PAPER • OPEN ACCESS

Condition based monitoring of gapless surge arrester using electrical and thermal parameters

To cite this article: Novizon *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **602** 012007

View the article online for updates and enhancements.

Condition based monitoring of gapless surge arrester using electrical and thermal parameters

Novizon[1], Z A Malek[2], Syafii[1], M H Ahmad[2], Aulia[1] and S A Ulfiah[1]

[1]Electrical Engineering Department, Engineering Faculty, Universitas Andalas, Padang, Indonesia
[2]High Voltage and High Current Institute, Electrical Engineering Faculty, Universiti Teknologi Malaysia, Malaysia

E-mail: novizon@eng.unand.ac.id

Abstract. A new method to assess the condition of metal-oxide surge arresters is presented. The thermal image and third harmonic leakage current are used as an indicator. The correlation between the leakage current and temperature of the arrester is processed using a neural network. The temperature profile of arrester, ambient temperature and humidity were as input to the neural network and the peak value of the third harmonic resistive current as a target. Results are presented with the training of neural network close to the target and testing result is 98% successfully.

1. Introduction

With the rapid growth of modern technology, maintenance plays a more and more important role in many industries. In some industries such as electric energy industry, reliability and maintenance are one of the most critical issues since a tiny failure may result in inestimable loss even fatal disaster. In recent decades, researchers pay more attention to research in maintenance and reliability. Maintenance is defined as all activities aimed at keeping an item in or restoring it to the physical state considered necessary for the fulfillment of its production function [1].

Traditional maintenance technique is breakdown maintenance, also called corrective maintenance, reactive maintenance and unplanned maintenance. It is limited to repair actions or item replacement caused by failures. The predominant characteristic of early maintenance is reactive since it only reacts to faults or failures. A more recent maintenance technique is time-based preventive maintenance (also called planned maintenance). It is proactive maintenance, which sets schedules to inspect or perform preventive maintenance instead of just reacting to failures.

One time-based preventive maintenance method is a constant-interval based preventive replacement method, in which failure replacements immediately are performed after failures occur, and preventive replacements are performed at constant intervals. Another time-based preventive maintenance method is the age-based replacement method, in which preventive replacements are performed when the component reaches a pre-specified age, and the optimization problem is to find the optimal preventive replacement age. The time-based maintenance technique is an improvement compared to early maintenance techniques, but at the same time makes the cost of preventive maintenance higher and higher.

Eventually, preventive maintenance cost has become a heavy financial burden of many utilities. Therefore, more effective maintenance approaches such as condition-based maintenance (CBM) are being adopted to solve the problem of high preventive maintenance cost, and to prevent unexpected failures at the same time.

The CBM is a maintenance process which decides maintenance actions using the information collected through condition monitoring. It is based on the understanding that a piece of equipment goes through multiple degraded states before failure. The health conditions can be monitored and predicted, and optimal maintenance actions can be scheduled for preventing equipment breakdown and minimizing total operation and maintenance costs [2]. CBM attempts to avoid unnecessary maintenance tasks by taking maintenance actions only when there is evidence that the failure is approaching. CBM has been widely used in many fields, such as aerospace industry, mining industry, petroleum industry, and power generation industry. CBM may use condition monitoring data collected from the substation, electrical analysis, mechanical analysis, environmental conditions, and so on, to make maintenance decision. The electrical analysis is the leakage current, partial discharge, waveform analysis of substation equipment such as transformers, circuit breakers, surge arrester, and others.

There are three key steps in the CBM process: data acquisition, data processing, and maintenance decision-making step, as shown in Figure 1. Data acquisition step is to collect the data related to system health. Data processing step is to process and analyze the acquired data. In maintenance decision-making step, effective maintenance policies will be obtained based on the analyzed information [1].
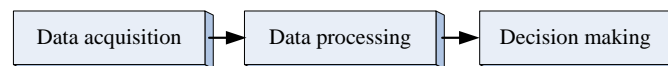
Figure 1. Condition monitoring process

A CBM program consists of two main categories of maintenance techniques: diagnostics and prognostics. Diagnostics focus on faults detection, isolation and identification when they occur, while prognostics attempts to predict faults or failures before they occur. Diagnostics is posterior event analysis and prognostics are prior event analysis. Prognostics are more effective than diagnostics since prognostics endeavors to prevent faults or failures, or at least has prepared spare parts and planned human resources ready for the problems, and thus avoid additional unplanned maintenance cost. Nevertheless, diagnostics cannot be neglected for the reason that prognostics are impossible to be 100% sure to predict faults and failures. Besides, diagnostic can help improve prognostics in the way that diagnostic information can be useful for preparing more accurate event data and hence building better CBM model for prognostics. Also, diagnostic information can be used as valuable feedback information for system redesign. A CBM program can be used to do both diagnostics and prognostics, or either one of them and the above three CBM steps should be followed.

