to reduce the relative error, it is necessary to increase the distance of the probes by the contour.
- the error reaches quasi-zero when the distance is more than 4 times the maximum length of GS.

In a practical way, it is possible to use 4 auxiliary electrodes located around the GS under investigation as shown in Figure 6 that shows the zones in gray where the error can influence the results in a not conservative way.

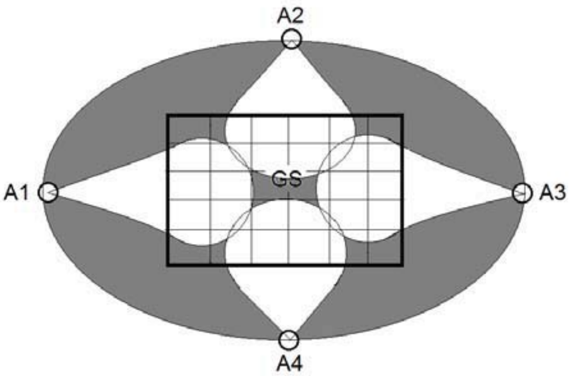

Figure 6 The gray zones are potentially the locations where the error can influence the results of Ut,s in a not conservative way.

III – Procedure for measurement tests

A procedure to apply the method with auxiliary probes at short distance for measurement tests of Ut/Us voltages on a GS can be summarized in the following step-by-step items.

Preliminarily, it is necessary to identify the points of interest inside the substation HV/MV where to check the safety conditions (Ut and Us below the limits) for the placement of the potential probe.

1) As first step, the operator makes the measurements by adopting an auxiliary current probe L located at long distance (Figure 7). The Ut and the Us are measured in the points of interest.

2) As second step, the operator makes the measurements by adopting an auxiliary probe (S1 in Figure 7) located at short distance SD. The probe A is located in the middle point of one side. The Ut and the Us are measured in the same points of interest of the first step.

3) As third step, the operator makes the measurements by adopting an auxiliary probe (S2 in Figure 7) located at the same short distance SD but in the corner of the GS. The Ut and the Us are measured in the same points of interest of the previous steps.

4) As forth step, the operator makes the measurement by adopting 4 auxiliary probes (A1, A2, A3, A4 in Figure 8) located at the same SD of the third step, symmetrically around the GS under investigation in the middle points of the sides. The Ut and the Us are measured in the same points of interest of the previous steps.

5) As fifth step, the operator makes the measurement by adopting 4 auxiliary probes (B1, B2, B3, B4 in Figure 8) located at the same SD of the previous step, symmetrically around the GS under investigation in the corners. The Ut and the Us are measured in the same points of interest of the previous steps.

6) As sixth step, the operator repeats the step 4 but with a distance equal to 2 times SD.

7) As seventh step, the operator repeats the step 5 but with a distance equal to 2 times SD.

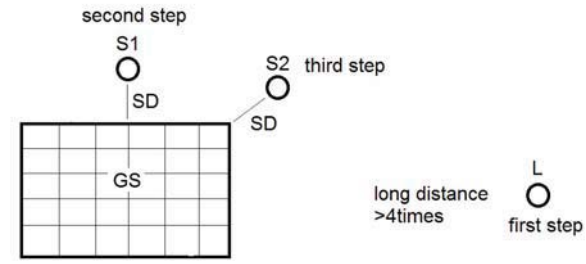

Figure 7 Locations of a sole probe at short distance

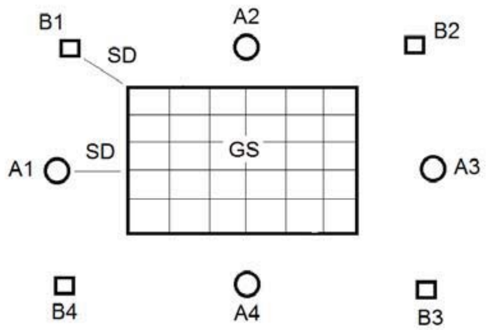

Figure 8 Locations of more probes at short distance

A special campaign of measurements has been made in order to validate the results of the conservative method.

