MEASUREMENT SYSTEM APPLIED TO ENERGIZED SUBSTATIONS GROUNDING GRIDS DIAGNOSIS

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Abstract: This paper presents the development of a system (hardware and software) applied to the evaluation of high voltage (HV) substations energized grounding grids. The diagnosis system is based on the measurement of the HV substation surface potentials. The measurement allows the identification and localization of eventual grounding problems (high values of ground resistivity, corrosion, discontinuity). The system hardware was developed using a PIC® microcontroller that perform the measurement of several surface potentials and stores the measured values in a digital memory. In the sequence, the stored values are transferred to a personal computer, where a developed software, based on finite differences method perform the analyses of the measured data. The obtained results are presented in form of text rapports and 2 and 3-dimensional graphics.

Key words: Grounding grid diagnosis, Surface potentials, Finite difference method.

1. INTRODUCTION

Grounding systems have performed an important role in the protection of power systems. The main objective of them is to ensure personal safety, prevent harm to installed equipment, establish a reference voltage point for all the interconnected power system, as well as, providing a low impedance path for currents originating from lightning, short circuits and static, from equipment housings, or electrical currents due to imbalance of electric charges fed by voltage source, [1] and [2].

Many times, in setting up installations, poor contact between electrodes results in an increase in resistance, and this hampers the flow of the currents. Another factor related to the poor performance of a grounding system is the corrosion process of the rods and cables, due to chemical action of the soil, which can reach high levels, which can provoke the infeasibility of the grounding system. In both of these cases, the potentials of the grid and their surroundings can reach values which not comply with safety standards, causing situations of risk, both to the electrical system and to people.

For these reasons, it is essential to analyze the behavior of grounding grids in substations over time, to detect possible faults or alterations.

In the bibliography, it was found that several methods can be used to perform the electrical grounding evaluation, for example: the moment's method [3], [4] had analyzed the structure behavior in the frequency domain, using the Green functions and the image theory; the Finite Elements method was used by [5] to solve the Maxwell equations in terms of the electric scalar potential and the magnetic vector potential, in a way to simulate transitory signals in grounding systems; the Finite Elements method was applied in grounding systems analysis by [6], where the Maxwell Equations were solved in the differential form, providing the instantaneous impedance results, that were validated by practical experiments.

Actually, some analytical methods used for grounding systems analysis, had been incorporated in computational routines. Some of these computational methods, in the majority of the cases, try to simulate real situations in grounding systems, promoting an additional analysis to the measurement methods. One indirect way to evaluate the grounding degradation level is analyzing the potentials distribution in its area and its surrounding. Grids that possess uniform potentials distribution and with low values do not present degradation problems, however, grids that possess high potential concentrations in determined areas can evidence its degradation.

This paper presents a measurement system capable to measure and process the surface potentials of an energized HV substation. The system has the functionality of measure several potentials voltages distributed throughout the grounding grid, with the objective of create a map of the HV substation superficial voltages, and allow to identify possible imperfections points. The measured data will be offline processed by a software, developed specifically for this purpose, where obtained results are evaluated with numerical rapports and 2 and 3D graphics.

2. THE PROPOSED METHOD

In the sequence, will be presented some details of the proposed method that is capable to detect and analyse the imperfections in energized HV substations, and verify if the measured potentials levels complies with the security standards.

2.1. Surface Potential Measurement

The surface potential measurement is performed with the HV substation in operation, it means, energized, with the grounding grid continuously receiving the imbalance current supplied by the transformers.

The simplest voltage potential measurement can be performed using a voltmeter and two copper rods inserted in the ground, as illustrated in Figure 1.
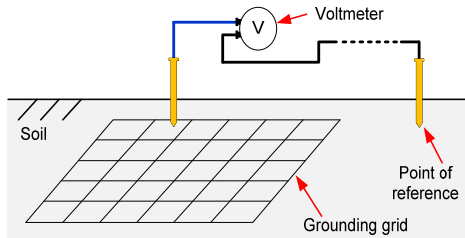

Fig. 1. Simplest surface potential measurement representation.

With the aim to perform an automatic potential measurement and facilitate the evaluation process, and obtain the peak value of the surface potential, for the same imbalance current, it was developed an electronic device capable to measure the surface potential in energized HV substations.

The measurement procedure is simple, using two copper rods, it was fixed a reference point (with a distance of approximately 40 m) for one copper rod, and the other rod is connected to multiples points of the grounding grid area and its neighborhood. In the sequence, is presented more details about the developed potential meter.