Electricity utilities are an industry which produces electric power and distributes to costumers. To distribute electric power, the system should be reliable and save. To make power system safely, the electric utilities required high voltage power system protection which protects the system from lightning overvoltage or switching overvoltage.

Usually, metal oxide (ZnO) gapless type of lightning arrester is used for protection of power system equipment from overvoltage. The primary function of a zinc oxide surge arrester is to protect the power equipment from overvoltages and to absorb electrical energy resulting from lightning or switching surges and temporary overvoltages.

Another assessment technique to monitor ZnO arrester degradation based on the thermal temperature arises on the arrester body. The thermal behavior of ZnO arrester is an important application consideration. Thermal capability of design takes advantage of overvoltage protection capability. The thermal capability of ZnO arrester depends on the assembly structure of the arrester. If the heat generated from the ZnO elements due to continuous operating voltages and surges are more

than the thermal power dissipation of the housing, the elements will severe in an aged condition and fail of performing their protective function.

The thermal change curve of the ZnO arrester can be shown in Fig.2. In the region below the temperature limit, t_1, the level of heat generation of the ZnO arrester block is lower than the level of heat dissipation. The temperature decreases gradually, then finally reaching a stable condition is shown in curve B. On the contrary, when the temperature of the ZnO arrester block reaches a level of higher than the temperature limit t_2, the level of heat generation becomes higher than the level of heat dissipation and degradation occurs as shown by curve A at the end, ultimately resulting in thermal runaway [3].
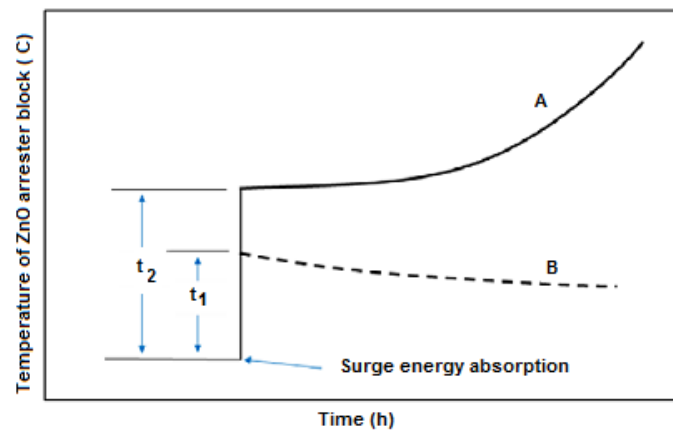
Figure 2. Thermal runaway phenomenon on ZnO surge arrester

The monitoring of surge arrester using thermal image technique and analyzed hot spot have conducted by several researchers [4-8]. The methodology to extract information to enable the detection and diagnosis of faults in surge arresters uses a digital image processing algorithm. The most study just using the hotspot temperature of arrester and based of this hotspot the condition of the arrester is known.

The purpose CBM of ZnO surge arrester using the correlation between the third harmonic resistive leakage current and the thermal image is proposed. The main idea of CBM of ZnO surge arrester is to predict and prevent a ZnO surge arrester from failure or damage to minimize maintenance cost.

2. Previous Study Assessing Condition of ZnO Surge Arrester

Many studies to asses condition of arrester have been conducted in the past. Some of them based on the resistive leakage current assessment. Another assessment using temperature due to internal and external factors.

2.1. The Third Harmonic Leakage Current of ZnO Surge Arrester Detection Method

The measurement of leakage current flowing through ZnO arrester under normal situations gives information about the real operating condition of the arrester. In the last five years, some methods for asses the condition of surge arrester have been developed. The condition surge arrester based on the third harmonic leakage current was developed by many researchers [9-14]. The method for determination of the condition of ZnO surge arrester is based on harmonic analysis of leakage current [10].

