Artificial Neural Networks Used for Failure Diagnosys in ZnO Arresters

ESTÁCIO TAVARES WANDERLEY NETO, EDSON GUEDES DA COSTA
Electrical Engineering Department
Universidade Federal de Campina Grande
Av. Aprígio Veloso, 882. Bodocongó. Campina Grande - PB
BRASIL

MARCELO JOSÉ DE ALBUQUERQUE MAIA
Companhia Hidro Elétrica do São Francisco - Chesf
Av. Delmiro Gouveia, 333. Bongi. Recife - PE
BRASIL

Abstract: - Surge arresters protect substation equipments against switching and atmospheric surges. A defective arrester may expose the power system to failures that can lead to a complete turn off of the system, or even explode damaging other equipments or hurting people [1]. An efficient predictive maintenance helps avoiding this kind of problem with arresters, indicating the necessity for their substitution when a permanent failure is detected. This work presents a series of tests done to relate thermal images and usual failures in ZnO arresters and the development of a computational algorithm based on artificial intelligence technique to analyze arresters thermal images..

Key-Words: arrester, artificial neural network, failure, metal oxide, monitoring, thermal image.

1 Introduction

A ZnO arresters present a very simple structure. They are composed of a series of stacked varistor blocks enclosed in a porcelain or polymeric housing. They are installed directly between line and ground, so that there is a continuous leakage current flowing between its terminals. Arresters work converting part of the power present in a electric surge in thermal energy and dissipating it to the environment. However, they are subjected to a series of influences that can degrade their components, decreasing their performance and lifetime. Some of these influences are humidity, long time discharges, internal discharges and premature degradation of varistors [2].

Although ZnO arresters are used for about 30 years, there is no consensual diagnosis method to indicate when an arrester must be replaced or the problem being presented [3]. The main problem in arresters failures analysis is the difficulty to make internal inspections in the equipments components, as though their opening results in their inutilization for the power systems. Anyway, even with these difficulties, there are some monitoring techniques widely diffused for arresters. Thermal inspection is on of these techniques.

The resistive leakage current and its harmonic components are responsible for the arresters heating by joule effect. Any change in arresters behavior results in changes in their leakage current [4] and, as consequence, in their temperature pattern, so that a thermal image can detect these variations. The thermal images analysis is a non-invasive technique applied for most equipments in power substations and transmission lines [5]. Although, for arresters, there is no specific methodology to lead the monitoring and diagnosis - each power company develops their own methodology and criteria for arrester analysis. Besides that, usually when an arrester is replaced, no further study is conducted so that the causes of failure can’t be evaluated. As result, there is no specific revisions about which are the main causes of arresters failure or if there is any alternative to avoid replacement of the equipment when the problem is not due to internal arrester failure.

This work presents an study with 96 kV ZnO arresters to evaluate the main problems that could be detected in operating equipments and their effects over the arresters thermal pattern. To achieve this objective, a series of tests was conducted in the High Voltage Laboratory of Universidade Federal de Campina Grande to simulate the most usual failures found in field arresters. Besides that, the results of an initial version of a software for the analysis of this thermal images, based on artificial intelligence techniques is shown, which will be an important tool for analysis and diagnosis of ZnO arresters.

2 Failures in ZnO Arresters

ZnO varistors were created as an evolution of semi conductive ceramics for electronics and became an alternative more efficient in relation to the silicon carbide ceramics used in power surge arresters. Besides the problem related to failures in ZnO arresters, there is also too little information about the natural ageing of ZnO varistors. That’s because the estimated lifetime of a varistor is about 30 years, that’s the approximate age of the first ZnO arresters put into operation in power systems.

To complete this overview, it is an usual practice in power companies to dispose off any defective arrester with no further analysis about the failure. So there is not much available information or studies about failure diagnosis in arresters so that these failures could become more easily identified with a thermal inspection.

Usually, when defective arresters are submitted to analysis, or when tests of degradation and aging are carried through, there is a series of defects whose occurrence is observed with more frequency. The majority of these defects presents well definite causes and characteristics, so that it is possible that the consequences, in the form of the extreme heating of the arrester, are perceivable through the thermal analysis.

2 Failures Tests

ZnO varistors were created as an evolution of semi A series of tests were conducted with five 96 kV arresters put out of operation by Chesf due to some irregularity presented during thermal inspection. These arresters were submitted to characterization tests, which indicated the presence of problems justifying their retirement from operation. After the characterization tests, the most common failures were introduced in the arresters and another series of tests were conducted to analyze the influence of this failures on the arrester thermal image.

