Intelligent Remote System for Automatic Thermographic Inspection

D. J. B. S. Sampaio, V. G. S. Sousa, A. F. Costa, R. Glatt, D. Rubbo, P. M. Sobrinho

***Abstract*--Thermographic inspection allows detection of early-stage failure processes generated by thermal anomalies. In this work, through a sequence of thermographic images of the surrounding region of a step-up transformer located in the outer area of a small hydroelectric power plant, we want to automatically identify faults. It was developed a monitoring system that was installed on a server computer connected to the company data network. This computer receives images from an IP camera with night vision and a thermographic camera installed on a microcontrolled support that enables vertical and horizontal rotation movement (pan and tilt) of the cameras. The system developed analyzes then regions of the target electrical system set and configured a priori and produces a diagnosis. The system allows also to a thermographer performs custom inspections within the field of view of the cameras remotely since the system can be accessed remotely and be operated in manual mode.**

***Index Terms*--Infrared imaging, Maintenance, Remote system.**

I. Introduction

Infrared thermal cameras were originally developed for military use during the war of Korea to enhance night vision. Quickly these cameras have found applications in public safety and then migrated to commercial use with various applications. Through this technology, it is possible to detect early-stage failure processes generated by thermal anomalies in a given component in electrical equipment, mechanical equipment and structures, before discontinuing their operation. Due to its digital processing, the actual thermographic camera allows easy storage, transmission and post processing of high quality infrared images.

Thermographic inspection in electrical systems identifies problems caused by thermal anomalies due to the joule effect. Hot spots in electrical circuits are usually caused by the increased ohmic resistance due to contact deficiency of components, contact corrosion or oxidation, inadequate load distribution or component failure. Although it seems a simple procedure, thermographic inspection, both in the acquisition of images as in the analysis of the same, depends on the knowledge and evaluation of various influences inherent in the process or inserted on it. These influences may be related to the qualification of the thermographer, the characteristics of the thermographic camera, target inspection characteristics and environmental conditions in which the inspection is carried out. If the first two cited influences are controlled, the main obstacles in a thermographic inspection in an electrical system will then be the emissivity of the inspected, variable charge current and environmental conditions (wind, humidity, temperature, solar radiation, etc.).

For the automatic identification of failures it was developed a monitoring system that was installed on a server computer connected to the company data network. This computer receives images from an IP camera with night vision and a thermographic camera installed on a microcontrolled support that enables vertical and horizontal rotation movement (pan and tilt) of the cameras. This system also has access to some real-time data such as active power, current and voltage through the OPC network of the company. A sensor for measuring temperature and humidity is also installed in the cameras support and it is possible to obtain the measurements through a data network. These data are important to calibrate the thermographic camera in order to have accurate temperature values. The system developed analyzes then regions of the target electrical system set and configured a priori and produces a diagnosis.

II. Literature Review

An important aspect is to understand the thermographic inspection process, its characteristics and limitations and also what is used in the process of analysis of thermographic images. The work of Epperly et al. shows that a thermographic inspection program using suitable equipment and adequately trained personnel can be extremely effective to prevent potential failures in electrical systems [1]. It presents a brief description of the infrared thermography and its advantages and limitations. Describes case studies, criteria for selection of a suitable thermal imager and presents various criteria and recommendations to determine the urgency of the repair after discovery of a defect by thermographic inspection. Already Madding and Lyon Jr. make a review of the factors that influence the evaluation of the result obtained using infrared thermography, from charge current until climatic elements [6]. The same Lyon Jr., a few years later, discusses the relationship between the current and the temperature of a faulty connection, as well as the thermal response as a function of load current

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[4]. They claim that procedures based only on the measurement of absolute temperature or temperature increase take the risk of incorrect diagnoses. The work of Madding, in 2002, points out how the emissivity affect temperature measurement and discusses techniques for its estimation [5]. Madding proposes to manufacturers that their equipment should be covered by high emissivity materials and bring information regarding thermal signatures and thermal models under all kinds of environmental conditions.