According to [10], the resistive leakage current of 75 mm diameter ZnO varistor for 20^0C and 50^0C which continuous operating voltage 0.8 pu is 150µA and 370µA respectively. That means about 40% increase of resistive leakage current for about 30^0C temperature difference. Also [11] investigated the condition of ZnO surge arrester using the third harmonic of the leakage current. Device to separate resistive leakage current from total leakage current was developed by [9]. Another device was

developed by [12], the device was based on harmonics analysis of the resistive leakage current of the surge arrester.

2.2. Thermal Image Condition Monitoring Assessment

There is no doubt that the great advances in infrared (IR) technology have been used by many researchers need. A thermography inspection is a technique widely used for high voltage electrical equipment monitoring. It plays a more important role in electrical equipment fault diagnosis. The thermal infrared camera can detect loose connections, unbalance load, an overload condition, deteriorating insulation, component deterioration and many other potential problems [15-17]. Its main advantage is the possibility of an inspection far from the equipment, as there is no need for direct contact. It is also a non-invasive technique being used with equipment operating under high voltage levels or conducting a high current [8, 18].

Diagnosing electrical equipment with internal faults by way of infrared thermography discussed by [19]. Some parameters such as relative humidity reflected temperature, atmospheric temperature, distance from an object and emissivity could also investigate [20]. Research on heating winding salient pole synchronous generator conducted by [21]. The research conducted by Bortoni shows how the usage of infrared (IR) thermal imaging techniques can reduce costs and the necessary time for the calorimetric method application. Also, contribution to the heat transfer coefficient determination and a new approach to consider conduction losses in the generator shaft.

Thermography inspections are also being used for ZnO arresters. Study with 96 kV ZnO arresters presenting the most common failures detected in substations and their effects on the thermal image was done by [22]. Netto et al. proposed monitoring technique of ZnO arrester using measurement of leakage current and the thermal analysis [23]. To classify surge arresters operative condition in faulty, normal, light, and suspicious applying the methodology uses a digital image processing algorithm based on the historical thermography data.

The temperature behavior of high voltage disconnector contact was investigated by [24]. The researchers evaluate the contact condition during the normal operation by the use of a thermography camera for the realization of a condition based maintenance strategy — the condition of high-voltage electrical contacts in electric distribution and transmission systems to provide maintenance decision support for high-voltage apparatus.

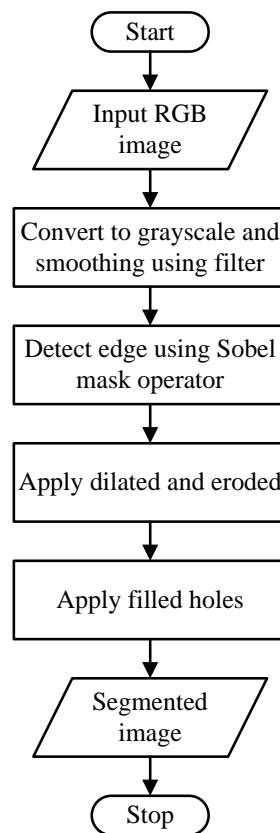## 3. Thermal image processing

The thermal image of ZnO surge arrester was captured in using the thermal camera as shown in figure 3. An NEC AVIO H2460 thermography camera with fusion technology was used to capture the images. The thermal imager consisted of a 160 - 120 focal plane array, uncooled micro-bolometer detector and operated in the infrared spectral band of 7.5 - 14 µm. The thermal lens captured images in the dimension of 640 - 480 pixels.
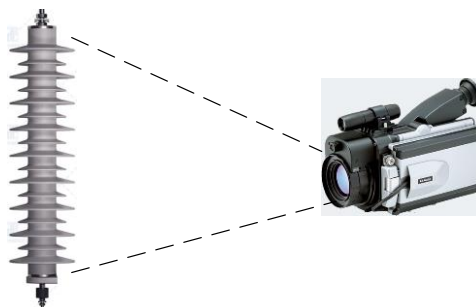
**Figure 3.** The thermal image capturing arrangement

For capturing the image, the thermal imager orientation was facing directly toward the arrester target to make an exact measurement. The length between the arrester and the camera is an important matter in measurement. The space between the arrester and the thermography camera was set between 1 to 1.5 m. The emissivity value was set at 0.95 as generally recommended for electrical equipment thermography.

The captured of the thermal image of ZnO arrester was processed thermal image analysis to obtain a temperature profile of hole arrester body and element. The flowchart of thermal image processing of ZnO arrester shown in figure 4. The thermal image was converted to grayscale and then segmented using edge detection with Sobel mask operator. Some parameter such as maximum and minimum temperature directly obtained from the thermal image.

