Submission date: 7 of September 2025
Acceptance date: 15 of January 2026
Publication date: 19 of February 2026

THE ROLE OF MEASUREMENT TECHNIQUES IN ELECTRICAL SAFETY AND SOCIAL RISK PREVENTION IN GROUNDING SYSTEMS

EL PAPEL DE LAS TÉCNICAS DE MEDICIÓN EN SEGURIDAD ELÉCTRICA Y PREVENCIÓN DE RIESGOS EN PUESTAS A TIERRA

Hugo Martínez Ángeles [1]
E-mail: hmartinez15@alumnos.uaq.mx
ORCID: https://orcid.org/0000-0002-8552-705X
José Gabriel Ríos Moreno [1]*
E-mail: riosg@uaq.mx
ORCID: https://orcid.org/0000-0002-8988-2729
Cesar Augusto Navarro Rubio [1]
E-mail: cnavarro15@alumnos.uaq.mx
ORCID: https://orcid.org/0009-0003-7541-5841
Mario Trejo Perea [1]
E-mail: mtp@uaq.mx
ORCID: https://orcid.org/0000-0002-7014-3379
Roberto Valentín Carrillo Serrano [1]
E-mail: roberto.carrillo@uaq.mx
ORCID: https://orcid.org/0000-0002-8246-8920
[1] Autonomous University of Querétaro. Santiago of Querétaro 76010, Mexico.
*Corresponding author

Suggested citation (APA, seventh ed.)

Martínez Ángeles, H., Ríos Moreno, J. G., Navarro Rubio, C. A., Trejo Perea, M., & Carrillo Serrano, R. V. (2026). The Role of Measurement Techniques in Electrical Safety and Social Risk Prevention in Grounding Systems. *Universidad y Sociedad 18*(1). e5763.

ABSTRACT:

This article analyzes the importance of measurement techniques in grounding systems not only from a technical perspective, but also in terms of their impact on electrical safety, the protection of human life, and the sustainability of social infrastructure. The correct implementation and evaluation of these systems are essential for the prevention of electrical accidents in residential, industrial, and public environments. Through a bibliographic review, this study examines how applied metrology contributes to the reduction of social risks, the strengthening of safety policies, and the responsible development of electrical installations for the benefit of society.

Keywords: Applied metrology, Energy, Ground enhancement material, Grounding systems, Electrical resistivity

RESUMEN:

Este artículo analiza la importancia de las técnicas de medición en los sistemas de puesta a tierra desde una perspectiva técnica, y también desde su impacto en la seguridad eléctrica, la protección de la vida humana y la sostenibilidad de la infraestructura social. La correcta implementación y evaluación de estos sistemas resulta fundamental para la prevención de accidentes eléctricos en entornos residenciales, industriales y públicos. A través de una revisión bibliográfica, se examina cómo la metrología aplicada contribuye a la reducción de riesgos sociales, al fortalecimiento de políticas de seguridad y al desarrollo responsable de instalaciones eléctricas en beneficio de la sociedad.

Palabras clave: Metrología aplicada, Energía, Material de mejora del terreno, Sistemas de puesta a tierra, Resistividad eléctrica.

INTRODUCTION

Electrical accidents represent a relevant social problem that affects human safety and the proper functioning of public, industrial, and residential infrastructure. Failures in electrical installations can lead to accidental electric shocks, serious injuries, and loss of life, as well as material damage and disruptions to essential services. Therefore, electrical safety should be understood as an important element of social well-being and the protection of human life (Serikov et al., 2021).

The impact of electrical risks extends to different sectors of society, including workers, communities, and users of public spaces. Deficient implementation of grounding systems increases the likelihood of electrical accidents, particularly in shared and high-use environments, resulting in social costs, service interruptions, and vulnerability in critical infrastructure. In this sense, electrical risk prevention acquires a clear social and preventive dimension (Butakov, 2025).

Universities play a fundamental role in addressing this problem through the education of professionals with social responsibility, the development of applied research, and the transfer of knowledge to society. From this perspective, applied metrology in grounding systems should be understood as a means to strengthen electrical safety and support infrastructure-related decision-making. Thus, academic knowledge contributes to reducing social risks and promoting sustainable development (Jasiūnas et al., 2021).

