20th IMEKO TC4 International Symposium and
18th International Workshop on ADC Modelling and Testing
Research on Electric and Electronic Measurement for the Economic Upturn
Benevento, Italy, September 15-17, 2014

Automatic Industrial Electrical Circuit Firing Prevention using Infrared Termography

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***Abstract* – An important problem in industrial system, both working in low and medium power, is the possibility that some circuits have a current dispersion, with a subsequent increasing in local temperature. This situation, if not immediately corrected, can produce, in some cases, firing accidents, with a great amount of money loss and long period of out-of-order systems. Although procedures based on Infrared Thermography to analyze and find critical situations already exist, these are always based on long manual procedures and usually are used for analysis of complex industrial systems. In this paper, after a short review of the common manual thermograph investigation, an automatic system based on two infrared thermograph cameras and an image processing real time analysis is proposed. The device demonstrates the possibility to take under control some critical systems and preventing firing accident in automatic way. This solution can be easily integrated in a SCADA architecture for monitoring and alerting the supervisor about over-temperature or current dissipation cases.**

I. INTRODUCTION

Nowadays an increasing importance is given to prevent accidents on electrical and electronic systems. This is usually made by means of electrical inspection activities. These kinds of activities are usually very expensive in time and human resources, requesting a team of people which verify, through vary level of testing, the state of all the connections to find in advance some current dispersions or over-temperature circuits, which can lead to firing accidents or in any case malfunctioning.

New non invasive technologies are now widely used in many situation to verify "goodness" of things, such as food [1], or artworks [2,3]. It is now emerging also the usage of these kinds of systems and techniques for the electronic circuits' analysis [4].

One of the most used systems is based on Infrared Thermography (IRT) [5-8]. IRT is about the science of acquisition and analysis of thermal information from non-contact thermal imaging devices. This device is used to detect infrared energy (i.e. the heat) and converts it into an electronic signal, which is then processed to produce a thermal image on a video monitor and perform temperature calculations. Due to its advantages in terms of being non-contact, free from electromagnetic interference, safe, reliable and able to provide large inspection coverage, IRT has taken a very important role in predictive and preventive maintenance programs [9-11]. It can instantly visualize and verify thermal profiles, quickly locate the hot spots, determine the severity of the problem and help establishing the period in which the equipment should be repaired.

IRT can monitor the thermal behavior of electrical equipment by sensing the emission of infrared energy (i.e. temperature) of the equipment. Although heat is not a perfect indicator of all problems in electrical systems, but heat produced by abnormally high electrical resistance, often could anticipate electrical failures [12]. It is well understood that the life of electrical equipment is drastically reduced as temperatures increase. Condition monitoring using IRT images can reveal the presence of any thermal anomalies in electrical equipment produced by the defects on the surface of the equipment. The defects will normally alter the thermal signature of the surface due to the change in the amount of heat generated and the heat transfer properties of the equipment [13].

Manually analyzing electrical defects using IRT can be difficult and expensive, in time and human resources. For these reasons, some semi-automatic methods are proposed to simplify the defect identification [4].

In addition is important underlying another interesting possible application of IRT: black box for legal issues. An IRT system can be designed to continuously register sensible areas, and in case of an abnormal increasing in temperature, can safe in a secure way this data stream in a dedicated storage. This storage has to be locked and any data inside it has to be encoded using some kind of cryptographic system, such as AES, RSA, or other ones widely recognized as proof of data integrity. In case of sensible electronic issues, the IRT system can identify the involved component and the video streaming can allow to clearly understand when, what and, in some cases, why the incident is happened.

In this paper, based on the use of two thermograph

ISBN-14: 978-92-990073-2-7

cameras, an automatic defect identification and alerting system based on IRT is proposed. The first one is used, with a dedicated image processing system, to identify the area with a probable over-temperature situation; the second one is automatically zoomed on that area for acquiring the actual temperature and verifying if the value is over a set of thresholds and it is necessary to request an intervention.