Figure 4. Flowchart thermal image processing to get temperature information

Figure 5 shows the example of a thermal image 132 kV polymeric ZnO arrester captured using the thermal camera with distance is 1.0 meter. The ambient temperature during the measurement was observed to vary from 27 to 31 °C. The emissivity value is 0.75 for polymeric encapsulated ZnO surge arresters.
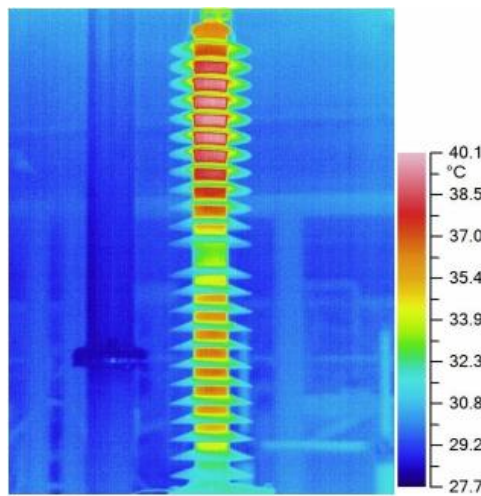
Figure 5. Example of the thermal image of ZnO captured by a thermal camera

4. Artificial neural network architecture

Artificial neural network (ANN) can work easily with non-linearly separable data, it is ideal for application in fault condition monitoring system as a tool, where the training data are sparse, and the neural network will have to generalize well. Some applications have demonstrated that a neural network can successfully classify and recognize multiple faults in a transformer [25]. In this research, multilayer back propagation (MLBP) ANNs have been used for correlation purposes. The MLBP ANNs used in this case consists of one input layer, a hidden layer and one output layer as shown in the figure.6, the hidden layer having a sigmoid activation function (1), while the output layer used a linear activation function (2).

$$\varphi_i = f\left(u_i\right) = \frac{1}{1+\mathrm{e}^{-u_i}} \tag{1}$$

As with the single layer, perceptron can calculate the net input from the weighted sum.

$$u_i = \sum_j W_{ij} a_j + \theta_i \tag{2}$$

Training of ANN networks is carried out using standard back-propagation (BP) algorithm with adaptive learning rate and momentum. The network is trained using a training and validation data set such as humidity, ambient temperature, maximum and minimum temperature of arrester and temperature whole body of arrester as an input and the third harmonic of resistive leakage current as a target as shown in figure 7. While the testing is carried out using a further data set feature set which is only input data set shown in figure 8. The data is propagated to the hidden layer and then to the output layer. This system has one output layer that is third harmonic of resistive leakage current. This is called the forward pass of the supervised learning backpropagation algorithm. In the forward pass, each node in the hidden layer gets input from all the nodes from the input layer, which are multiplied with appropriate weights and then summed. The output of the hidden node is the non-linear transformation of this resulting sum. Similarly, each node in the output layer gets input from all the nodes from the hidden layer, which are multiplied with appropriate weights and then summed. The output of this node is the non-linear transformation of the resulting sum.

The output values of the output layer are compared with the target output values. The target output values are those that attempt to teach the network. The error between actual output values and target output values is calculated and propagated back toward the hidden layer. This is called the backward pass of the backpropagation algorithm. The error is used to update the connection strengths between

nodes, weight matrices between input-hidden layers and hidden-output layers are updated. During the testing phase, no learning takes place, meaning all weight matrices are not changed. Each test vector is fed into the input layer. The feed forward of the testing data is similar to the feedforward of the training data.