Likewise, metrology plays a crucial role in the design, installation and maintenance stages of GS. First, in the design phase, metrology is used to measure and analyze terrain characteristics, such as soil resistivity, which influence the effectiveness of the GS. These measurements are important, because they determine the ideal and efficient distribution of the rods or electrodes, as well as the ideal configuration of the GS network (Ellinas et al., 2024). During GS installation, metrology ensures that system components are correctly positioned and properly connected, improving their response to failure events or electrical discharge in the system since, there are strata, such as those composed mainly of rocks, that present resistivities of up to 500,000 Ohm per centimeter (Ωcm).

In this sense, metrology makes use of precise measurement techniques in order to verify the resistance that exists between the connections and the continuity of the grounding paths. Any anomaly that is not in accordance with the established standards can be detected by means of the corresponding measurement techniques and based on this, the errors can be corrected and prevented from causing damage and becoming a possible safety risk for the electrical equipment or the people who interact with the GS (Zainuddin et al., 2024).

Corrective and preventive maintenance of the GS, through the measurement of the earth resistance, should be a periodic thing, which, when using metrological techniques, would be greatly benefited. Also, periodic measurements of the resistance and potential of the ground allow the identification of possible problems, such as corrosion of the electrodes or deterioration of the connections, before they affect the efficiency of the electrical system. All of the above must always be quantified based on compliance with the applicable regulatory and safety requirements (Raizer et al., 2024).

Finally, the accuracy and reliability of measurements based on metrological techniques are essential to ensure the sustainability and reliability of GS, since even the smallest variations can have important consequences for electrical safety. For example, a higher-than-expected earth resistance can increase the risk of electric shock or damage to electrical and electronic equipment, or even human accidents, due to electric shock. Similarly, an inefficient connection can compromise the reliability of the entire system (Ehrenwerth, 2021).

The objective of this article is to show the importance of measurement techniques in the design, implementation and monitoring of the efficiency of improved GS through the use of ground improving materials. To this aim, several investigations involving the mentioned aspects will be reviewed, focusing on the use they make of the concepts involved in the measurement of the resistance of the GS.

DEVELOPMENT

Function and Relevance of Grounding Systems in Electrical Protection

A GS is a fundamental component of electrical networks, as it provides a controlled route for transient fault currents to be discharged harmlessly into the earth. This system is established through an intentional electrical connection, commonly involving the neutral conductor, to an electrode installed in the soil. Conventional GS are typically composed of metallic elements such as rods, plates, or mesh configurations that are electrically bonded to system components, enabling excess electrical energy to be conveyed to deeper soil layers where it can be safely dissipated (Sarker et al., 2025).

Depending on the installation requirements, grounding electrodes may be positioned vertically, horizontally, or in hybrid arrangements to enhance their capacity to conduct overvoltage currents into the ground. In events such as lightning strikes, the grounding system functions as a critical transfer point for electrical charges, making its effectiveness highly dependent on proper design, layout, and material properties. Consequently, the level of protection afforded to electrical and electronic equipment is closely tied to the performance of the grounding system (Navarro et al., 2025).

Lightning activity represents a significant global hazard, with an estimated average of approximately 40 strikes per second worldwide, amounting to nearly 1.2 billion events annually. These phenomena are responsible for extensive material damage and considerable human casualties, with yearly fatalities estimated between 6,000 and 24,000. Many of these losses are attributed to inadequate grounding system design or poor operational conditions. When fault currents lack a suitably engineered grounding path, supported by appropriate measurement techniques and periodic maintenance, they may follow unintended routes, potentially involving human contact (Hugo et al., 2024).

Materials such as copper and steel are widely used in the fabrication of grounding electrodes due to their favorable electrical conductivity, mechanical strength, longevity, and economic viability. The practice of installing deeply driven grounding rods remains common in residential applications across numerous regions. In addition, construction-based grounding methods, such as the Ufer grounding technique, take advantage of embedded structural metal elements in buildings, towers, or similar infrastructures (Putra et al., 2023).

Maintaining grounding resistance within recommended limits is essential to ensure system reliability and personnel safety. In Mexico, the standard NOM-001-SEDE-2012 establishes a maximum allowable grounding resistance of 25 Ω. For lightning protection purposes, several studies recommend values closer to 10 Ω. Despite these guidelines, a universally accepted resistance threshold has not been established across all regulatory bodies. Nonetheless, organizations such as the IEEE and the NFPA advocate for grounding resistance values not exceeding 5 Ω (Zainuddin et al., 2024).

