WIRELESS SENSOR NETWORK APPLIED TO ZnO SURGE ARRESTERS

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Abstract: Surge arresters are equipment used for the electrical power system protection. They limit the voltage level during the occurrence of switching and atmospheric surges. A surge arrester failure can cause equipment insulation breakdown or flashover, or even surge arrester explosion. To avoid this problem, the maintenance of these equipments is made by means of regular monitoring. Measurement of the resistive leakage current and analysis of its harmonic components is one of the most used techniques to evaluate the degradation level of metal oxide surge arresters. In this paper, a wireless sensor network capable to perform the ZnO surge arrester wireless monitoring is presented. For each transmission line, at least three surge arresters are necessary, and the collected information is sent to the substation operation area to be analyzed in the form of a graph or a report.

1 INTRODUCTION

Zinc oxide (ZnO) surge arresters are equipment used for the protection of electrical power systems and have been employed for more than 30 years with the purpose of increasing the reliability of the electrical system. The basic function of the ZnO surge arresters is to protect the electrical system against flashovers caused by atmospheric and manoeuvre discharges in substations and on transmission lines. The surge arresters must behave as insulators for voltage values inferior or equal to the operation voltage and as good conductors for any tension above this value, thus limiting the voltage surge level, and protecting the substation equipment.

Several techniques [1] - [4]. are used for monitoring ZnO surge arresters, but a consensus in relation to the best technique to be applied does not exist. Each technique presents advantages and disadvantages. The existing techniques do not allow identification and classification of the possible problems detected in the monitoring.

Among the diverse techniques used in the evaluation of ZnO surge arrester degradation, the measurement of the leakage current is one of the techniques that presents trustworthy information about equipment integrity or degradation level. The leakage current monitoring of the surge arrester in operation can indicate permanent problems or transient imperfections [5] – [7].

In this paper a system based on the measurement and harmonic analysis of the leakage current is presented. The system can perform the degradation level evaluation by using the measurement and harmonic analysis of its leakage current. For the current measurement, the system uses an inductive, not invasive, sensor with high magnetic permeability based on a nano-crystalline alloy composition [8].

The system can supply the following information: the measurement of the total leakage current that circulates in the surge arresters, the total leakage current decomposition, which means the calculation of the resistive and capacitive components and the calculation of the third harmonic component. The details of these functionalities are presented in the sequence. The obtained data are sent to the substation control room by using a wireless communication system, based on the ZigBee® protocol, operating in the frequency range of 2.4 GHz.

2 THEORICAL FUNDAMENTATION AND BIBLIOGRAPHIC REVIEW

ZnO surge arresters are widely used in electrical power systems and are formed mainly by non-linear resistive elements, known as varistors. After the sintering process, the metallic oxide varistors become a polycrystalline material formed by semiconductor ZnO grains, with well defined grain contours [9]. They are presented graphically in Figures 1 and 2, respectively, the idealized microstructure and the real one. In Figure 3, the micrograph of ZnO varistor is presented, produced in a joint research between the Materials Engineering Department and the Electrical Engineering Department, of the UFCG. The research had as its main objective the development of varistors with highly nonlinear characteristics and good stability [11].

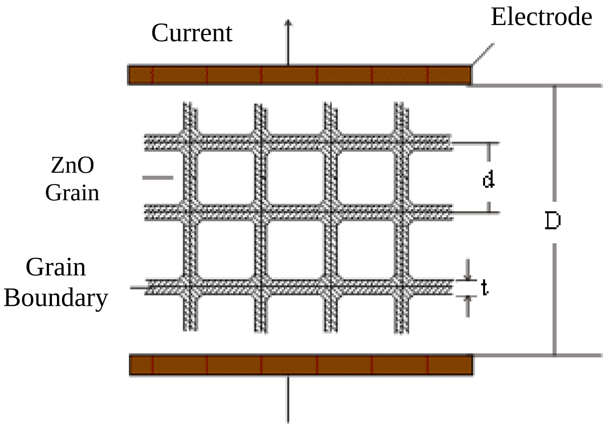

Figure 1: Idealized Microstructure of a ZnO varistor.