The input data of the neural network is designed for more than five hundred data set. The computer ability for running huge data became a problem. Figure 6 shows Multi-Layer Back Propagation (MLBP) neural network configuration.
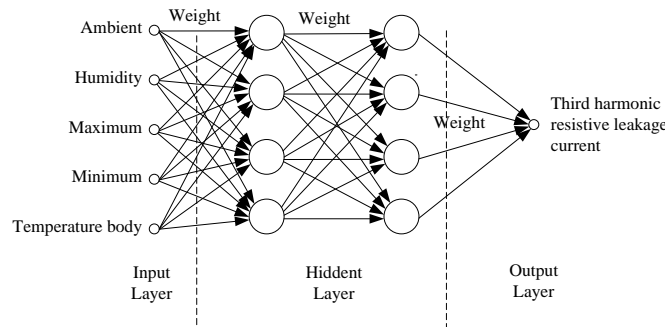
Figure 6. MLBP neural network configuration
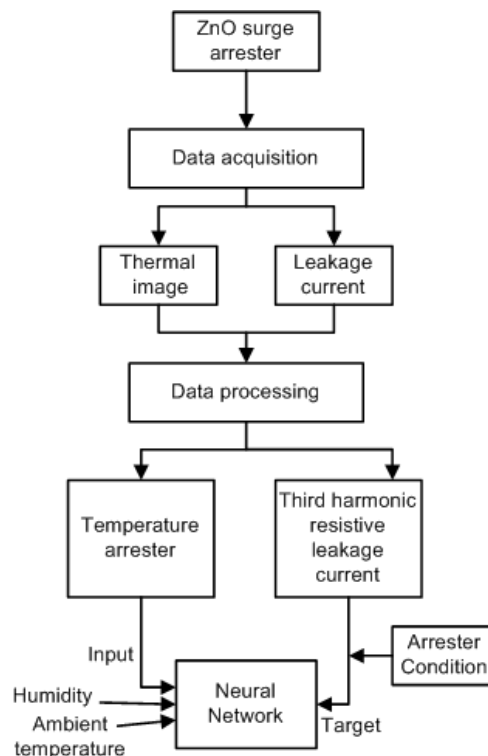
Figure 7. Training MLBP flowchart

In this study, all applications such as image processing, third harmonic resistive leakage current, and neural network application were built under LabVIEW software. The flowchart of training and testing of the arrester condition monitoring system are shown in figure 7 and eight respectively.

The input data of temperature whole arrester body is obtained from a histogram of a thermal image segmented processed. Also input data with some environment data such as humidity and ambient temperature. The third harmonic of resistive leakage current is the target of the neural network system.
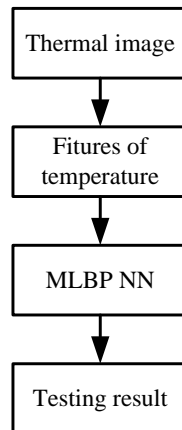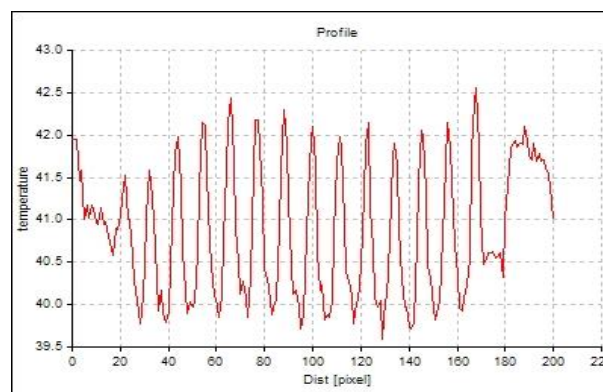
Figure 8. Testing MLBP flowchart

5. Results

The data that obtained from this study is consist of electrical data and temperature data. The electrical data inform the leakage current which is measured directly using a current sensor using a 1kΩ resistor. And temperature data obtained using the thermal camera. Example of the temperature profile of the arrester body is shown in figure 9. The features from the thermal image as shown in figure 10 were used as an input of MLBP NN. The leakage current of ZnO arrester was separated become capacitive and resistive current. The resistive current of ZnO arrester was used as a target in MLBP NN.

**Figure 9.** Example of the temperature profile of the thermal image

Figure 10. Example of features of the thermal image was used as an input

The training of MLBP NN was done to train the neural network system to recognize the input and output relationship. The input, hidden and output layer was defined in a neural network configuration