The overall resistance of a grounding system is determined by several interrelated factors, including electrode length and burial depth, electrode diameter, the quantity of electrodes used, the geometric configuration of the system, and, most importantly, the electrical resistivity of the surrounding soil. Accurate measurement and evaluation of these parameters through metrological practices are essential to verify system performance and ensure compliance with safety requirements.

The Role of Measurement Tools in the Management of Grounding Systems

During the design of a GS, metrology plays a crucial role, from the measurement of ground resistance to the quality assurance of the electrodes and the monitoring of compliance with the corresponding regulations.

The design process of the GS is outlined below, considering six development phases where metrology has significant implications for the correct design (Navarro et al., 2025).

a. Site evaluation: In this initial phase, a detailed assessment of the site where the GS is to be installed is carried out. This involves measuring soil resistivity and other relevant characteristics using metrological techniques such as checking electrical continuity, equipment calibration and soil quality assessment.

b. Ground network design: Based on the data collected during the site assessment, the ground grid design is developed. This involves determining the optimum distribution of grounding electrodes and the arrangement of connections to ensure effective grounding.

c. Selection of grounding electrodes: At this stage, suitable grounding electrodes are selected based on the soil characteristics and resistance requirements of the system. Metrology plays a crucial role in the accurate selection of electrodes to ensure optimum system performance by verifying ideal material properties.

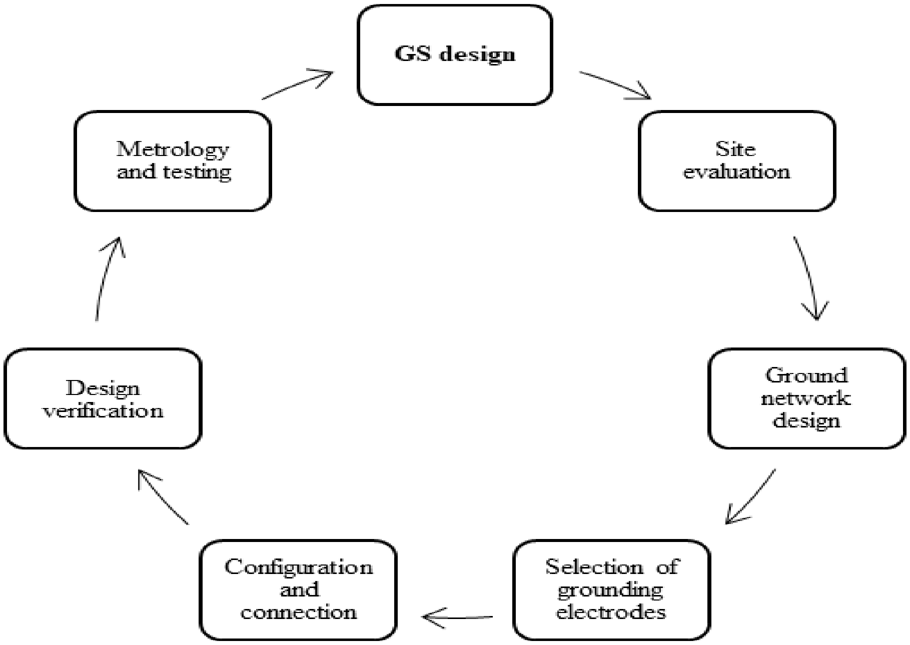
d. Configuration and connection: The final GS configuration is established and the electrodes and other components are connected according to the predetermined layout. Metrology is used to verify the strength of connections and ensure proper installation.

e. Design verification: Before final implementation, the system design is verified to ensure compliance with established standards and requirements. This may involve conducting additional simulations and analyses using metrological techniques. Some of these techniques include electric field simulations, leakage current and current distribution analysis, impedance measurement and simulation, transient electrical simulations (lightning), sensitivity analysis (using statistical techniques and simulations to assess how changes in soil resistivity, electrode configuration, and other parameters affect system efficacy), and electromagnetic compatibility (EMC) testing, among others.

f. Metrology and testing: Once the system is installed, metrological tests and measurements are conducted to verify its functionality and performance. This includes measuring ground resistance, ground potential, and other relevant variables to ensure the system meets the required safety and performance standards.