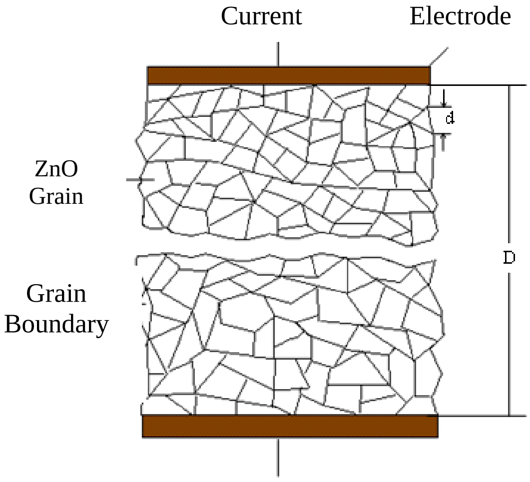

Figure 2: Real Microstructure of ZnO varistor.

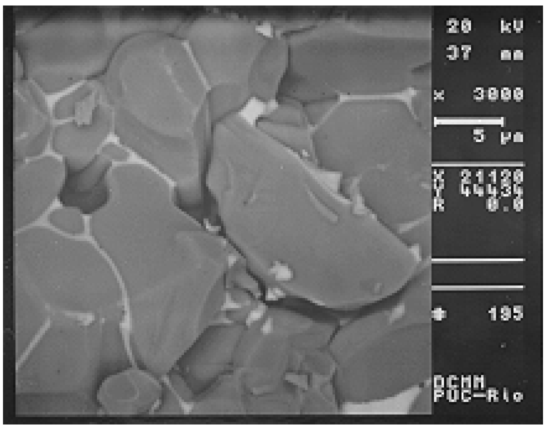

Figura 3: Micrograph of a ZnO varistor produced in the UFCG.

The surge arrester lightning rods possess housing (porcelain or polymer) that assures equipment sealing. If the varistors have contact with pollutants and humidity, the useful operation of the surge arrester is reduced, and consequently, its functioning can be incorrect.

The high voltage surge arrester is normally physically installed in a pedestal between the bus bar and the associated equipment. Geographically, they are the first equipment of a substation and are installed between the overhead line conductor and the effective earth, and consequently the surge arresters are vulnerable to eventual surges which occur on the transmission lines. The geographic localization of a ZnO surge arrester in a high-voltage substation can be observed in Figure 4.

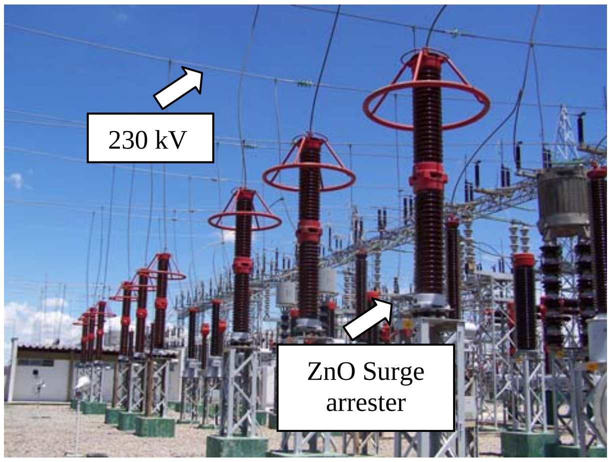

Figure 4: ZnO surge arrester localization in a 230 kV substation - CHESF.

Based on the electric characteristics presented by the ZnO varistors, influenced by the chemical composition and manufacturing process, a low intensity leakage current circulates in the surge arrester in normal operation when connected to the system voltage. The total leakage current, IT, is composed by two components (capacitive IC and resistive IR), as presented in Figure 5, which also presents the electrical model of the surge arrester [10].

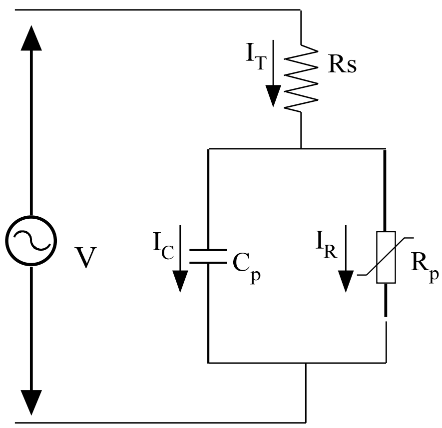

Figure 5: Simplified electrical model of a ZnO surge arrester.

In Figure 5, R_s represents the resistance of the ZnO grains, R_p, the nonlinear resistance of the intergranular region of the varistors, and C_p

represents the capacitance formed by the ZnO grains. The resistive current, with nonlinear characteristic is responsible for the electric losses and the aging of the ZnO blocks. The resistive current presents a small value in normal operating and voltage conditions of the system, when compared to the capacitive component.