The work of Ishino states that thermal imaging is commonly used to inspect electrical distribution equipment. The proposed method uses a camera attached to an aerial cable to shoot pin insulators on top of a pole of distribution. At first, one should extract the insulators of the image taken by the camera. As the temperature of the pole and your arm is uniform, it is possible to value it and then subtract it from the original image leaving in theory only objects with a temperature higher than that, which are actually the objects under study [3].

Salem, Ibitayo and Geil present a methodology for calibration of infrared camera based systems for characterization of electronic and high power components [11]. Omar at al. shows that self-reference is an infrared technique, which eliminates the need for prior knowledge of an area for the automatic identification of defects in thermograms. This technique consists in dividing the thermographic image in small neighborhoods [10]. The work of Ng revises the Otsu method for selecting optimal thresholds for both unimodal and bimodal distributions [8]. Already the work of Neto, Costa and Maia shows the results obtained from tests designed to assess the accuracy of temperature measurements of materials under different conditions, through a thermographic camera. In addition, meant to define the most appropriate emissivity values for materials normally found in a substation equipment. In general, for most of the tested materials, the best values of emissivity found were within the range of 0.85 to 0.95 [7].

The work of Oliveira proposed the use of thermography for predictive maintenance of electric transmission lines [9]. An important topic discussed is the image processing, where were used several known algorithms (ITADA to segmentation of image and OTSU to threshold selection) to find the hotspots of the image. It was made a qualitative and quantitative classification of hotspots using FUZZY logic. The work of Usamentiaga et al. shows that the temperature measurement based on infrared radiation depends on correct emissivity setting. However, the emissivity setting is not an easy goal because emissivity is not usually known with precision, is influenced by the effects of radiation, and can also change with temperature [12].

In this work, through a sequence of thermographic images of a target electrical system, we want to identify faults in this electrical installation automatically, by applying image processing and artificial neural network techniques. In order to validate this work, the target electrical system will be the region of a step-up transformer located in the outer area of a small hydroelectric power plant whose inspected elements will be switch-disconnectors, lightning rods, insulators, step-up transformer output connections and various connectors that join cables between the output of the transformer and the power transmission line.

III. The Developed Monitoring System

The monitoring system was developed for automatic identification of failures of a target electrical system through a sequence of thermographic images. The parts of this monitoring system are showed in the Fig.1.

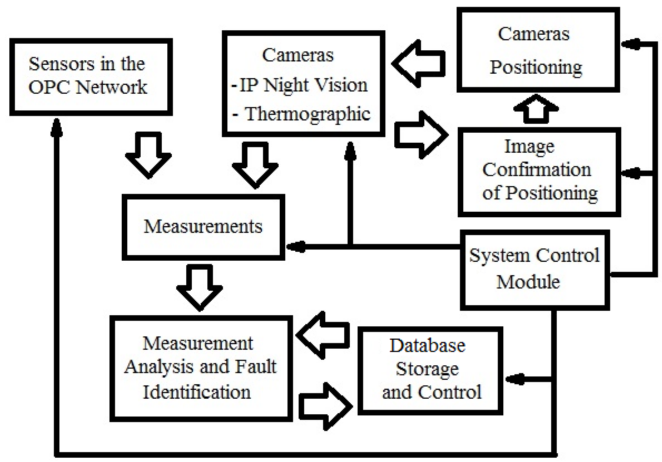

Fig. 1. General Overview of the Intelligent Monitoring System.

A. *Sensors in the OPC Network*

The hydroelectric power plant have several installed sensors used to measure voltage, current, active power, reactive power and power factor of the generated power. These sensors are connected in a OPC Network and through it is possible to obtain the instantaneous value of each of these variables. These measurements are important to calibrate the data obtained by the analysis of the images acquired using the Infrared Thermal Camera.