2.2. Potential Meter

The developed measurement system is based on PIC® microcontroller, and presents a low cost, easy implementation and reduced size. One advantage to use the microcontroller is its internal A/D converter of 10 bits. In the Figure 2, is presented the developed device.
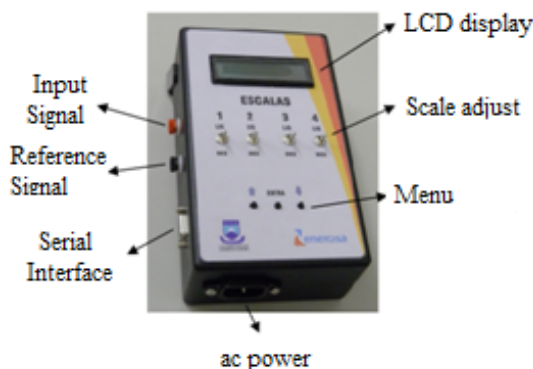

Fig. 2. Potential Meter photograph.

The surface potential datalogger perform the measurement of several points (inside and outside of the HV substation), distributed throughout the energized grounding grid. It is capable to measure and store a total of 127 distinct potential values, and the measured voltages are stored in a external memory and later, is transmitted to a personal computer using a serial communication interface, the measured data is analyzed using a developed software based on C# language.

A. Device Description

The device hardware is composed by a conditioning circuit (formed by resistive voltage dividers), a protection overvoltage circuit, a peak detector circuit and a LCD display for the results visualization.

Also, it is used in the device development a PIC® microcontroller, external memories and serial communication module. In the Figure 3 is illustrated the device functional block diagram.
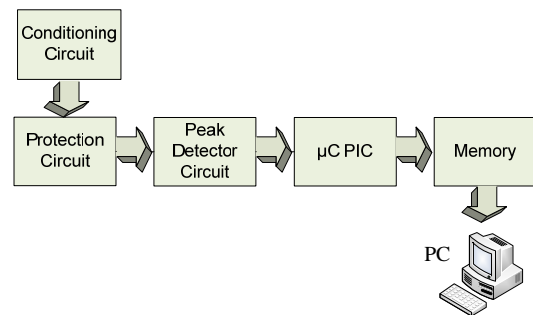

Fig. 3. Potential meter block diagram.

The voltage dividers circuits reduce the magnitude of the input signal to a range of 0-5V that is the A/D converter acceptable input voltage.

The system was projected to operate in 4 different scales, it means, for each scale is necessary a different voltage dividers ratio. In scale 1 the system is adjusted to measure surface voltages in the range of 0 - 25 V, scale 2 for the range of 25 - 50 V, scale 3 for 50 - 100 V and scale 4 for the range of 100 - 200 V.

The protection circuit has the function to protect the device against over-voltages from surges during the measurement, and it provides the electrical isolation between the input signal and the microcontroller. The circuit is basically formed by amp ops and diodes.

The peak detector circuit perform the detection of the maximum value of the measured surface voltage, generating a direct current signal (DC) corresponding to each surface voltage peak.

In the sequence, the DC signal is digitalized by the microcontroller PIC internal A/D converter. The microcontroller is responsible for coordinates and perform the surface voltage acquisition process, the measurements are stored and the data can be transferred to the personal computer in a posterior time.

B. Measurement Process

An interactive menu was developed for the interface between the electronic device and the user. The menu can be accessed by the user using 3 buttons (Increment, Enter and Decrement), and all the functionalities of the menu can be visualized using the LCD display (Figure 2).

The measurement process is performed selecting initially the scale 1, if the measured signal is in the correct range, the process will continue, in contrary the user will be asked to

change for the next scale, until the measured signal correspond to the ideal voltage range. The equipment is limited to measure surface voltages until 200 V. The flowchart of the measuring process is presented in Figure 4.
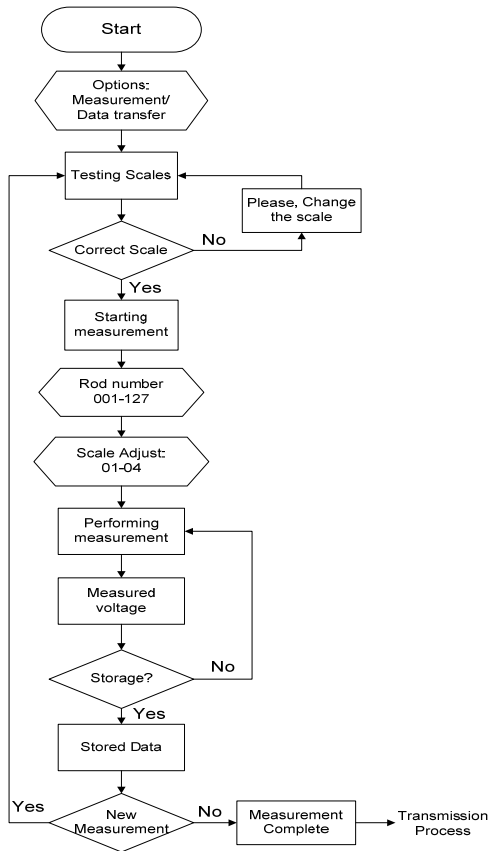

Fig. 4. Measurement process flowchart.