Thermal images after the failures creation were compared to the thermal images obtained when the arresters were received in the lab. Thermal profile graphs were created to help the recognition of the most significative points in the thermal images. This graphs were also used later to feed the algorithm created for thermal image analysis.

3.1 Sealing Failure

A sealing failure in a ZnO arrester causes alterations in its heating pattern due to the circulation of gases, made easier because of the paths connecting inner and outer arrester envioroments. It is known that, with the temperature increase, there is an increase of the chamber pressure of the arrester. If there is some cracking in the sealing, the gas that constitutes the intern media of the arrester will be free to circulate. A result of this effect is the reduction of the level of security in the performance of the equipment. As it has a continuous leakage of gases, the system of protection against explosions becomes inefficient, being no capable to act on an extreme heating. In a similar way, a sealing failure also allows the entrance of gases and humidity from the external environment. Depending on the type of gas or the level of humidity to penetrate in the arrester, its internal insulation can be compromised due to the occurrence of superficial discharges [6].

For the failure tests, some arresters were intentionally closed with failures in the sealing material so that a conduction path for gases and humidity could be generated. The main effect observed in the thermal profile is a decrease in the temperature peaks in the regions where a greater heating was observed (the upper varistor groups), so that these regions which used to be easily identified are not well defined anymore. This is explained because the gas circulation inside the arrester aids the heat dispersion by means of convection.

3.2 Humidity

The presence of internal humidity in arresters is usually the result of some failure in the sealing material. The main problem caused for the humidity is the occurrence of partial discharges, which can occur in different ways. The first one of them is the formation of a humid path along the surface of the varistors column, leading to insulations problems and electrical sparks.

One another problem related to the humidity entrance is related to possible strange gases or particles of pollution which can follow the humidity in the interior of the equipment. Depending on the type of gas or particles, there can be a reduction in the internal isolation. Finally, the internal humidity can also be responsible for the premature degradation of the varistors.

For this test, clean water was vaporized on internal columns of arresters to simulate the presence of humidity in the interior of the equipment. Analyzing the thermal images and the temperature patterns it is possible to notice that different effects were obtained for each tested arrester. Anyway, in both cases, a large increase of temperature was visible in distinct regions of the arrester. These regions had suffered this increase from temperature probably due to circulation of vapor and to the occurrence of internal discharges, as explained previously.

3.3 External Pollution

Superficial pollution is a common problem not only in arresters, but also in most equipments or structures that present a larger height to improve a minimum level insulation between phase and ground, as insulators and equipment bushings. Depending on the region where the equipment is located, this problem can be accentuated due to high air humidity or salinity. Basically, the superficial pollution is classified in dry pollution (Fig. 3) or humid pollution, being the second one the most harmful. Its main effect is to decrease the distance for the current conduction making possible the occurrence of discharges in the surface of the porcelain or polymer that constitutes the arrester housing.

Fig. 3 – Arresters covered with salty pollution.

Superficial pollution can also generate dry bands in the surface of the porcelain. Dry bands cause superficial discharges in the porcelain, modifying the electric field in the region and heating the varistors located in the height where these dry bands are formed. This heating stabilizes the dry bands turning them permanent, even in high humidity conditions [7]. As results of this problem, there is the formation of limited heated region of the arrester and the influence in the voltage distribution along the varistors column.

For the failure tests, the arrester was put in to a salty fog in order to simulate the presence of a more severe pollution on its surface. On of the consequences of the salty fog was the appearance of superficial discharges on terminals of the arrester. This discharge probably was resultant from the presence of water drops the neighborhoods of the terminal. The thermal images indicated a greater heating in the proximities of the terminals and in the downer part of the arrester. As though there is a lower heating in its upper portion. A possible explanation is that the pollution was concentrated in the downer region of the arrester, causing partial discharges there. Other possibility is the increase of superficial currents in the upper region of the arresters which would cause a lower leakage current to be conducted by the varistors. It is possible that at some point in the middle region of the housing, this superficial current decreases, as though the leakage current through the varistors increase. It would explain the larger heating in the downer part of the arrester instead of what is usually observed.