B. *Cameras and Cameras Positioning*

This part of the system consists of a camera support unit which is able to tilt and spin almost 180° in each direction. The movement of the camera is realized through two stepper motors which are controlled by an Arduino Microcontroller which is an open-source electronics prototyping platform and a widely used low-cost microcontroller board for home automations. There are two cameras, one of which is a regular IP network night vision webcam and the other one is a FLIR Infrared Thermal Camera [2]. Additionally the temperature and the humidity at the camera are monitored.

The control of the cameras is integrated into a Labview user interface, or front panel, with controls for the motors and indicators for the temperature and humidity. The software communicates with the Arduino using an Ethernet connection. In order to inspect all the wished elements in the target electrical system is necessary to move the cameras to six different positions. The coordinates of those positions are stored in the system Database and internally converted into steps of the stepping motors. The stepping motors are used due to them high precision for positioning. The images with the target elements of those six positions are shown in the Fig. 2 and Fig. 3, respectively, for the IP network night vision webcam and the Infrared Thermal Camera.

Fig. 2. Images from the six positions of interest obtained with the IP network night vision camera.

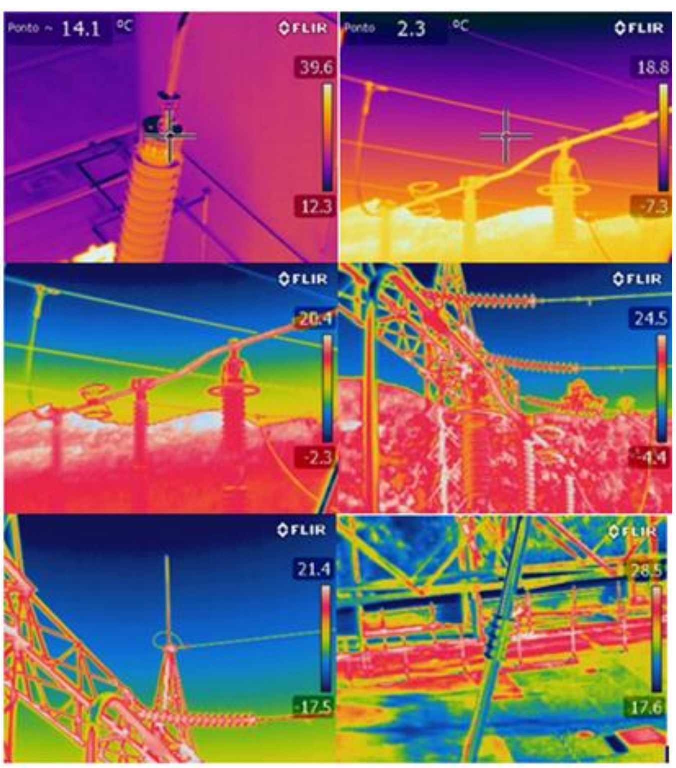

Fig. 3. Images from the six positions of interest obtained with the Infrared Thermal Camera.

C. Image Confirmation of Positioning

Comparing a stored pre-processed image with an image acquired just after positioning of the camera is possible to check if the positioning was successfully done. This is necessary because is not possible to detect mechanical failures of the stepping motors. The contours of objects in the image are obtained using a standard Sobel high pass filter. If some selected parts of the stored pre-processed image match with the same parts in the just acquired image means that the positioning was successfully done. Otherwise the cameras are sent to a starting position where a microswitch is installed and used to calibrate the zero position of the cameras. After calibration, the cameras are sent again to the wished point and the positioning is again tested by image matching. After three tries, if the positioning does not work, the system stops and send an error message to the maintenance team.

D. Measurements

After confirmed the positioning of the cameras, the image acquired from both cameras and the instantaneous data acquired from the sensors connected in the OPC network are sent to analysis and fault identification.

E. Measurement Analysis and Fault Identification

Each position of interest has a processed image stored a priori in the system database. For each position, the region of each relevant element is marked. An image containing all the pixels belonging to each element of interest is created and stored. An example of such image is shown in the Fig. 4.