2.1 Leakage current Measurement

The leakage current measurement is based on the measurement of the current that flows through the electric connection between the surge arrester and the earth of the substation. In the surge arrester degradation process, the resistive component current is influenced. Its amplitude increases sufficiently with the degradation, thus, being a good indicator of the ZnO surge arrester physical conditions [6].

To perform the measurement of the leakage current of the surge arrester, an inductive current sensor based on electromagnetic induction was developed. In this sensor, for a given leakage current flow I_T, a proportional magnetic field H is produced around the current carrying in the conductor and an output voltage proportional to the current intensity is supplied. In the sequence, the output voltage conditioning and processing of the signal is performed, and the interest information is obtained.

For the magnetic flux acquisition generated around the magnetic core, magnetic material with high permeability and toroidal format was chosen, aiming to confine the leakage current flux. The current sensor is composed of a high-sensitivity toroidal coil, followed by a differential amplifier and an integrator. The developed sensor diagram is represented in Figure 6 [8].

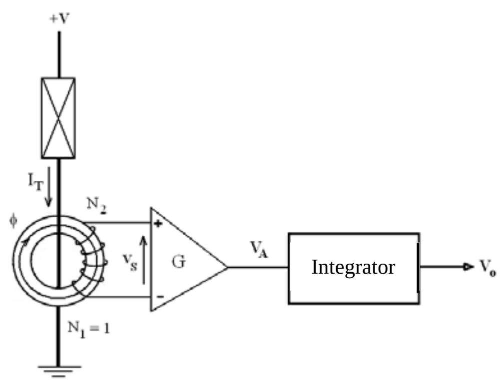

Figure 6: Current- voltage converter diagram.

Based on these characteristics, the greater the material magnetic permeability value of the toroidal core, the greater the current sensor output voltage V_o will be.

2.2 Leakage current decomposition

The resistive and capacitive components calculation was performed by using the phase shift measurement technique, which is based on the total leakage current measurement and its phase delay in relation to the applied voltage. The applied voltage in the surge arrester has the same phase of the resistive leakage current, as presented in Figure 7 [7].

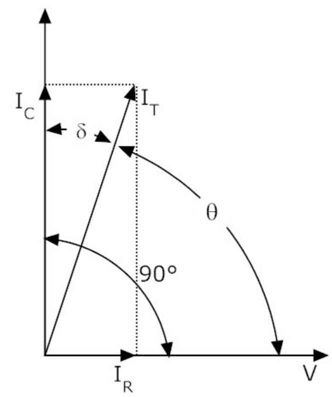

Figure 7: Phasor diagram of the applied voltage and the leakage current components [7].

From the measurement of the phase shift angle θ, between the total leakage current I_T and the applied voltage V (in phase with the resistive current I_R), it is possible to determine the leakage resistive current component, as can be observed in Equation (1) [7]:

$$I_R = I_T \cos \theta. \quad (1)$$

2.3 Wireless Sensor Network (WSN) – ZigBee Protocol

The wireless communication modules XBee-Pro® based on the ZigBee technology allow a relatively fast implementation and low power consumption to develop a wireless sensor network.

In the sequence, some details about the wireless communication protocol ZigBee IEEE 802.15.4 developed by the ZigBee Alliance in association with the IEEE (Institute of Electrical and Electronics Engineers) will be presented.

The developed WSN allow the real time monitoring of the ZnO surge arrester leakage current and make it possible for the operator of the substation control room to visualize the leakage current waveform, as well as its numerical values.

The XBee-Pro® modules, series 2 from Maxstream were used, due to the transmission range and easy implementation. In Figure 8, a communication module based on the ZigBee® technology is presented.

Figure 8: Maxstream® XBee ProTransceiver**.**

The ZigBee network is called Personal Network Area (PAN). Each network is identified by a 16 bit address for each sensor. In this network, there are three types of devices: coordinator, router and end device. Each one of these devices is described below:

- Coordinator: Responsible for the distribution and initialization of the communication channel and the network PAN.
- Router: Responsible for the expansion of the network, it could be connected to others Routers or End-Devices, increasing the communication distance.
- End-device - Device in which sensors or microcontrollers can be connected.