3.4 Varistors Degradation

Varistors degradation can be resulted from its natural ageing, from its premature ageing due to severe electrical surges or its breaking [8]. However, in many cases, when a varistor failure diagnosis is done, vestiges of some factors that can have caused its failure are found. Premature degradation of varistors is a factor that can contribute to the occurrence of thermal runaway (Fig. 4). There are still some external aspects that should be considered when evaluating the premature aging of the varistors. Example are the environmental temperature and the entrance of humidity. It is known that these factors favor the increase of the leakage current and, as a consequence, there is an increase of temperature and acceleration of the aging process.

Fig. 4 – Varistors degraded by excessive heating.

For the failure tests, a varistor in the active column was replaced by broken one. The broken varistor presented a longitudinal crack. The obtained thermal image indicated more intense temperature on the region to which belongs the broken varistor. This bigger heating is evidenced by the analysis of the temperature profile, where a peak of temperature in the region of the broken varistor is easily perceived. Such heating can be explained by the greater electrical stress suffered for the broken varistor which can present difficulty for the current conduction and heat dissipation.

3.5 Displaced Varistors

Displacement of varistors along the arrester column is not a very usual failure, although it is observed in some equipments when they are opened. Most times, this displacement is result of a non appropriate transportation or storage. As most arresters manufacturers present a high control level of their producing processes, a displacement due to an assembly problem is not very usual to happen, although it is possible.

For the continuity of the failure tests, some varistors were assembled in a displaced position along the active columns. For this case, no significant modification could be observed for the thermal images of the arresters. However, a further analysis, made with the aid of the thermal profiles indicates a modification in the temperature distribution mainly in the inferior part of the arrester. Probably, a preferential conduction path for the current was created in the areas where the varistors keep contact.

3.6 Irregular Voltage Distribution

Irregular voltage distribution is a very usual problem in power equipments that present a larger height. In arresters, it is characterized by the occurrence of larger voltage drops in the upper region of the equipment, close to the high voltage terminal.

The level of irregularity in the voltage distribution depends on the geometry of the equipment and the used materials. The existence of earth capacitances is the main responsible for this problem. It is known, by means of tests and calculations that an increase of heating and leakage current in varistors present a straight relation with the level of earth capacitances in the arrester [7]. Pollution along the arrester housing is a problem that increases the voltage distribution irregularity, as though they create more intense earth capacitances.

A simple solution to avoid this problem or reduce its effects is the application of grading rings. They allow a better voltage distribution along the arresters, reducing the effects of the earth capacitances. Another solution to avoid this problem is assembling the arrester with a larger concentration of varistors in the upper region so that there is a better performance where there is a larger voltage drop. Short-circuits in the inner region of the arrester are also a possible cause of voltage distribution irregularities in ZnO arresters.

For the execution of failure tests conductive materials were used to short-circuit some varistors located in different positions along the arrester active column (Fig. 5). This situation simulates a problem in varistor that would cause an excessive current conduction for it and, as consequence, an alteration in the voltage distribution. As results, a decrease in the heating on the region of the short-circuited varistors could be noticed. The explanation is the fact that these varistors are not presenting thermal dissipation like they used to present before they were shor-circuited.

Fig. 5 – Short-circuited varistors in an arrester column.

4 Results for Failure Tests

As an example of the results obtained with the failure tests, Fig. 6 depicts the thermal image and profile of an arrester the way it was received from Chesf, while Fig. 7 shows the thermal image and profile after humidity inclusion. A fast comparison between the thermal images is enough to indicate the change caused by the humidity. An analysis of the thermal profiles indicates more precisely the level and location of the alterations in the arrester thermal behavior.

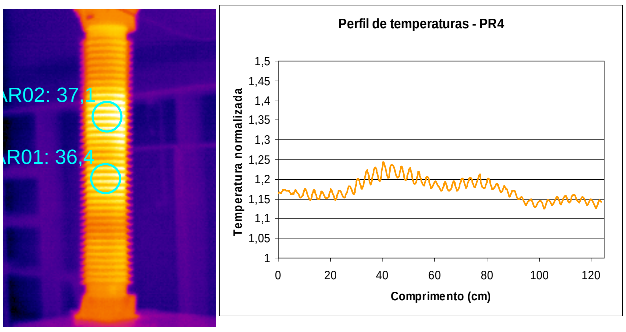

Fig. 6 – Thermal image of an arrester when it was received from Chesf.

