The Global Grounding System: Definitions and Guidelines

(Article begins on next page)

The Global Grounding System: Definitions and Guidelines

G. Cafaro+, P. Montegiglio+, F. Torelli+, P. Colella^, R. Napoli^,E. Pons^, R. Tommasini^, A. De Simone', E. Morozova', G. Valtorta', A. Barresi", F. Tummolillo", A. Campoccia*, M. L. Di Silvestre*, E. Riva Sanseverino*, G. Zizzo*, L. Martirano°, G. Parise°, L. Parise°

+ DEI – Politecnico di Bari, Bari, Italy; ^ DENERG – Politecnico di Torino – Torino, Italy; ' ENEL Distribuzione SpA – Roma, Italy; "IMQ – Roma, Italy; * DEIM - Università di Palermo - Palermo, Italy; ° DIAEE - Università "La Sapienza" di Roma - Rome, Italy

***Abstract*—The present paper presents the preliminary results of the ongoing Italian METERGLOB project on the contribution given by the exposed conductive parts to a Global Grounding System. One of the expected results of METERGLOB is to carry out guidelines for the identification of a Global Grounding System. These guidelines must be defined on the basis of the definitions and methods present in the current international standards on grounding and safety. In the paper some definitions and elements to be taken into account for the identification of a Global Grounding System are given.**

Keywords— Global Grounding System; Ground Fault; Guidelines; Definitions.

I. Introduction

METERGLOB is the acronym of an Italian research project funded by the Italian Minister of the Economic Development through the Research on the Electric System initiative [1] and devoted to the evaluation of the contribution of the extraneous conductive parts on Global Grounding Systems.

Global Grounding Systems (GGS), also named Global Earthing Systems (GES), have been firstly introduced in 1998 by CENELEC Document HD 637-S1 [2].

According to [2] a GES is as an equivalent grounding system created by interconnecting local grounding systems and ensuring, by the proximity of the ground electrodes, that there are no dangerous touch and step voltages. Such systems permit the division of the ground fault current in a way that results in a reduction of the ground potential rise (GPR) at the fault location. Such a system could be said to form a quasi-equipotential surface.

In 2014, the International Standard IEC 61936-1 [3] confirmed the original definition without including further elements for the identification of a GGS.

It is easy to understand that GGS is an innovative concept able to introduce a revolution in the evaluation of the safety requirements of the grounding systems in distribution networks.

ANSI/IEEE standards dealing specifically with grounding [4-6], do not give any definition of GGS, even if the frequent influence between European and American standards and codes occurred in the last years [7].

In the last three years, the Institutions involved in the METERGLOB project, have faced the issue of GGSs, studying all the correlated aspects. In particular:

- mathematical models have been defined for the simulation of interconnected MV/LV substations grounding systems and for studying the effects of exposed or extraneous conductive parts on the safety conditions;
- touch and step voltages innovative measurement methods have been defined and tested;
- field tests on different grounding systems have been performed.

One of the expected results of METERGLOB is to carry out guidelines for the identification of GGSs. The guidelines must be defined on the basis of the definitions and methods present in the current international standards on grounding and safety and on the other results of the METERGLOB project. In the paper some main definitions and elements to be taken into account for the identification of a Global Grounding System are given.

II. DEFINITIONS

Terminology plays an important role in the understanding of the purpose of an object or an action. For this reason the first step of each analysis should be the statement of a precise list of definitions.

The most important definition, representing the starting point of the guidelines for GGSs identification, is that of GGS given by [2-3].

Other definitions can be taken from the international standards on safety. The reference document are:

- IEEE Standard 80-2000, concerning safety and grounding in AC substations [4];

- IEEE Standard 665-2001, concerning grounding in generating station [5];
- IEEE Standard 142-2007, concerning grounding in industrial and commercial power systems [6];
- IEEE Standard 367-2012, reporting methods for evaluating the electric power station GPR and induced voltage due to a ground fault [8];
- IEC Standard 60050, International Electrotechnical Vocabulary [9];
- IEC Standard 61936-1, containing indication on grounding and safety for AC power installations exceeding 1 kV [3];
- IEC Standard 60909 series, concerning the calculation of short-circuit currents AC systems [10-14];
- EN Standard 50522, concerning specifically grounding of AC power installations exceeding 1 kV [15];
- NFPA70, National Electrical Code [16].

Finally in [17], the authors provides some important definitions for the study of safety related to ground faults.