Figure 9. HV/MV substation situated in Carpi (Italy)

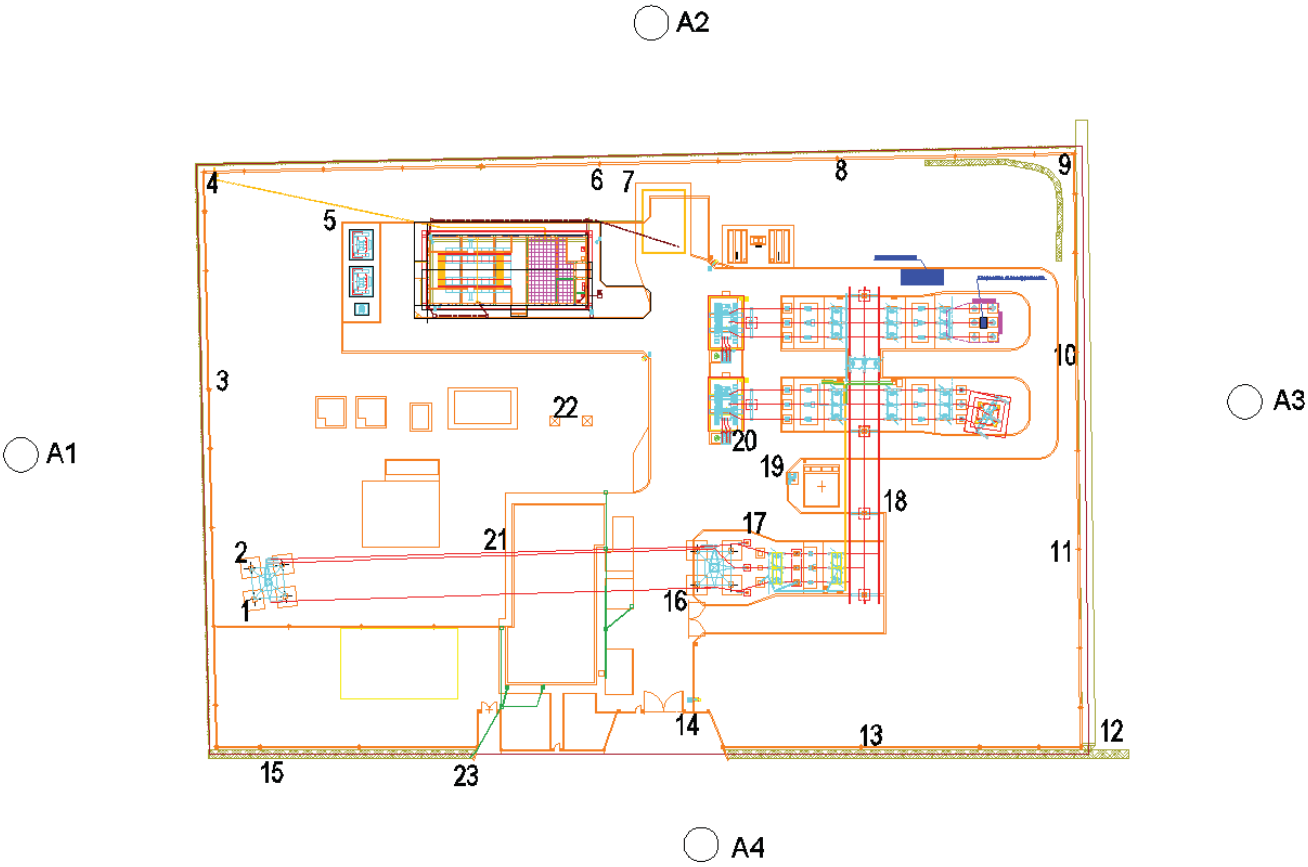

Figure 10 Grounding system of a HV/MV substation situated in Carpi (Italy): tested points