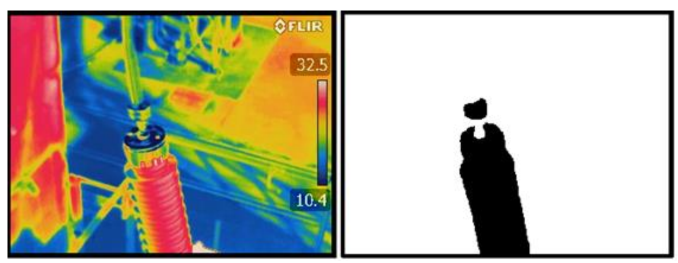

Fig. 4. Image created with the regions of each element of intereset.

In Fig. 4, it is possible to identify two regions. One region belongs to the insulator head and the other to a connector. All the temperature values are read in the new acquired image for each region. Using the data of temperature and humidity at the camera, the temperature values are corrected and stored. The average temperature, the maximum temperature, the minimum temperature and the median temperature for each region are stored together with the values of current, active power, reactive power and power factor. A priori, an artificial neural network (ANN) was trained for each region using the following configuration: 5 neurons for the input layer, 5 neurons in the hidden layer and 1 neuron in the output layer. The five variables submitted to the input layer are: temperature at the camera, humidity at the camera, current, active power and reactive power. The output layer is related to the estimated median temperature for that region according with the submitted conditions. The output value of the ANN is compared with the median temperature value obtained in the region of the actual image. If the difference is bigger than a tolerance (in this work it was used 15%), a warning message is generated. The maximum temperature is also compared with a maximum temperature allowed for the material of the analyzed region and if is bigger than the maximum acceptable, a fault is directly reported. All the values are stored in the system database and a chart with the temperature trend for each region is updated. If the region with warning message persists after three inspections in the sequence, a fault is also reported and a diagnosis is produced based in the difference between the expected value and the measured value. A diagnosis is also produced comparing regions from different images. For example, the switch-disconnectors are installed in the three different phases of the electrical system. Since the system is submitted to the same conditions and the equipment has the same specifications, the difference of temperature between those regions should be very small. If a difference of temperature between those regions is bigger than 10%, a fault diagnosis is also produced.

F. Database Storage and Control

For this project we use a MySQL database since it is an open source database. In the system database we find the data acquired from the OPC network, the images obtained with the cameras and the processed images (for the images only the information necessary to access then is stored). Therefore we have the data necessary for the diagnosis and also the data produced by the diagnosis. The data is stored chronologically.

In the database we find also a time schedule for the system, defining every moment in which the elements of interest of the system must be inspected. The control of activities is done using the software Labview.

IV. Conclusion and Future Work

The system developed analyzes the regions of the target electrical system set and configured a priori and produces a diagnosis. The system allows also to a thermographer performs custom inspections within the field of view of the cameras remotely since the system can be accessed remotely and be operated in manual mode. This makes the system be attractive for monitoring hard-to-reach electrical systems, installations in hazardous areas or operated remotely since the thermographer does not need to be present, being able to access the cameras remotely through an internet connection or connected on the company data network.

The system is still in the implementation and improvement phase but with the results obtained so far is possible to say that the goals of this work are been achieved. The next steps in this work are the development of a digital image correction for small deviations in the positioning and a fully automatic thermographic inspection report based on national and international standards.

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VI. References

[1] Epperly, R.A., Hebertein, G.E., Eads, L.G., *A tool for reliability and safety: predict and prevent equipment failures with thermography*, IEEE IAS 44th Annual Petroleum and Chemical Industry Conference, Sept. 1997, pág. 59 a 68.

[2] Flir Systems, *Technical Data FLIR A300*, Part number 48201-1001, pp. 1-30, [EN:ENGLISH], 2013.

[3] Ishino, R., *Detection of a Faulty Power Distribution Apparatus by Using Thermal Images*, Image (Rochester, N.Y.), vol. 0, no. c, pág. 1332-1337, 2002.