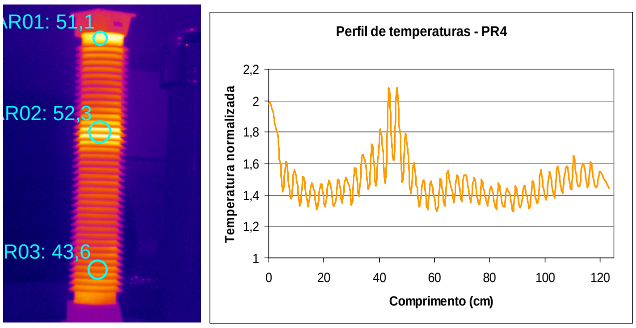

Fig. 7 – Thermal image and thermal profile graph of arrester in Fig. 6 after humidity was introduced in its inner region.

The humidity example, shown behind is a case where a simple eye analysis is able to indicate the presence of the failure. In other cases, like a short circuit in a varistor located in the middle portion of the an eye inspection may not be enough to percept the failure. In this case, a computational processing, with the thermal profile graphs and a technique for analysis of the temperature points could indicate more precisely the presence of the broken varistor. To aid with these analysis a thermal image analysis algorithm is being developed, as detailed in the next topic.

5 Thermal Image Analysis

A more detailed analysis of a thermal image can be done if computational techniques are used. Artificial Intelligence (AI) based techniques, like artificial neural networks (ANN) can scan the temperature values of a thermal image, identifying some characteristics or patters that could not be perceived by eye.

For some cases. Like in Fig. 8 and Fig. 9, although the maximum temperature doesn't change in a significant way, it can be seen that the curves profile differs from each other. Probably, if these thermal images were analyzed only by eye inspection, the sealing failure could not be perceived, like it would be after the computational processing and analysis of the obtained temperature values.

For this work, ANN were chosen because they are a promising technique for the analysis of arresters thermal images, as they are already a consolidated technique used for pattern recognition. Besides that they present a simple algorithms and they are easy to develop and process.

5.1 Artificial Neural Networks

An artificial neural network is a computational processing structure based on the human brain. The brain can be analyzed as a computational structure presenting an extremely high level of complexity with non-linear and parallel processing. If some of the brain characteristics, like its control system or pattern recognition, are analyzed it is clear that there is no developed machine or computational system presenting capable of developing the same tasks so fastly and precisely. So, in a simplified way, an ANN tries to copy the biological neural network using computer algorithms to develop a processing structure presenting the main characteristics of the brain: non-linearity, parallelism, plasticity and generalization – resulting in a system with learning capacity and information storage [9].

The ANN main structures are the neurons, which presents structures similar to biological neurons. Each neuron presents one or more inputs and one output and they are connected to each other by the synapses. Each synapse presents a numerical weight that imposes more or less importance to the numerical value of its corresponding input.

The numerical values corresponding to the synaptic weights can changed when the ANN is trained. For this, a learning algorithm must be used, which presents a series of rules for the solution of each specific problem. Usually, during the training process, after all the inputs are processed by the neural network, the final value in the output is compared with a desired value. The obtained error is a parameter to adjust the synaptic weights so that for the next iterations, the error will be reduced and the ANN will present the desired behavior.

A very simple ANN structure is the perceptron [10]. It is composed of a single neuron with variable synaptic weights and it is used to classify linearly separable patterns in to groups. An extension of the perceptron, the multilayer perceptron, allows the separation of patterns in several groups. For its simplicity it will be used here as a first test to development of the thermal image analysis system.

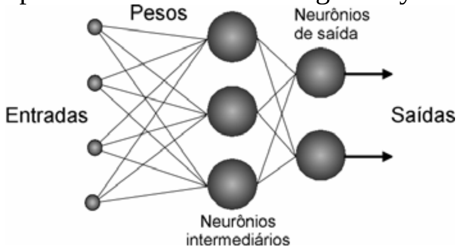

Fig. 8 – Multilayer perceptron.

Multilayer perceptrons uses a learning algorithm known as backpropagation algorithm, based on error correction. Its is structured into two steps. The first step is the forward one, the propagation. A series of signs – numerical values, used as inputs are processed for the whole ANN, layer by layer, till they reach the output of the network. The second step, is the backpropagation, when the error signal of the final output runs in the backward direction so that all the synaptic weight in the way are adjusted.

It is important to notice that the final output pf a neural network is limited by a activating function, so that the results will not diverge. These functions usually limit the values in the intervals [-1; 1] or [0; 1], being the sigmoid functions the most used ones.

5 Results for the developed ANN

For the objective of this work, a multilayer perceptron based on backpropagation learning algorithm was developed to analyse the temperatures from an arrester thermal image. As explained previously, from the thermal image, a graphic thermal profile from the arrester can be built. This thermal profile supplies the necessary values for the neural network inputs.