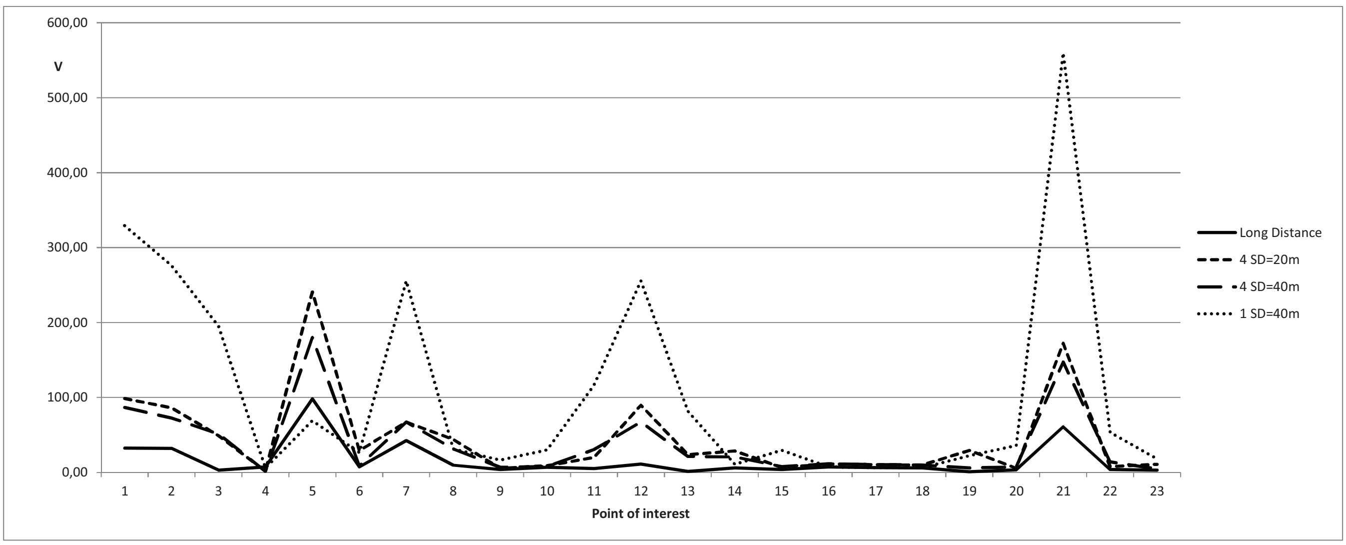

Figure 11

The objective of the campaign was to check the measured values of the Ut and Us through the use of more probes located at a short distance compared to the values measured with the typical use of one probe located remotely.
The GS under investigation presented in this paper is a grounding system of a HV/MV substation situated in Carpi (Italy) (Figures 9 and 10).
The substation is surrounded by cultivated fields. Only in the south side, there is a fuel station.
Figure 10 shows the points of interest identified in the sample case.
The measurements have been made:

1) with one auxiliary probe at long distance,
2) with 4 probes at short distance SD=20m,
3) with 4 probes at SD=40 m,
4) with 1 probe at SD=40m

The global test current is of 38 A. The current distribution is shown in Table I.

Table I Current distribution

	Long distance	4 SD=20m	4 SD=40m	1 SD=40m
A1		9 A	14 A	
A2	60A	12 A	15 A	10A
A3		10 A	6 A	
A4		7 A	3 A	

Table II Test results in the selected points of the GS

#	Point of Interest	Long Distance	SD=20m	SD=40m
1	Pylon 1	32,40	98,56	86,66
2	Pylon 2	32,23	86,28	72,63
3	Fence north	3,26	49,03	51,38
4	Fence corner north	7,42	1,68	1,56
5	Power factor correction	98,16	240,88	179,94
6	Fence est	7,33	29,23	8,83
7	Coil	42,59	67,25	67,25
8	Fence Est	9,84	44,00	31,41
9	Fence corner south	4,19	5,42	6,97
10	Fence south	7,00	9,00	7,91
11	Fence south	4,96	20,03	30,65
12	Fence corner south	11,16	89,72	67,26
13	Fence road	1,55	23,85	21,53
14	Gate entrance	6,03	28,79	20,63
15	Gate road	4,10	6,78	7,77
16	Pylon interior	7,28	11,38	11,50
17	Pylon interior	6,53	10,32	10,32
18	Bars	6,28	9,91	9,91
19	Stairs	0,90	29,32	5,88
20	Conductors support	3,71	5,47	7,30
21	Office	60,90	172,38	147,25
22	Pylon base	3,91	7,91	14,08
23	Lamp on the road	3,19	10,92	4,75

By the assessment of the data of the measurements, shown in table II, it is possible to verify that the results of the tests at short distance are generally conservative. The Figure 11 graphically shows the results of Ut versus the point numbers.
The not-conservative result in the point n. 4 is caused by the fact that the same point is in the corner of the GS.

IV - CONCLUSION

The adequacy of GSs has to be verified periodically in the operational time. For the GSs of facilities and HV/MV substations in the urban or industrial areas, it is very rare to have around areas with sufficient accessibility to choose suitable locations for auxiliary electrodes and so rigorous ground resistance measures can result impossible. This paper has suggested a practical procedure with auxiliary probes for testing touch voltage and step voltages that allow to verify the GSs adequacy in areas with reduced accessibility and to monitor its development in the time.

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