[4] Lyon Jr, Bernard R., Orlove, Gary L., Peters Donna L., The Relationship between Current Load and Temperature for Quasi-Steady State and Transient Conditions, Infrared Training Center, 2002.

[5] Madding, Robert, Emissivity Measurement and Temperature Correction Accuracy Considerations, Infrared Training Center, 2002.

[6] Madding, Robert; Lyon Jr., Bernard, *Environmental Influences on IR Thermography Surveys*, Maintenance Technology 1999.

[7] Neto, E. T. W., Costa, E. Da, e Maia, M., *Influence of emissivity and distance in high voltage equipments thermal imaging*, Transmission & Distribution Conference and Exposition: Latin America, 2006. TDC'06. IEEE/PES, 2006, vol. 0, pág. 1–4.

[8] Ng, H., *Automatic thresholding for defect detection*, Pattern Recognition Letters, vol. 27, no. 14, pág. 1644-1649, Outubro, 2006.

[9] Oliveira, J. H. E., Lages, W. F. - *Robotized Inspection of Power Lines with Infrared Vision*, 1st International Conference on Applied Robotics for the Power Industry, October, 5-7, Montréal, Canada, 2010.

[10] Omar, M., Hassan, M., Saito, K., e Alloo, R., *IR self-referencing thermography for detection of in-depth defects*, Infrared Physics & Technology, vol. 46, no. 4, pág. 283-289, Abril, 2005.

[11] Salem, T. E., Ibitayo, D., Geil, B. R., *Calibration of an Infrared Camera for Thermal Characterization of High Voltage Power Electronic Components*, 2005 IEEE Instrumentation and Measurement Technology Conference Proceedings, Vol. 2, Pág. 17-19, Maio, 2005.

[12] Usamentiaga, R., Garcia, D. F., Molleda, J., Bulnes, F. e Perez, J. M., *Comparing temperature measurement using infrared line scanners and the wedge method*, 2010 IEEE Instrumentation & Measurement Technology Conference Proceedings, pág. 1256-1261, 2010.

VII. Biographies

Daniel Julien Barros da Silva Sampaio was born in São José dos Campos, Brazil, on September 20, 1976. He undergraduated in Electrical Engineering from the Univ. Estadual Paulista – UNESP – Guaratinguetá Campus, did his Master in Sensor Systems Technology at the Hochschule Karlsruhe – Germany and graduated in Mechanical Engineering (Mechatronics) at the University of São Paulo - USP. His experience includes the company Siemens - Brazil, Fraunhofer Institute – Germany, IAF/HsKA - Germany, UNESP – Brazil. He is actually Full Time Professor in the Electrical Engineering Department at UNESP – Guaratinguetá Campus.

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Ruben Glatt was born in Karlsruhe, Germany, on August 8, 1979. He achieved a German Diplom in Mechatronics from the Karlsruhe Institute of Technology (KIT) in 2011. Before he started his academic training he was working as a datacenter technician. He is actually finishing another Master course in Mechanical Engineering at the Univ. Estadual Paulista (UNESP) with a focus on data analysis and Machine Learning.

Daniel Rubbo was born in São Paulo, Brazil, on January 6, 1987. He is actually a last year undergraduate student in Electrical Engineering at the Univ. Estadual Paulista – Unesp – Guaratinguetá Campus.

Pedro Magalhães Sobrinho is graduated in Mechanical Engineering from the Taubaté University (1986), Masters in Mechanical Engineering from Univ. Estadual Paulista – UNESP – Guaratinguetá Campus (1990), and Ph.D .in Mechanical Engineering from Univ. Estadual Paulista – UNESP – Guaratinguetá Campus (1999). He is currently associate professor in Thermal Engineering at Univ. Estadual Paulista – UNESP – Guaratinguetá Campus (2011). He has experience in Mechanical Engineering with an emphasis on Fluid Mechanics, acting on the following topics: energy conservation, energy efficiency, energy, cogeneration and cooling.