In the GGS definition three important concepts are expressed:

- Interconnection;
- Proximity;
- Quasi-equipotentiality;

nevertheless, the above-listed standards do not provide any definition of those. A proper definition of “interconnection”, “proximity” and “quasi-equipotentiality”, should be a specific task of the research on GGS. Some preliminary indications can be found in [17-18].

In the following some consideration of these three important features of a GGS are provided.

A. Interconnection

The interconnection among the local grounding systems can be realized through:

- PEN conductors;
- Medium Voltage (MV) or High Voltage (HV) cable metal shields;
- bare buried ground conductors (copper or steel conductors directly buried);
- overhead ground wires (OHGWs);
- metal water/gas pipes;
- rails and fences.

Interconnection or continuity must be assured during the whole life of a GGS. For this reason, DSOs should check the continuity of cables shields, PEN and ground conductors at regular time intervals. On the contrary, DSOs are not able to verify the interconnections existing through metal pipelines, rails and other extraneous conductive parts, belonging to other Utilities.

A definition of “Interconnection” in GGS study could be given starting from that of “equipotential bonding” as defined by the International Electrotechnical Vocabulary [9] and taking into account the considerations above expressed. Therefore; “interconnection is the provision of electric connections between conductive parts, intended to achieve equipotentiality and maintained during the whole life of the GGS”.

In this way, the definition takes into account the equipotential bonding of all the exposed and extraneous conductive parts to the grounding systems of the GGS, the interconnection between single grounding systems by cables' metal shields, OHGWs, PEN conductors and buried ground conductors, but does not include the eventual additional interconnection that can be realized thanks to metal pipelines, rails, etc. Therefore, this definition is on the side of safety.

An in-depth analysis of bonding can be found in [17].

Fig. 1 shows a graphical representation of the concept of “interconnection” in a GGS.

B. Proximity

The concept of “proximity” should include both a geographical and an electrical meaning. This implies that two grounding system can be considered nearby for two reasons: because the installations to which the grounding systems belong are not distant, and because the series distributed impedance of the elements realizing an electric bonding between the grounding systems is low.

With regards to MV/LV substations grounding systems, the physical distance between the ground electrodes varies in a very wide range, usually 30÷1000 m, depending on the load density of the considered area.

In industrial areas, there is a very high concentration of high rated power installations, usually connected to the MV grid. Therefore in these areas there is a great number of MV/LV substations belonging both to the DSO and to private users. Distances between substations in industrial areas are in the range 30÷100 m.

Urban areas are characterized by a very high concentration of LV users and, in some zones, MV users. Therefore in these areas there are mainly DSO MV/LV substations. Distances between substations in urban areas are in the range 100÷400 m.

Finally, in extra-urban areas MV/LV substations distances are in the range 300÷1000 m.

With regards to the series impedance of the bonding elements, OHGWs and bare buried conductors have a distributed series impedance lower that cables metal shields and, therefore, can give a highest contribution to the distribution of the ground current among the interconnected ground electrodes.

On the basis of the previous considerations, the following definition of proximity can be given: “Proximity is a feature of a grounding systems that, thanks to the low value of the impedance of the connection to another grounding system, can drain a significant part of the ground current".

C. Quasi equipotentiality

"Quasi equipotentiality" is a typical feature of HV stations areas. Analogously to HV stations is, a GGS must behave as a quasi-equipotential surface where no hazardous voltages can rise. The concept of quasi-equipotentiality is related to two factors:

- the presence of electric bonding between grounding systems and conductive parts (both the exposed and the extraneous ones);
- low values of the Ground Potential Rise in the area for every possible fault event and location.

In this contest is very important to define also the possible fault conditions:

- 1LTG1: single line to ground fault inside a MV/LV substation;
- 1LTG2: single line to ground fault inside a HV/MV station;
- 2LTG: double line to ground fault in the MV grid;
- 2G: double ground fault in the MV grid.

For realizing an effective binding of all the conductive parts in a GGS, it is important to respect the practical indications provided by IEEE guides [4]-[6] and EN standard 50522.

Quasi-equipotentiality should be periodically checked.

Following the above exposed considerations, the following definition of "Quasi-equipotentiality" can be given: "quasi-equipotentiality is the absence of dangerous touch and step voltages, for any fault condition, in any point of the area on which a GGS insists and maintained during the whole life of the GGS".