In this way, some of the benefits of using measurement tools in the GS design and installation process can range from safety by preventing electrical accidents, regulatory compliance, system optimization, preventive maintenance and cost reduction by avoiding damage to electrical equipment due to poor overcurrent dissipation.

Figure 1 illustrates the interaction process between metrology and the design of a GS, detailing its various stages (Hugo et al., 2024), from the design and evaluation of the installation site to the measurement of the components and the importance of metrology in this entire process.



Figu 1: Process of interaction between metrology and GS design development

From a social perspective, this process from Figure 1 illustrates how the systematic application of metrology throughout the design and development of grounding systems contributes to the prevention of electrical accidents and the protection of human life. By supporting informed technical and infrastructure-related decisions, this approach enhances electrical safety in public, industrial, and community environments, reinforcing the social value of preventive electrical practices.

In addition, the most common approach to designing a GS involves the use of a single grounding electrode, which is often installed in outdoor areas of residential and workplace environments. However, more complex GS designs incorporate multiple interconnected components such as rods, mesh or grid networks, plates, and loops. These advanced systems are typically implemented in critical infrastructure, including power generation substations, corporate headquarters, and cellular tower sites, to provide enhanced protection and reliability (Figure 2) (Dove, 2023).

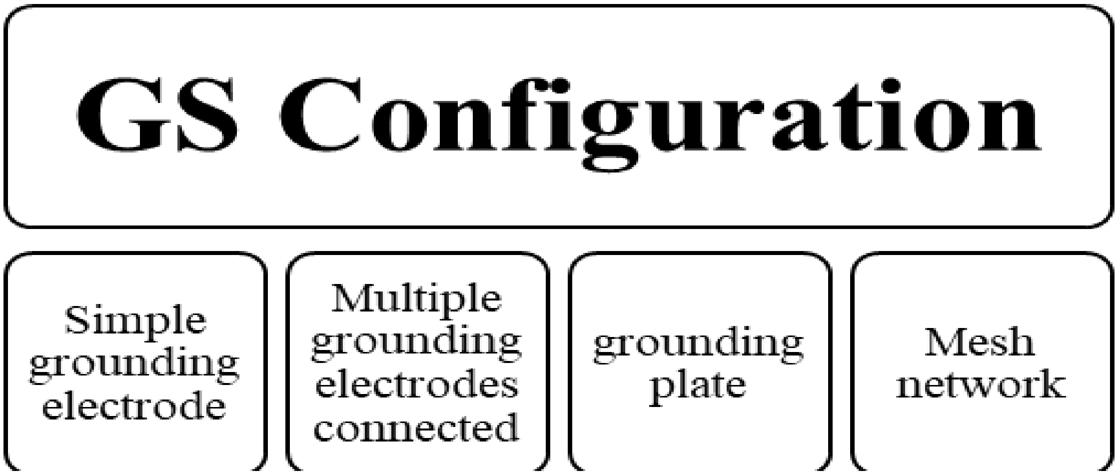


Fig 2: Various options for configuring a GS

From a social perspective, the different grounding system configurations shown in Figure 2 highlight how design choices can influence electrical safety in residential areas, workplaces, and public infrastructure. Selecting an appropriate configuration according to local conditions helps reduce electrical hazards, prevent accidents, and improve the protection of people and critical facilities.

Soil Conditions and Their Impact on Electrical Safety in Grounding Systems

Soil is the Earth's topmost layer, formed through the long-term interaction of biological and geological materials. It serves an important role in terrestrial ecosystems by providing structural support for plant growth, acting as a medium for water cycling and nutrient, providing a habitat for organisms. Electrical efficiency refers to the degree to which electrical energy is utilized effectively to perform a specific task or function. Higher electrical efficiency indicates that less energy is required to achieve the same outcome, resulting in resource conservation and cost savings (Serikov et al., 2021).

Table 1 shows the electrical performance of the grounding, considering the type of soil, resistivity, factors affecting its performance, efficiency in the GS, as well as solutions to improve the grounding when necessary.

Table 1: Electrical characteristics of different soil types for grounding.