front panel as shown in figure 11. The select the transfer function which employs in hidden layers. The transfer function in this project was provided for three types such as sigmoid, tangent hyperbolic and linear. The LabVIEW front panel is used to select the transfer function as figure 12.
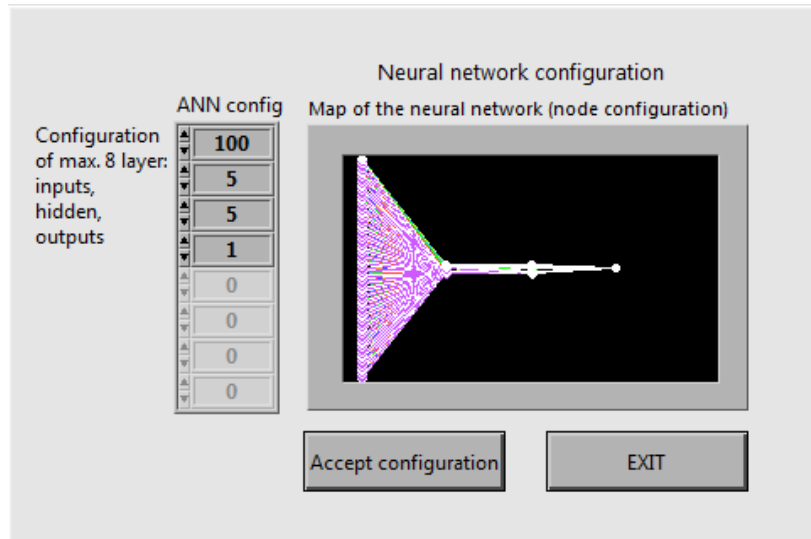
**Figure 11.** Neural network configuration front panel
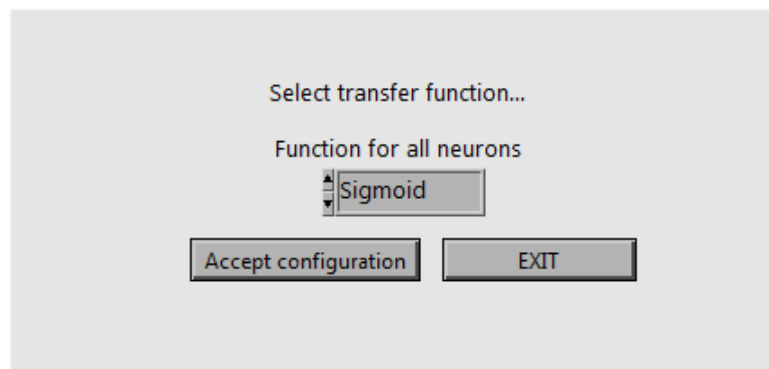
Figure 12. Select transfer function front panel

5.1. Training and testing MLBP Neural Network System

The training and testing result using the MLBP neural network is presented in figure 13. The results of training inform the number of the epoch, learning rate, and error training. This result error training is about 1% can be classified into good training result. The train correlation is about 0.999 that means the good correlation between input and target. The testing results are shown in figure 14. It showed the testing result was close enough to the target with an error of about 1.5%.
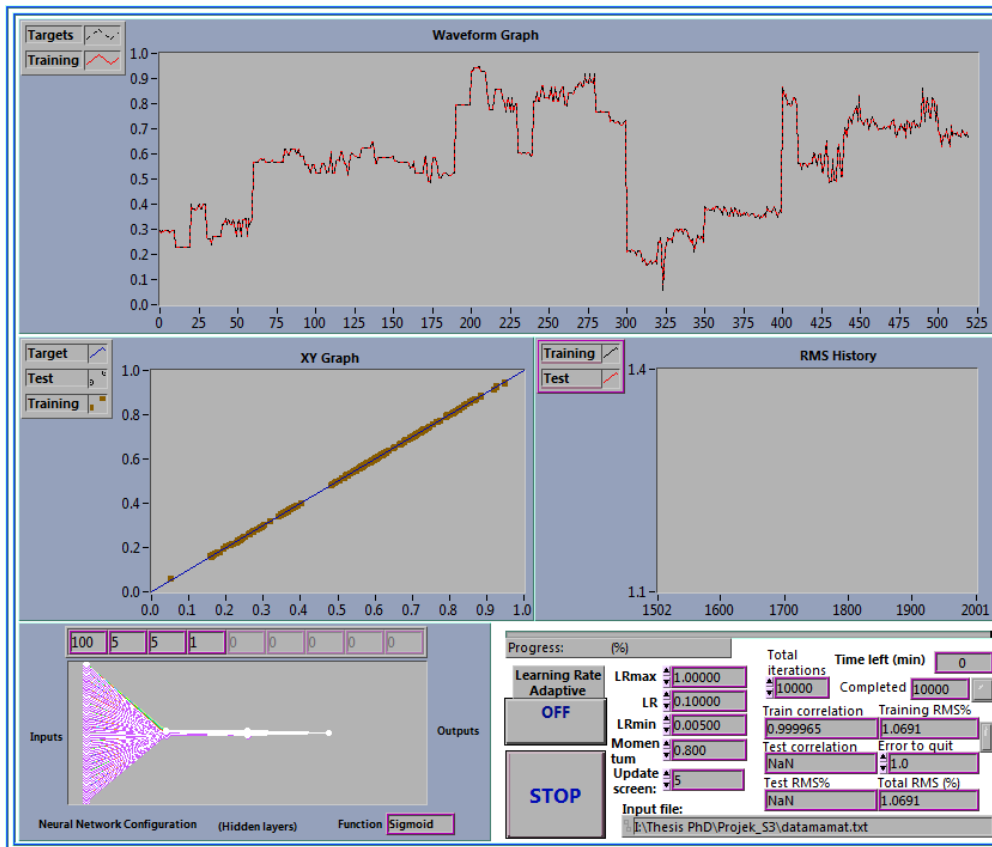
Figure 13. The front panel of data training neural network for monitoring system
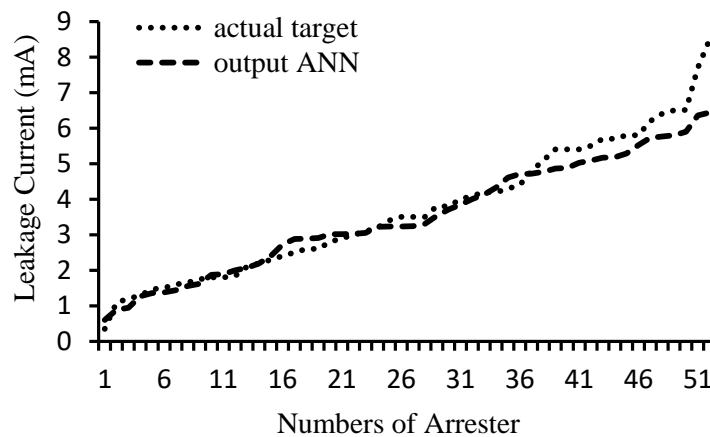
Figure 14. The result of testing compared to the actual data target