This kind of systems can be easily used in a Supervisory Control and Data Acquisition (SCADA) architecture [14,15] which are usually used to monitor and control a plant or equipment in industries such as telecommunications, water and waste control, energy, oil and gas refining, and transportation (airport, traffic control, rails) for allowing a deep monitoring and control for industrial systems.

As described before, the proposed system can also be used as part of a black box security system, with the saving, in encoded form, of the video streaming, the date and time indication of the incident, if any. In addition, also the related temperature evolution in the analyzed area, using the first IRT and, in case of an accident, of the involved components, using the second IRT, can be stored, in secure form in the locked and secured external memory storage.

II. IRT FOR ELECTRICAL DEVICE DIAGNOSYS

Electrical devices are usually rated for power that indicates the amount of energy that the device can conduct without being damaged. If the device is operated at a power above its specifications, the excess power causes overheating on the device, which is in turn, reduces its life cycle and efficiency. This condition can potentially lead to fire ignition especially with outdated electrical wiring that is deteriorating, inappropriately amended, or insufficient to support the existing electrical loads. Over the time, the electrical installations and their contact surfaces will begin to deteriorate, resulting in an increased resistant.

This kind of problem can be recognized by inspecting the heat pattern via IRT camera where the highest temperature point indicates the location of the problem. Ideally, electrical systems are designed and sized to meet the load demands for a facility. However, over the time and due to building expansion, additional loads have caused the electrical system equipment reaching beyond its original design capacity. Improper and under sizing of electrical equipment and components can also cause an overload conditions. An overload condition usually shows a uniformed heat pattern that appears through the entire circuit. Total heat generated from the equipment depends on the load and the environment operating temperature of the equipment.

In three phases electrical system, a perfect system should have similar operating condition on each phase or at least not vary greatly load differences between phases. IRT camera can clearly shows the condition where the higher loads phase will be warmer than other phases.

Another very common cause of overheating is the physical reduction of conductive surface area in the mechanical connections that join conductor together and so an increase of resistance. Because of compromised connections, assuming constant the load conditions, the current flow becomes more concentrated in conductive areas as areas of resistance increase, resulting in localized hot spots.

Other problems that can contribute to thermal anomalies in electrical equipment are open circuits, inductive heating and defective equipment. Under the normal operating conditions, an open circuit conductor shows colder thermal pattern when compared to adjacent conductor under similar loads. This is due to lack of current flow through that conductor. Inductive heating is resulted from the proximal interaction of non-carrying electric devices with the magnetic field around conductors. The heat intensity is depending on the amount of current passing through the conductor and the affected electrical components can reach temperatures up to several hundred degrees.

Finally, IRT can also be used to detect the defective electrical equipment such as power transformer, uninterruptible power supply (UPS), current transformer, lightning arrester and many others.

III. PROPOSED SOLUTION

A. Thermographic Cameras System

The proposed solution is based on two Thermograph Cameras able to acquire IR radiation. The system has one camera fixed to acquire an electronic system such as a medium voltage chassis, or a complex industrial electronic cabin. This camera sends to a central processor the image, acquired every 1 second (the system could also works in real time, but for this kind of application is not mandatory). An Image Processing Software segments the image in a set of zones, e.g. 16. In this way, every sensible area in the electrical chassis is under control. In case the system reveals a zone with a temperature over a predetermined threshold, adaptive respect with the environmental temperature and conditions, a second camera will zoom on the indicated area. A remote controlled stepping motor moves this second camera, and the zoom is automatically defined. In this way, the second camera can precisely define the temperature in the interested zone. If this second temperature, more precise than the previous one, is over an alerting threshold, the system will alert the maintenance operator. If the temperature is higher than a second critical one, specific for each area, depending from the electrical devices present in that zone, the interested device, if possible, or the entire electrical cabin, if necessary, will be shutdown, for further investigations, avoiding any possibility of firing of the headers in that area.