Each measurement and analysis leakage current system possesses a ZigBee transceiver configured previously as End-Device. It sends the obtained surge arrester leakage current information to the substation control room, where the coordinator device is installed. After the data reception, the results are presented in form of graphs and numerical reports. The system representation is presented in Figure 9.

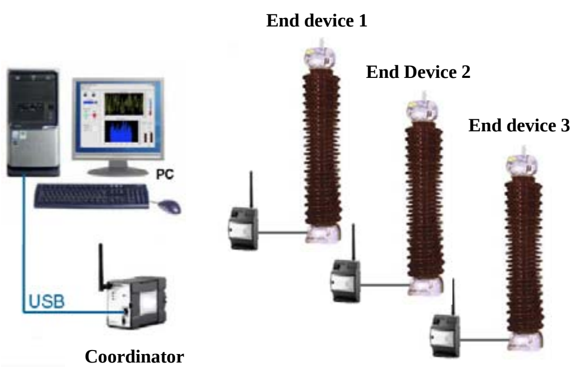

Figure 9: Wireless sensor network graphic.

Considering that each transmission line needs at least 6 surge arresters, 3 located in the input transmission line and 3 in the output transmission line, the WSN implementation is justified. Therefore, it allows the reduction of monitoring costs and permits a greater trustworthiness of the electrical system as a whole.

3 RESULTS

For the wireless sensor network implementation, a tree topology was used, in which three sensors were installed in different surge arresters. The information about the leakage current and its harmonic components were sent to the CHESF substation control room with a distance of approximately 900 meters.

The coordinator device is connected to a personal computer. Additionally, software was developed to present the real time results, such as the waveform and numerical reports.

In Figures 10 and 11, the waveforms of the measured leakage current are presented, by using an oscilloscope, and by using the developed measurement system, respectively.

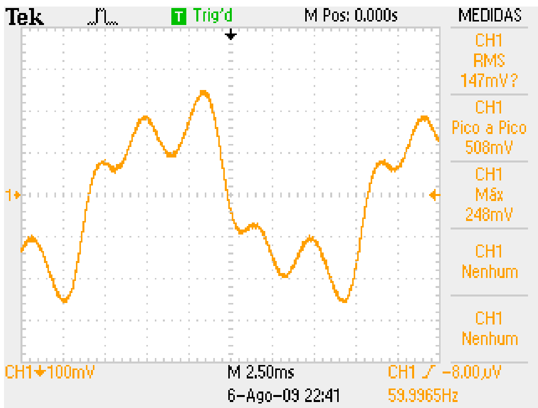

Figure 10: ZnO surge arrester leakage current waveform measured with the oscilloscope.

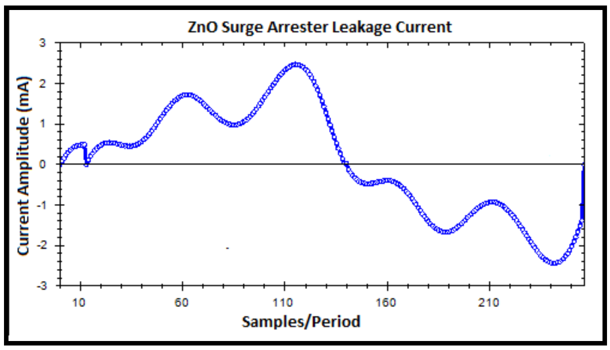

Figure 11: ZnO surge arrester leakage current waveform measured with the proposed system.

Figure 10 corresponds to the total leakage current signal obtained with a digital oscilloscope. The curve presented in Figure 11 corresponds to the leakage current signal presented in the substation control room, after the current measurement, processing and transmission.

4 CONCLUSION

In this paper a system of ZnO surge arresters monitoring, based on the measurement, analysis and transmission of the leakage current was presented. The proposed system allows the transmission of the obtained information after analyzing the leakage current signals by using a wireless sensor network based on the use of the ZigBee® technology.

Although the monitoring system is installed in a high-voltage substation, that is, in an environment with high electromagnetic interference, the wireless communication between the diagnosis system and the substation control room was robust and efficient, performing a satisfactory communication with a distance of approximately 900 meters without presenting errors in the communication.

5 ACKNOWLEDGMENTS

The authors wish to thank the National Council for Scientific and Technological Development- CNPQ, and the CHESF (P&D Project CT-I-92.2007.8690.00), for their support in the institutional research, and the Electrical Engineering and Informatics Center of the Federal University of Campina Grande, for its support during the experimental tests.

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