Soil	Resistivity (Ωcm)	Factors affecting performance	Efficiency in the GS	Improvement solutions
Coastal soil	100-3000	High salinity and conductivity	Excellent	Use resistant electrodes
Clay	500-5000	Compaction and humidity	Excellent	Not required
Peat soil	500-5000	High humidity, organic matter	Excellent	Not required
Compacted soil	3000-30000	Pressure and humidity	Excellent	Not required
Silty soil	1000-10000	Water retention, compaction	Good	Not required
Soil with organic matter	1000-100000	Humidity and compaction	Variable	Add clay or bentonite
Humid sandy soil	5000-30000	Loss of humidity	Acceptable	Maintain humidity, improve compaction
Volcanic ash	10000-100000	High porosity, low compaction	Deficient	GEM Compounds
Dry sandy	20000-500000	Lack of humidity, structure.	Deficient	Use of conductive salts, bentonite
rocky soil	> 100000	High resistivity, low porosity	Very deficient	Use of deep electrodes

Source: Own elaboration based on Hajian & Razi-Kazemi (2017)

From a social perspective, the information presented in this Table 1 highlights how soil characteristics directly influence the effectiveness of grounding systems, which in turn affects electrical safety in residential areas, public facilities, and community infrastructure. Understanding these conditions supports informed decision-making aimed at preventing electrical accidents and protecting people and critical infrastructure.

Furthermore, metrology is a fundamental element to understand and optimize the influence of soil on the electrical efficiency of the GS in order to provide tools and techniques to characterize the soil, design the GS accordingly, verify the accuracy of the medical teams and analyze the models to simulate its behavior (Figure 3) (Sengar & Chandrasekaran, 2023).

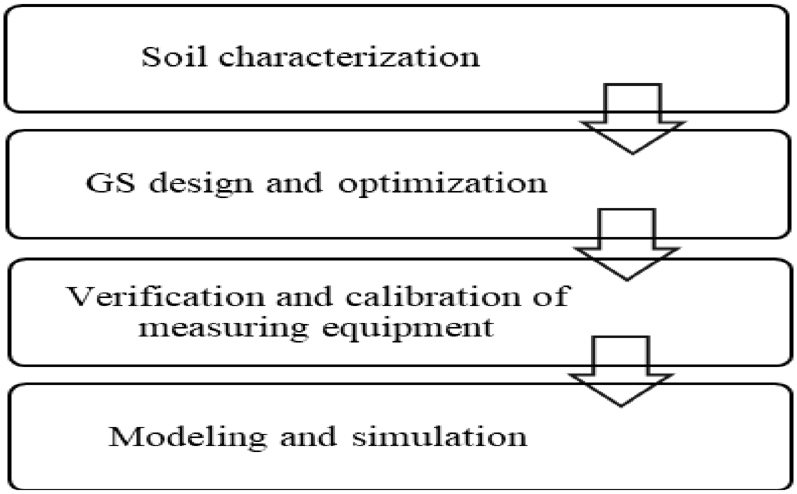


Fig 3: Relationship of metrology and soil influence on the electrical efficiency of GS

g. Soil characterization: Metrology provides tools and techniques to measure the electrical resistivity of soil, which is crucial to understanding how soil influences GS efficiency. Soil resistivity determines how easily electrical current can flow through it, directly affecting GS efficiency in dissipating unwanted currents.

h. Design and optimization of GS: Ground resistivity data obtained using metrological techniques allows optimal GS to be designed to maximize electrical efficiency. This involves selecting the appropriate type of electrodes and determining their spatial distribution to minimize GS resistance and ensure efficient current dissipation.

i. Verification and calibration of measuring equipment: Metrology is also crucial to ensure the accuracy of the measurement instruments used to assess GS electrical efficiency. Periodic calibration of these instruments is essential to obtain reliable and accurate measurements, which in turn allows potential problems in GS to be identified and corrective measures to be implemented.

j. Modelling and simulation: Metrology goes beyond direct measurement and includes the development of models and simulations to better understand how different soil parameters and GS components interact. These models can help predict system performance under various conditions and optimize system design and operation.

Use of Ground Enhancement Materials in Grounding System

The installation of a GS is challenging to implement when the soil has high resistivity or when there is insufficient space available. In these circumstances, the use of various ground resistance reducing agents is preferred. Thus, several researchers have introduced some techniques to maintain and reduce ground resistance at low and safe levels. These techniques involve the use of GEM as a complementary material to interact between the GS and the soil. A GEM is a specialized conductive material designed to overcome grounding challenges, particularly in areas with poor soil conductivity, such as rocky terrains, sandy soils and mountaintops. GEM effectively reduces soil resistance and impedance, enabling better electrical dissipation and often allowing for a smaller GS design (Butakov, 2025).