2.2. Energized Grounding Grids Diagnosis Software

A diagnosis software for grounding grid was developed with the objective of revealing the operational conditions of the grounding grids in energized substations. This software is capable of mapping the potentials on the surface of the grid and in its surroundings, indicating the possible field concentrations or the difficulties of the grid in draining the electrical current, externalizing the probable zones of high resistivity, zones of wearing or the existence of discontinuity in the grid, both in steady state and in the short circuit occurrence.

The Finite Difference Method (FDM) was used in developing the software. This is a method of mapping that can solve the Laplace equation iteratively, as described in [7] and [8]. The software has as input the measured and stored values in the memory of the developed potential datalogger device.

The current imbalance of the transformer, the short circuit current furnished by the project, the soil resistivity, the dimensions of the ground area wished to map for the surface potential, the dimensions of the grounding grid, aside from the coordinates of the points where the surface

potentials were measured, were also part of the input data on the software.

The software generates graphs in 2 and 3 dimensions that present the behavior of the potentials on the soil surface, both in steady state and in the occurrence of a short circuit, referring to the same point of reference.

Aside from the generated graphs, the software is also capable of calculating and externalizing in the form of a report the step voltages at the moment of a short circuit, presenting the locations and the respective values of the potentials that pass a maximum pre-established limit. To be conservative, the safety limit was fixed at 75% of the maximum limit calculated from the recommendations established in [9].

3. RESULTS AND DISCUSSION

3.1. Surface Potential Measurements Results

It is illustrated in Figure 5 a sketch of a substation area, used for the surface potential measurements. Inside the substation, the ground area was gridded and divided into 70 distinct points, encompassing the effective area of the substation and its surroundings. In Figure 5, the location of the reference point can also be seen. The point of reference was positioned at 40 m from where the substation's grounding grid is located.

The surface potentials measurement were performed using the developed potential device, which was capable of performing the measurements, storing the peak values of the potentials, and successfully transferring these values to a personal computer. The surface potentials values are treated and analyzed, via software.
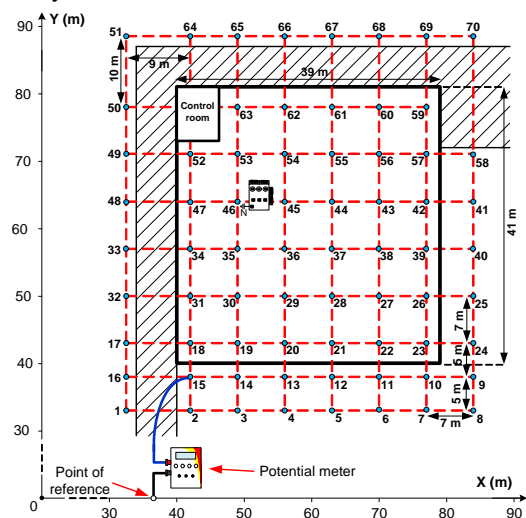

Fig. 5. Sketch of the land area of the substation which was used to measure the surface potential.

3.2. HV Substation Grounding Grid Diagnosis Software.

The surface potentials level mapping is performed using the developed analysis software that use the measured values and other characteristics, as presented in the item 2.

The dimensions of the substation and the grounding grid, along with the coordinates of the measured surface potentials are presented in Figure 5. The measured

imbalance current of the transformer was 4.24 A and the short circuit current calculated for the original grid project was 4.866 kA.

For the studied substation, the software calculated a value of 3,049.90 V for the maximum step voltage permitted for a person of 50 kg. Thus, a safety limit of 2,287.43 V was attributed, corresponding to 75% of the calculated value.

The software was capable of mapping the potentials on the soil surface, indicating the probable field concentrations, both in steady state and in the occurrence of short circuit, generating graphs in 2 and 3 dimensions for both situations, referring to the same point of reference. The obtained results are presented in Figures 6, 7 and 8.
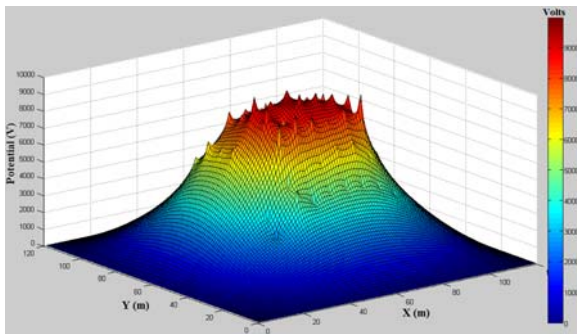