A. Image Processing Analysis

The first Thermograph camera, also called coarse, sends an image every second to a remote processor. This image has the dimension of 320 x 240 pixels and is divided in 16 blocks of 20 x 15 pixels (16 is only for example, and it is not a constraint). The system verifies if any block has an extrapolated temperature (i.e. the relative temperature acquired from the whole thermal image, highly influenced by environmental conditions, which can change the actual punctual value) over a controlling threshold. If the extrapolated temperature is over this threshold, the system commands the second camera, also called fine, to zoom on the interested area. In this way, it is possible acquiring the actual temperature and a detailed image of the interested circuit. If the actual temperature is over an alerting threshold, the system sends an alert to the maintainer operator. If the actual temperature is over a critical value, the system is automatically shutdown.

Verifying the sequence of images the Image Processing software is also able to understand if there is an evolution in temperature and alerting the operator in case of rapid increase, even if the actual temperature is lower than the alerting or the critical temperature. For avoiding alerting or improper automatic shutdown during electronic system start-up phases, the software takes into account the rapid evolution only after a long period of "constant" temperature values.

In case of more than one "hot spot", the system will command the second thermograph camera on the hotter one, and then on the others, in order of estimated temperature.

Finally, if the number of "hot spots" is higher than a critical number, the system will automatically drive the shutdown of the entire electronic system, without any other fine temperature acquisition, to avoid a high possibility of failure and firing accidents.

IV. MEASUREMENT BENCH AND FIRST EXPERIMENTS

As Fig. 1 shows, the measurement bench is realized with a Personal Computer that is directly connected, by USB connectors, to two thermal imagers.

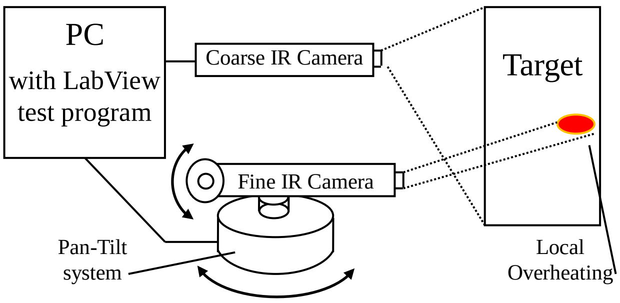

Fig. 1. Measurement Bench.

The first takes the picture of a generic electric panel; after, the image is acquired by a PC where a program developed in LabView evaluates if there is an anomaly point as, e.g. an overheating.

Fig. 2 shows an image captured by the IR camera where an overheating is clearly viewable; in this case, we using a heater have generated the overheating.

As already explained, if the software detects an overheating, it acts on the second camera executing the following steps:

- Switch on the camera, this covers an area of only thirty square centimeters to well focus the interested area;
- Acts on the tilt-pan system developed by us to aim the interested area.
- Capture the overheated area.

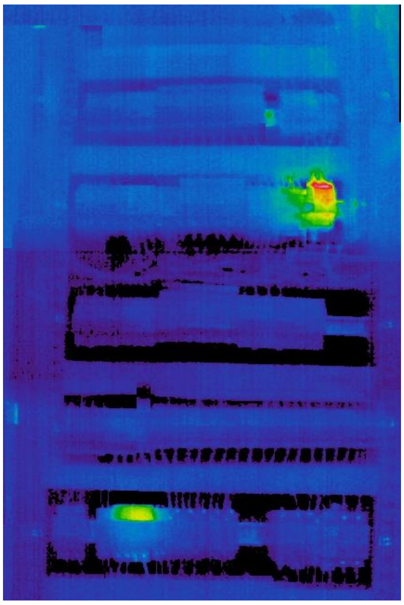

Fig. 2. IR picture of an electric panel with an artificial overheating.

Fig. 3 shows a zoomed image of the overheated area of the electric panel captured by the fine camera.

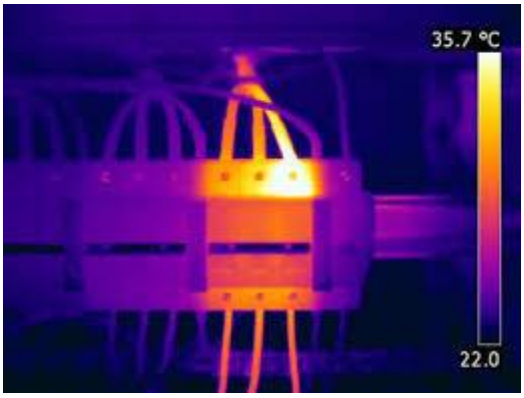

Fig. 3. Overheated area: detail of the electric panel.