GEM is typically applied by placing it in the trench where the GS electrode is installed, either mixing it with the natural soil or replacing the existing soil altogether. The use of chemical and natural substances as GEM is a widespread practice globally. By reducing the soil's electrical resistance, GEM helps maintain a low-impedance connection between the electrical system and the ground, which is essential for ensuring the efficiency and reliability of the GS (Adegboyega & Odeyemi, 2011).

The current market trend in GEM is the widespread use of bentonite due to its proven effectiveness in reducing soil resistivity. Bentonite, a natural clay primarily composed of minerals from the smectite group-most notably montmorillonite-exhibits hygroscopic properties, allowing it to absorb moisture from its surroundings. This ability to retain water enhances its conductivity, making it a preferred material for improving the performance of GS (Jamieson, 2023).

Commercially, two main types of bentonites are available: sodium bentonite and calcium bentonite. Sodium bentonite is known for its higher swelling capacity and superior water absorption, making it more effective for grounding applications. However, the primary drawback of using bentonite as a GEM is its high cost, driven by the industrial processing required to prepare it for commercial use. Additionally, as a limited natural resource, bentonite is often imported from developing countries, further increasing its cost and environmental impact (Šťástka et al., 2022).

In this way, from a social perspective, the evaluation of soil electrical resistivity is a key factor in preventing electrical accidents and ensuring safe living and working environments. Accurate soil assessment supports the design of grounding systems that protect people, public facilities, and community infrastructure from electrical hazards. By informing infrastructure planning and safety-related decisions, applied metrology contributes to reducing social risks, improving resilience in critical installations, and promoting sustainable and responsible development. In addition, measurement may also involve the assessment of the uncertainty associated with the sun resistance measurements (Mohamad Nor et al., 2013).

There are several methods to measure soil electrical resistivity; however, the most widely used criterion in the world is specified by the Institute of Electrical and Electronics Engineers (IEEE) which has published a guide to help set up soil electrical resistivity measurements. Therefore, the Wenner technique, by utilizing metrological techniques, is suitable for measuring soil resistivity before and after using a GEM. Thus, the measurement of soil electrical resistivity will be the indicator to confirm or dismiss the effectiveness of the GEM in reducing the impedance of the GS (Ahn et al., 2022).

Verification of Grounding Systems for Electrical Safety

From a social perspective, the verification of grounding systems represents a critical preventive action to protect human life and ensure the safe operation of electrical installations. Regular and reliable verification processes help identify potential failures before they result in electrical accidents, service disruptions, or damage to public and private infrastructure. In this context, applied metrology supports decision-making aimed at strengthening electrical safety, reducing social risks, and promoting safer environments for communities and essential services.

Metrology plays a fundamental role in verifying the GS by ensuring precise and reliable measurements, which contributes to the safety and optimal performance of electrical installations, likewise Figure 4 shows the most commonly used methods for verifying GS (Rubio et al., 2025).