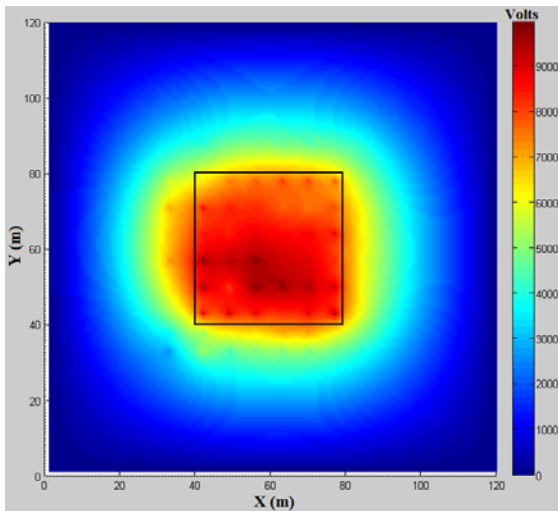**Fig. 6. 3D representation of the surface potential levels for the analyzed substation.**

Fig. 7. Superior view of the potential surface levels, with the exact localization of the grounding grid.
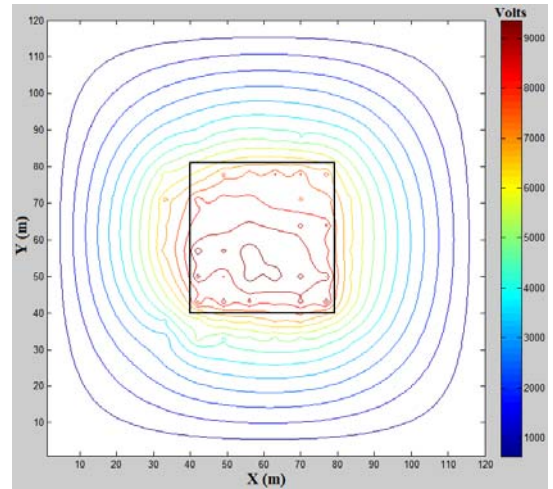

Fig. 8. Equipotential lines representation of the HV substation.
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3.3. Comparison between the developed measurement device and a digital oscilloscope.

To verify the accuracy of the obtained results of the developed surface potential datalogger, some measurements were performed using a Tektronix® digital oscilloscope model TDS 2024B and the developed device simultaneously. The results are the medium value of three distinct measurements.

The point's number corresponds to the grid connection presented in Figure 5. The results are presented in Table 1.

Table 1 Measurement comparison between the developed device and a digital oscilloscope.

Measured Surface Potentials (V)			
Points	Developed Device	Oscilloscope	Error (%)
3	3.75	3.84	2.34
4	3.67	3.68	0.14
5	3.80	3.92	3.06
14	5.56	5.60	0.71
19	7.97	8.0	0.375
30	7.65	7.60	0.65

Comparing the obtained results is possible to verify the satisfactory performance of the developed measurement device.

3. CONCLUSION

An important factor in the quality of the energy is the grounding system. The majority of the HV substation equipments use the ground grid as voltage reference for the other operational voltages and for the security. The obtained results using the developed system were satisfactory and present several information's about the grounding grid degradation level, it means, it was possible to diagnose and localize zones with voltage potentials concentration, using a low cost system.

REFERENCES

[1] H. Moreno, P. F. Costa: "Aterramento Elétrico", Procobre, São Paulo, Brazil, 1999.

[2] G. Kindermann, J. M. Campagnolo: "Aterramento Elétrico", Sagra-DC Luzzatto, Porto Alegre, Brazil, 1995.

[3] W. A. Chisholm and W. Janischewskyj, "Lightning surge response of ground electrodes", IEEE Transactions on Power Delivery, vol. 4, n. 2, pp. 1329-1337, Jan. 1989.

[4] Z. Flizowski, C. Mazzetti and B. D'Elia, "Risk assessment method for the protection against lightning overvoltages", Proceedings of the 24th International Conference on Lightning Protection, pp. 842-847, Birmingham, Sep. 1998.

[5] V. A. Rakov and M. A. Uman, Lightning - Physics and Effects, Cambridge, Cambridge University Press, 2003.

[6] M. Trlep, A. Hamler, and B. Hribernik, "The analysis of complex grounding systems by FEM," IEEE Trans. Magn., vol. 34, no. 5, pp. 2521–2524, Sep. 1998.

[7] A. Thom, C. J. Apelt: "Field Computations in Engineering and Physics", D. Van Nostrand, London, 1961.

[8] W. H. Hayt Jr, J. A. Buck: "Eletromagnetismo", LTC, Rio de Janeiro, Brazil, 2003

[9] IEEE Std 80: "IEEE Guide for Safety in AC Substation Grounding", 2000