6. Conclusion

The work had successfully shown that the arrester's surface temperature could be correctly correlated with the well-known aging indicator, namely the leakage current. With the help of the artificial neural network, this correlation has been proven. This finding is significant since an alternative technique of the ZnO arrester condition monitoring which is contactless and convenient is now available. The requirement to measure the leakage current arrester for arrester condition monitoring is no longer needed.

Acknowledgments

References

[1]   A K S Jardine, D Lin, and D Banjevic 2006 A review on machinery diagnostics and prognostics implementing condition-based maintenance. *Mechanical Systems and Signal Processing,* vol. **20**, pp. 1483-1510.

[2]   Z Tian, D Lin and B Wu 2009 Condition based maintenance optimization considering multiple objectives. *Journal of Intelligent Manufacturing,* pp. 1-8.

[3]   S-B Lee, S-J. Lee and B-H Lee 2010 Analysis of thermal and electrical properties of ZnO arrester block.*Current Applied Physics,* vol. **10**, pp. 176-180.

[4]   E T W Neto, E G da Costa, M J A Maia, T C L Galindo and A H S Costa 2004 Electro-thermal simulation of ZnO arresters for diagnosis using thermal analysis. in *Transmission and Distribution Conference and Exposition: Latin America, 2004 IEEE/PES*, 2004, pp. 338-343.

[5]   X Chen, X Tian and L Fan 2008 Research of Infrared Diagnosed with Faults of Arrester. in *High Voltage Engineering and Application, 2008. ICHVE 2008 International Conference on*, 2008, pp. 637-640.

[6]   C A Laurentys Almeida, A P Braga, S Nascimento, V Paiva, H J A Martins, R Torres, *et al.* 2009 Intelligent Thermographic Diagnostic Applied to Surge Arresters: A New Approach. *Power Delivery, IEEE Transactions on,* vol. **24**, pp. 751-757.

[7]   C A L Almeida, W M Caminhas, A P Braga, V Paiva, H Martins and R Torres 2005 Intelligent detection and diagnosis of lightning arrester faults using digital thermovision image processing techniques. Orlando, FL, USA, 2005, pp. 109-120.

[8]   C Ying-Chieh and L Yao 2009 Automatic Diagnostic System of Electrical Equipment Using Infrared Thermography. in *Soft Computing and Pattern Recognition, 2009. SOCPAR '09. International Conference of*, 2009, pp. 155-160.