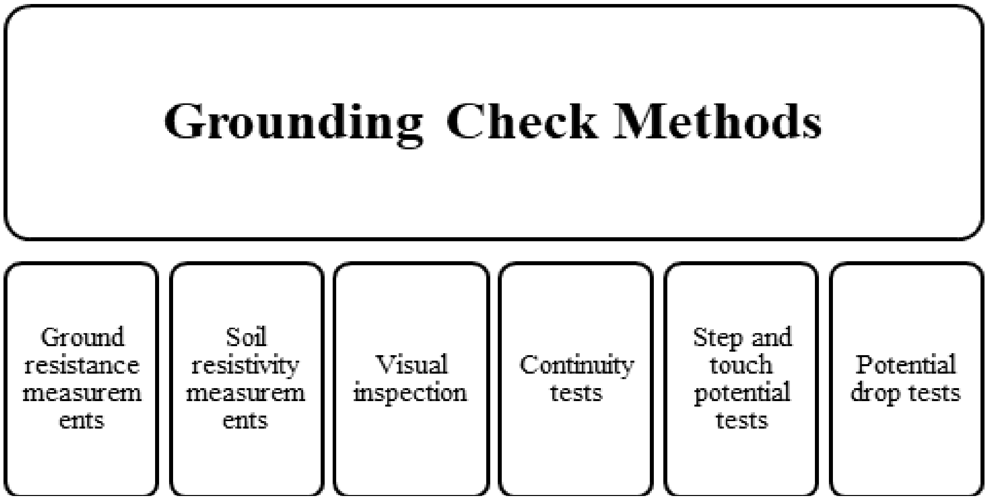


Fig 4: Methods to check grounding system effectiveness

From a social perspective, the methods illustrated in Figure 4 emphasize the importance of verifying grounding system performance as a preventive measure to reduce electrical risks. Proper verification helps avoid electric shock accidents, protects workers and users of public spaces, and enhances the safety of critical infrastructure, reinforcing the role of grounding systems in safeguarding communities.

Additionally, Table 2 (Rubio et al., 2025) provides a brief discussion on each of the Grounding check methods described in Figure 4. In which the information can be divided according to:

a. Basic methods (visual inspection, continuity tests) that are useful for routine maintenance.

b. Advanced electrical methods (ground resistance measurements, soil resistivity measurements, potential drop tests) which are important in evaluating the efficiency of the GS.

c. Security tests (step and touch potential tests) which are necessary to avoid risks of electric shock to people and animals.

Table 2: Measurement methods applicable according to the type of installation and soil characteristics.

Method	Type of installation	Influence on the soil	Advantages	Limitations
Ground resistance measurements	Substations, telecommunications	Critical in rocky and sandy soils	High precision	Requires space for electrode testing
Soil resistivity measurements	Studies prior to the installation of the GS	Only in soils of variable resistivity	Optimization in GS design	It does not measure the resistance of the installed GS
Visual inspection	All installations	Corrosion in humid soils	Simple and without equipment	No internal faults detected
Continuity tests	Residences, commercial buildings and industries	Areas at risk of corrosion	Checking for defects in connections	It does not measure the total resistance of the GS
Step and touch potential tests	Substations and power plants	Critical in rocky and sandy soils	Electric shock risk assessment	Requires specialized equipment
Potential drop tests	Substations, power plants	Critical in rocky and sandy soils	Soil evaluation under real conditions	Requires live testing

Source: Own elaboration based on Rubio et al. (2025)

Based on the information presented in Table 2, from a social perspective, the verification methods play a crucial role in reducing electrical risks and preventing accidents that may affect workers, users of public spaces, and surrounding communities. The systematic application of these methods allows the early identification of failures in grounding systems, contributing to safer electrical installations. This preventive approach supports the protection of human life, reduces social and economic costs associated with electrical incidents, and strengthens the reliability of critical infrastructure.

In addition, these verification practices provide technical support for decision-making processes related to public safety policies and infrastructure management. By ensuring that grounding systems operate within established safety limits, they help create safer environments in workplaces, educational institutions, healthcare facilities, and other high-occupancy spaces, reinforcing the social value of preventive electrical safety measures.

Ground Enhancement Material as a Material to Improve Soil Resistivity in Communities

In numerous circumstances, achieving a low level of impedance in rocky and sandy soils is extremely challenging. Therefore, it becomes necessary to introduce various substances, such as the previously mentioned GEM, to reduce and maintain ground resistance at low and safe levels. On the other hand, the literature currently identifies three variants of GEM studied as soil enhancers, which are composed of materials from natural agents, waste, and chemicals. These are used to reduce the electrical resistance of the soils surrounding the electrodes, each presenting its own inherent limitations (Amry et al., 2021).

Natural GEM is derived from agricultural waste, renewable resources, or naturally occurring materials found on Earth. These materials are considered environmentally friendly and cost-effective alternatives to synthetic or chemical-based GEMs. One of the key advantages of using natural GEM is that they do not introduce foreign or hazardous substances into the soil, thereby reducing the risk of environmental contamination. This contrasts with chemical methods, which may introduce pollutants into the surrounding soil. The use of natural GEM aligns with sustainable practices, offering a greener, safer, and more cost-efficient option for improving the performance of GS (Navarro et al., 2025).

Materials derived from waste originate from diverse sources, including industrial waste, urban waste, and construction and demolition debris. These materials are produced through the treatment and processing of solid, liquid, or gaseous waste, allowing them to be repurposed or reintegrated into the production chain. This approach promotes sustainability by reducing waste and minimizing the need for raw materials, making it an eco-friendly alternative for GEM (Martínez et al., 2026).