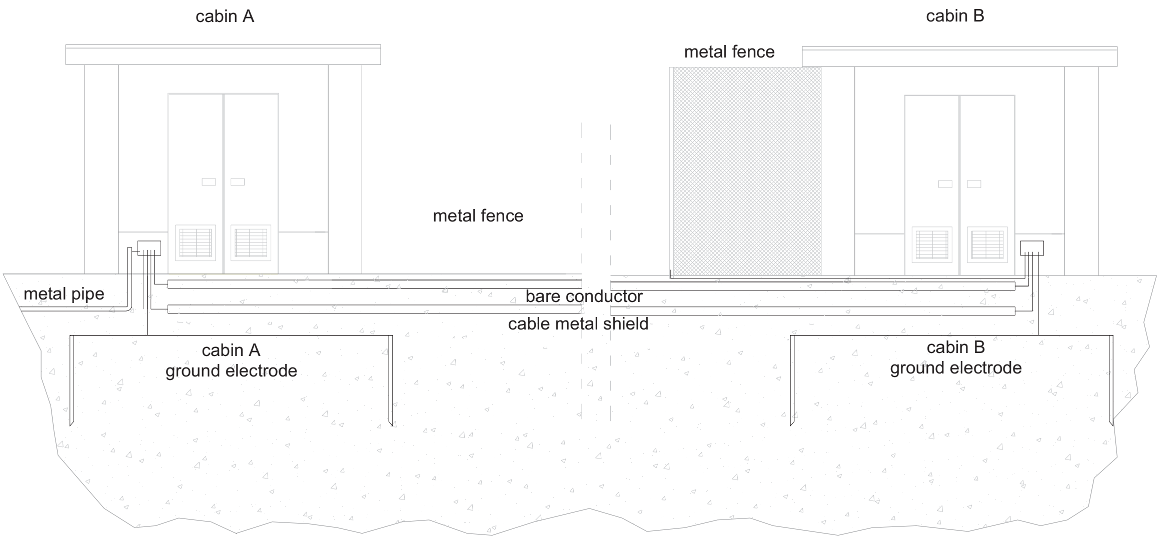

Fig. 1. Interconnection in a GGS.

III. GUIDELINES

The METERGLOB project is putting into evidence the difficulty of defining the boundary conditions ensuring the presence of a GGS in a given area. Various DSOs provide criteria based on geometrical factors for identifying urban areas GGS but very few areas have been declared GGS [19-20].

Nevertheless, geometrical methods are not able to take into account numerous factors influencing safety and depends on the specific features of the networks of a given DSO.

A general methodology for the identification of GGSs, instead, must be built considering universal electrical parameters.

In Fig. 2 a precautionary procedure that a DSO could follow for individuating GGS is shown.

In a first step, accurate or simplified circuit models [21] can be used for simulating the interconnected grounding system behavior.

In a second step, field measurements are needed in order to:

- check the presence of the interconnections;
- check the results of the calculations.

The measured GPR are usually lower than the calculated ones due to numerous bonding elements and auxiliary ground electrodes neglected in the circuit models.

IV. SAFETY CONDITIONS

As represented in Fig. 2, a very important issue for GGS is to define the safety conditions to be checked. Safety requirements depends on the voltage level and on the grounding of the LV distribution network. In every possible fault conditions, safety against electric shock must be assured by the GGS [22]. Indeed, according to the definition given in [1] no dangerous touch (and step) voltages must rise in a GGS. IEC Standard 61936-1 and EN Standard 50522 impose mandatory limits for ground potential rise (GPR) as reported in Table I.

TABLE I
SAFETY REQUIREMENTS FOR PROTECTION AGAINST ELECTRIC SHOCKS.

LV system grounding	Neutral state	Mandatory requirements	
		LV installation inside the area delimited by the cabin ground electrode	LV installation outside the area delimited by the cabin ground electrode
TT	-	$U_E \leq 2 \cdot U_{Tp}$ (or $U_E \leq 4 \cdot U_{Tp}$)*	
TN	PEN single grounding through the cabin ground electrode	$U_E \leq U_{Tp}$	$U_E \leq U_{Tp}$
	PEN multiple grounding		$U_E \leq F \cdot U_{Tp}$ $2 \leq F \leq 5$
* whit recognized specified measures M			

As shown in Table 1, in a GGS can be very important the implementation inside substations areas of specified measures M listed in EN 50522. These measures are reported in Table 2.