The developed ANN presented 77 inputs, corresponding to temperature points along the arrester length, and a hidden neuron layer with 4 neurons. The backpropagation algorithm was used for 1,000 epochs (complete iterative process) and the output should indicate a defective or non-defective arrester. In a databank containing 60 examples, 70% of the examples were used for the network training and 30% for the test procedure. As a result, the network presented the desired results for 89% of the cases. Although this is not a bad result as a very simple ANN structure is used, it is not still an acceptable value for the classifying software.

Based on this first neural network, a new structure was developed, trying to improve the network efficiency. This new network will presented selective inputs so that only the maximums and minimum values of the temperatures were used. The databank was also improved, presenting 100 examples of thermal images. The results were not the expected, as only 89% of the results were corrected. Probably, the reduction in the number of inputs eliminated important values for the network processing.

A next step in the ANN development is being conducted. Now, a new network based on Resilient Propagation (RPROP) algorithm and probabilistic networks is being developed. Experiences show that the utilization of RPROP algorithm improves drastically the results for the backpropagation based ANN.

4 Conclusion

The results obtained for the failure tests indicates that the thermal imaging is an adequate method for arresters inspection, as it is able to detect minimum variations in the thermal profile of the equipment.

For all the tested samples, some kind of variation could be detected. This variation could be perceived more easily when a graphical temperature profile was built. The small variations can be used as a starting point for the failures diagnosis in the equipment.

A first attempt to develop a failure diagnosis computational algorithm was made by means of artificial neural networks techniques. A very simple neural network a was developed to classify the arresters in two different groups and a good percentual level (89%) for the right classification tax was obtained, although this level is not good enough.

A new algorithm, based on more efficient learning techniques, is being developed for the neural network as though the databank of arresters thermal images is being increased. It is expected now an improvement for the network processing so that the percentual level of right results should increase.

This work is the first step for the development of a monitoring and diagnosis tool for arresters based on thermal images analysis. Used along with leakage current measurement, it would be a powerful tool for a complete analysis of the arrester electro-thermal behavior.

References:

[1] P. M. Pereira et ali., Equipamentos elétricos - especificação e aplicação em subestação de alta tensão. Rio de Janeiro: Furnas, 1985.

[2] C. Heinrich, V. Hinrichsen, “Diagnostics and monitoring of metal oxide surge arresters in high-voltage networks- comparison of existing and newly developed procedures”, *IEEE Transactions Power Delivery*, vol. 16, nº 1, pp. 138 – 143, 2001

[3] P. F. P. Sobrinho et ali, “Avaliação do estado e do comportamento de pára-raios de média e alta tensão, dos tipos de carboneto de silício (SiC) e de óxido metálico de zinco (ZnO)”, Seminário interno de manutenção de subestações CTEEP e EPTE, 2001.

[4] HINRICHSEN, V., Scholl, G., Schubert, M., Ostertag, T.: “Online Monitoring of High-Voltage Metal-Oxide Surge Arresters by Wireless Passive Surface Acoustic Wave (SAW) Temperature Sensors”. Proceedings of The 11th International Symposium on High-Voltage Engineering, London, UK, August 23-27, 1999.

[5] KORENDO, Z., FLORKOWSKI, M.: “Thermography based diagnostic of power equipment”. *IEE Power Engineering Journal*, February 2001.

[6] K. Lahti, K. Kannus, K. Nousiainen, “Diagnostic methods in revealing internal moisture in polymer housed metal oxide surge arresters”, *IEEE Transactions on Power Delivery,* Vol. 17, No. 4, pp. 951-956, 2002K.

[7] S. Harasym, H. Z. Brosz, S. S. Shur, T. Shelepeten, W. Janischewskyj, “Pollution Performance and Voltage Distribution in Surge Arresters Enclosed in Porcelain Housing – Measured and Calculated”. 10th International Symposium on High Voltage Engineering. August, 25 – 29, 1997. Montreal, Canada.

[8] EDA, K.: “Destruction Mechanism of ZnO Varistors Due to High Currents”. *J. Appl. Phys.*, Vol. 56, N° 10, pp. 2948 - 2954, November 1984.

[9] S. Haykin, *Redes Neurais – Princípios e prática,* 2ª Edição, Porto Alegre: Bookman, 2001.

[10] F. Rosenblatt, “The Perceptron: A probabilistic model for information storage and organization in the brain”, Psychological Review, vol. 65, pp. 386-408.