In addition to the use of natural and waste-derived materials to reduce soil resistivity, artificial or chemical methods are also employed. Chemical enhancement materials are highly effective in significantly lowering soil electrical resistance. However, their use is associated with certain drawbacks. As highlighted in various studies, these materials can lead to soil contamination and accelerate the corrosion of grounding electrodes. Such effects not only pose environmental risks but also compromise the long-term durability and performance of the GS. For this reason, natural and waste-derived GEM are often preferred for sustainable and environmentally conscious GS design (Martínez et al., 2025).

Social and Educational Implications of Grounding Systems

Grounding systems play a fundamental role in the prevention of electrical accidents that may affect individuals, communities, and public infrastructure. Properly designed and maintained grounding systems reduce the risk of electric shock, equipment failure, and fire, particularly in residential areas, workplaces, and public spaces. From a social perspective, effective grounding contributes to safer environments and supports the protection of human life, making electrical safety a shared societal responsibility rather than a purely technical issue (Ehrenwerth, 2021).

Failures in grounding systems can generate significant social and economic costs. Electrical accidents often result in injuries, loss of life, damage to infrastructure, service interruptions, and increased public and private expenditures related to emergency response, medical care, and system repairs. These impacts disproportionately affect vulnerable populations and essential services, highlighting the importance of preventive strategies based on reliable grounding practices and continuous system verification (Mane et al., 2025).

Grounding systems are especially critical in the protection of essential and strategic infrastructure, such as hospitals, educational institutions, transportation systems, communication networks, and energy facilities. In these contexts, electrical failures can compromise public safety and disrupt vital services that communities depend on daily. Ensuring the effectiveness of grounding systems in critical infrastructure enhances resilience, supports continuity of operations, and contributes to the overall stability and safety of society (Jasiūnas et al., 2021).

Universities play a strategic role in addressing these challenges through education, applied research, and knowledge transfer. By integrating electrical safety, grounding system design, and metrology into academic curricula, universities contribute to the development of technical solutions that respond to real social needs. Moreover, collaboration between academic institutions, industry, and public agencies supports evidence-based decision-making and strengthens public policies related to electrical safety and infrastructure management (Amry et al., 2021).

The education of professionals with social responsibility is essential to promote sustainable and safe electrical practices. Engineers and technical professionals must be trained not only in technical competencies but also in ethical considerations, risk prevention, and social impact assessment. In this way, higher education institutions contribute to forming professionals capable of designing and implementing grounding systems that prioritize human safety, environmental sustainability, and the well-being of communities (Martínez et al., 2025).

CONCLUSION

The proper design, implementation, and verification of grounding systems are not only technical requirements but also essential actions for protecting human life and ensuring social well-being. Electrical safety directly affects residential areas, workplaces, public facilities, and critical infrastructure, making grounding systems a key preventive element in reducing electrical accidents and associated social risks. In this sense, applied metrology plays a fundamental role by enabling reliable evaluations that support safer electrical environments.

Communities benefit from effective grounding systems through increased safety, reduced likelihood of electrical accidents, and improved reliability of essential services. Adequate grounding contributes to the protection of public infrastructure, minimizes social and economic costs derived from electrical failures, and strengthens the resilience of systems that support daily activities such as healthcare, transportation, communication, and education. These benefits translate into safer living conditions and greater confidence in the infrastructure that communities depend on.

Universities play a strategic role in this context by fostering the education of professionals with technical competence and social responsibility, promoting applied research focused on real societal needs, and facilitating the transfer of knowledge to industry and public institutions. Through academic training, scientific research, and collaboration with stakeholders, universities contribute to the development of safer electrical practices and to the formulation of policies that prioritize human safety, sustainability, and social impact. In this way, academic knowledge supports the construction of safer, more resilient, and socially responsible electrical infrastructure.

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CONFLICTS OF INTEREST:

There are no conflicts among authors.

Author Contributions:

Autor	Roles
Hugo Martínez Ángeles	In charge of: Writing – original draft, Methodology
José Gabriel Ríos Moreno	In charge of: Validation, Formal analysis
Cesar Augusto Navarro Rubio	In charge of: Writing – review and editing
Mario Trejo Perea	In charge of: Resources, Supervision, Validation
Roberto Valentín Carrillo Serrano	In charge of: Funding acquisition, Investigation

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