Fig.4 shows an image of the electronic control card of the Pan-Tilt system based on a Microchip PIC 16f876 developed to drive up to ten stepping motors. The PIC receives the commands from the PC through the serial port. By a software written in BASIC, the commands are elaborated by the PIC, which drivers the stepping motors by a stepper-motor translator/driver, the UCN 5804 of the Allegro Microsystems [16]. This provides a complete control and drive for four-phase unipolar stepper-motor with continuous output current ratings to 1.25 A per phase and 35 V.

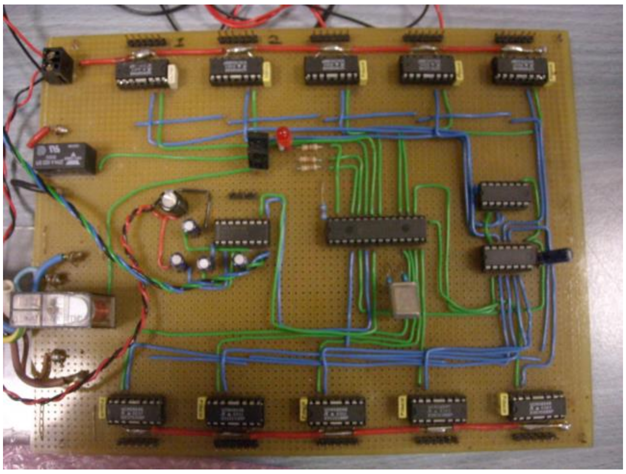

Fig. 4. The Pan-Tilt electronic control card.

V. THE FORENSIC APPLICATION

The system shown has been conceived to automatically acquire images on the thermal state of the electric devices under control. The images are locally stored in the PC memory but can also sent to a remote server and there stored also in encoded form. The database of images so realized could help in case of lawsuit. The images, showing the overheating components, help the court expert to reconstruct the scene preceding the event, resulting fundamental to determine what exactly happened. In fact, each defect that may be encountered during an infrared inspection, presents specific recognition signals [17], e.g.:

- compromised connections are recognized by having a localized heat pattern at the highest point of resistance that dissipates away from the loose connection;
- conductors displaying a colder than normal pattern under normal operating conditions, when compared to adjacent conductors under similar loads, usually signify an open circuit somewhere along the line;
- circuits with elevated heat patterns are examples of over-load conditions;
- uneven loads cause conductors to heat unevenly and are readily detectable with an infrared camera. As with all load generated heat, the entire conductor warms evenly, but the one or more conductors with have either warmer or cooler temperatures;
- when faced with perplexing heat patterns on components that should not be hot, inductive heating may be to blame;
- defective electrical components display abnormal heating patterns.

The images are also time stamped so indicating also the time when the event is happened.

VI. CONCLUSIONS

In this paper a new fully automatic system to prevent firing accident in electronic system has been proposed. The system is based on two thermograph cameras and a remote pc with a dedicated image processing software, which could be connected to a SCADA system. It allows monitoring and alerting in case of over-temperature problems on devices or systems particularly important or on areas where the human intervention for normal maintenance is not allowed or not easy to perform without closing the entire system. In addition, the recorded data can be stored in encoded form in a secured external storage system, for legal purposes, implementing a black box system for SCADA architecture. This solution allows to save not only time stamped video information related to over temperatures, but also the temperature evolution in the analyzed area and the temperature in the components involved in a thermal accident.

The proposed solution has shown the potentiality of the IRT in SCADA systems and architectures in case of automatic systems, and not only for normal maintenance activities.

Further works will be focused on the possibility to move the system in a way that allows the monitoring of more than one system, with the automatic determination of all the necessary parameters (i.e. number of cells in the controlling grid, zoom level, thresholds values etc.).

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