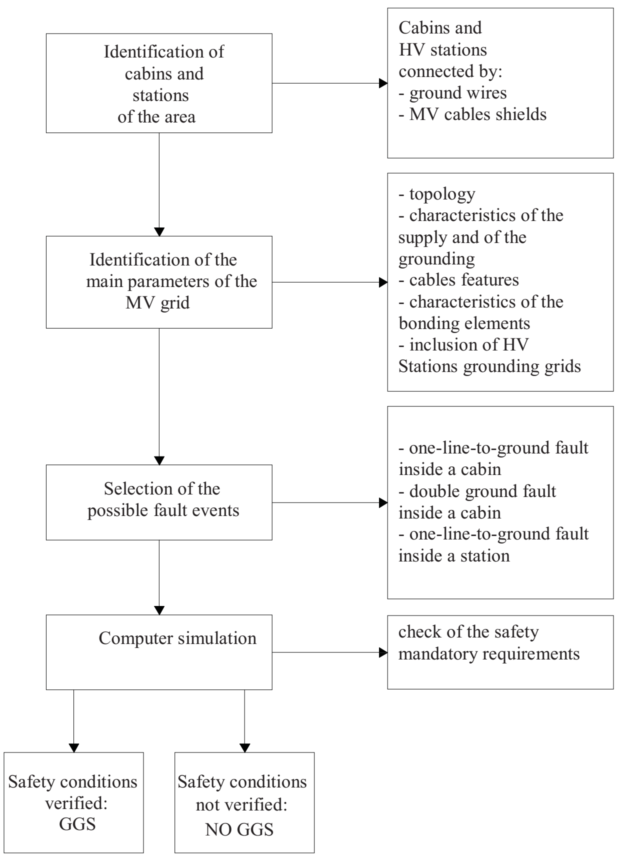

Fig. 2. Step for identifying GGS.

TABLE II
RECOGNIZED SPECIFIED MEASURES M

1.1	Non-conductive outer walls and no grounded metal parts accessible from outside the cabin/station.
1.2	Horizontal ground electrode connected to the grounding grid at a distance of 1 m outside the outer walls and buried at a depth not over 0.5 m, for potential grading (PG).
1.3	Insulation of the working location with: - a crushed stones layer (thickness not less than 0.1 m); - an asphalt layer on an adequate base; - an insulating mat (minimum 1m x 1m and a thickness of not less than 2.5 mm) or a measure ensuring equivalent insulation.
2.1	Non-conductive perimeter fences.
2.2	In case of conductive perimeter fences, potential grading as described in M1.2. Not mandatory bonding between the grounding grid and the perimeter fence.
2.3	Insulation of the operating location according to M1.3 and grounding of the fence either in accordance with Annex G of EN 50522 or by connection with the ground grid.
2.4	PG or working location insulation according to M1.3 at the gates if perimeter fences gates are connected to the grounding system. When the gates in a separately grounded conductive fence are to be connected to the main grounding system, the gates shall be isolated from the conductive parts of the perimeter fence establishing a separation of not less than 2500 mm. Electrical separation must be assured also in the case of totally open gates.
3.1	Equipotential grading by embedding grid-type electrodes in the building foundations and connection to the grounding system at not less than two different locations. If concrete steel reinforcement is also used for dissipating the fault current, check by calculations its capability. If structural steel mats are used, then the adjacent mats have to be interconnected at least once and all the mats together have to be connected to the grounding system at not less than two separate locations.
3.2	Construction of the operating locations from metal and connection to any metal parts which have to be grounded and which can be touched from the operating location.
3.3	Insulation of the operating locations for the GPR according to M1.3. Equipotential bonding of all the metal parts which have to be grounded and which can be simultaneously touched from the working location.
4.1	At working locations: PG by a horizontal ground electrode at a depth of 200 mm and a distance of 1000 mm from the equipment to be operated. The electrode has to be connected to all metal parts which have to be grounded and can be touched from the working location. Or Construction of the operating locations from metal and connection to the metal parts which have to be grounded and which can be touched from the working location. Or Insulation of the location according to M1.3. Equipotential bonding of all the metal parts which have to be grounded and which can be simultaneously touched from the working location.
4.2	Burying a horizontal ground electrode surrounding the grounding system as a closed ring. Inside a meshed ground grid has to be buried, whose meshes have a maximum size of 10m x 50m. At individual parts of the installation, outside of the ring and connected to the grounding system, a grading ground electrode at a distance of 1000 m and a depth of approximately 200 mm has to be provided.

IEEE Standards do not provide recommendations equivalent to the recognized specified measures M, described in Table 2.

On the contrary, they only give precise indications for fence building, grounding and bonding and for rails and pipelines outgoing the stations, that must be followed in any case, independently on the conditions in Table 1.