[9]   Z Abdul-Malek, Novizon and Aulia 2008 Portable device to extract resistive component of the metal oxide surge arrester leakage current. in *Power Engineering Conference, 2008. AUPEC '08. Australasian Universities*, 2008, pp. 1-5.

[10]   J Lundquist, Stenstrom, A Schei and B Hansen 1990 New method for measurement of the resistive leakage currents of metal-oxide surge arresters in service. *Power Delivery, IEEE Transactions on,* vol. **5**, pp. 1811-1822.

[11]   B-H. Lee and S-M. Kang 2005 A new on-line leakage current monitoring system of ZnO surge arresters. *Materials Science and Engineering B,* vol. **119**, pp. 13-18.

[12]   L Huijia and H Hanmei 2010 Development of Tester of the Resistive Leakage Current of MOA. in *Power and Energy Engineering Conference (APPEEC), 2010 Asia-Pacific*, 2010, pp. 1-4.

[13]   A Gakiya Kanashiro, M Zanotti, P Futoshi Obase and WR Bacega 2011 Diagnostic of silicon carbide surge arresters using leakage current measurements. *Latin America Transactions, IEEE (Revista IEEE America Latina),* vol. **9**, pp. 761-766.

[14]   Z A M Novizon N, Nouruddeen Bashir, N Asilah 2013 Thermal Image and Leakage Current Diagnostic as a Tool for Testing and Condition Monitoring of ZnO Surge Arrester. *Jurnal Teknologi UTM,* vol. Vol.**64**.

[15]   Z Azmat and D J Turner 2005 Infrared thermography and its role in a rural utility environment. in *Rural Electric Power Conference, 2005*, 2005, pp. B2/1-B2/4.

[16]   L Baoshu, Z Xiaohui, Z Shutao and N Wendong 2006 HV Power Equipment Diagnosis Based on Infrared Imaging Analyzing. in *Power System Technology, 2006. PowerCon 2006. International Conference on*, 2006, pp. 1-4.

[17] L Huangqiang, S Yunlian and L Hong 2009 Research on HV-Power Equipment Diagnosis by Infrared Image Edge Detection. in *Power and Energy Engineering Conference, 2009. APPEEC 2009. Asia-Pacific*, 2009, pp. 1-4.

[18] Z Korendo and M Florkowski 2001 Thermography based diagnostics of power equipment. *Power Engineering Journal,* vol. **15**, pp. 33-42.

[19] H Niancang 1998 The infrared thermography diagnostic technique of high-voltage electrical equipment with internal faults. in *Power System Technology, 1998. Proceedings. POWERCON '98. 1998 International Conference on*, 1998, pp. 110-115 vol.**1**.

[20] Baran, x, M ski and A Polak 2010 Thermographic diagnostic of electrical machines. in *Electrical Machines (ICEM), 2010 XIX International Conference on*, 2010, pp. 1-3.

[21] S Stipetic, M Kovacic, Z Hanic and M Vrazic 2011 Measurement of Excitation Winding Temperature on Synchronous Generator in Rotation Using Infrared Thermography. *Industrial Electronics, IEEE Transactions on,* vol. PP, pp. 1-1.

[22] E T W Neto, E G da Costa, T V Ferreira, and M J A Maia 2006 Failure Analysis in ZnO Arresters Using Thermal Images. in *Transmission & Distribution Conference and Exposition: Latin America, 2006. TDC '06. IEEE/PES*, 2006, pp. 1-5.

[23] ET Wanderley Neto, E Guedes da Costa, R Trajano de Souza, EC Tavares de Macedo and MJ de Albuquerque Maia 2006 Monitoring and Diagnosis of ZnO Arresters. *Latin America Transactions, IEEE (Revista IEEE America Latina),* vol. **4**, pp. 170-176, 2006.

[24] M Muhr, S Pack, S Jaufer and H Lugschitz 2006 Thermography of aged contacts of high voltage equipment. *e & i Elektrotechnik und Informationstechnik,* vol. **123**, pp. 537-543.

[25] H Malik, Tarkeshwar and R K Jarial 2011 An Expert System for Incipient Fault Diagnosis and Condition Assessment in Transformers. in *Computational Intelligence and Communication Networks (CICN), 2011 International Conference on*, 2011, pp. 138-142.

[26] M V Lat 1983 Thermal Properties of Metal Oxide Surge Arresters. *Power Engineering Review, IEEE,* vol. PER-**3**, pp. 43-43.