EXPERIENCE PERFORMING INFRARED THERMOGRAPHY IN THE MAINTENANCE OF A DISTRIBUTION UTILITY

José MARTÍNEZ
Edenor S.A. – Argentina
jmartinez@edenor.com

Rodolfo LAGIOIA
Edenor S.A. – Argentina
rolagioia@edenor.com

ABSTRACT

Nowadays, distribution utilities face new technical-economical requirements, aiming at improving the profitability of the electricity distribution systems. Such context requires both, a high reliability and availability of the electric networks. In order to do so, it is necessary to minimize outages, reducing at the same time, their duration. This situation leads to redefine the current maintenance strategies, pointing at predictive actions to minimize the unavailability of the equipment and reduce maintenance costs, searching for a more cost-effective scheme of the business. Within this framework, Edenor S.A. has decided to incorporate thermographic inspections as part of the Predictive Maintenance Annual Plan of its HV Transformer Stations, adopting this technique as an important predictive diagnostic tool of its facilities condition.

This paper presents a brief theoretical introduction of the Infrared Thermography technique. Next, thermal criterions developed to apply for the abnormalities detected, characteristics of the technical management for the execution of the project and the advances of the plan are described. The experience obtained is exposed, just as the improvements applied in the development of the plan, describing how its application was extended from detecting abnormalities in contact points visually exposed to the thermographer to "out of sight" situations. The obtained results along a seven-year-period are presented and analyzed, also describing how by performing routine scans, both, unscheduled outages were prevented and several routine maintenance tasks could be turned into condition ones, avoiding unnecessary scheduled outages.

1. INTRODUCTION

Edenor distributes electric energy in the northern part of Buenos Aires and the Great Buenos Aires area, covering a surface of 4.637 km^2, with a population of about 7 million inhabitants.

The company arose in 1992, as a consequence of the privatization of the argentine public utilities. At the end of 2005 it had more than 2,3 million clients and got incomes for energy sales of u$s 435 million, having sold 15,660 GWh. Among its installations Edenor has 66 HV/HV and HV/MV transformer substations, with voltage levels that reach 500kV.

The transformation of the electric market that took place all over the world at the beginning of the 90´s, brings about changes related to maintenance strategies, focused on optimizing the available resources and minimizing the time of unavailability of the equipment, besides reducing maintenance costs [1], strengthening to do so, predictive maintenance actions [2], [3].

In such context, by performing Infrared Thermography (IR), a faster and more effective Predictive Maintenance (PdM) on HV facilities with a large number of items to scan can be carried out. The use of IR scans allows electric utilities to minimize unplanned outages of equipment and facilities reducing emergency repairing, due to the early detection of abnormalities, prior a failure take place. Starting from the identification of thermal abnormalities at the initial stage of its development, level of damages of the items affected can be minimized, reducing maintenance costs and extending the equipment's lifetime. Finally, IR inspections allow to check the effectiveness of the maintenance and repairing tasks carried out, as well as identifying non appropriate working practices in the maintenance tasks development and introducing improvements in their execution.

2. DEVELOPMENT

2.1 The Infrared Thermography

All the bodies emit energy from their surface as electromagnetic waves, which magnitude is directly related to their temperature. The hotter the object is, the more energy it tends to radiate. Such temperature settles the wavelength of the emitted energy; the colder the object is, the higher its wavelength will be, whereas the hotter it is, the lower its wavelength will be. This last case, is the one of the infrared energy, non visible to the human eye, but visible by means of an infrared camera [4].

The radiation measured by the infrared camera depends not only on the temperature of the object but also on its emissivity. The radiation coming from the surrounding area and reflected on the object also influences the measuring. Therefore, to measure the temperature accurately, besides the effects of different sources of radiation that interact with the object, other variables such as emissivity, distance between the camera and the object scanned, environment temperature and humidity, must also be considered. In addition, due to the characteristics of the infrared radiation, to detect any overheating by IR scans, the heat generated must be "directly" in sight of the thermographer.

The IR technique is used in many different areas of science and industry. In the electric industry, it is a valuable tool in the PdM of equipments and facilities [5]. Deficiencies that can be caused in electric connections, such as insufficient adjustment, rust, conductors with strings cut, in all the cases become clear generating an increase of temperature, which by means of IR scans can be detected early and accurately [6]. So, by IR scans, non detectable abnormalities during an eye inspection can be identified and "documented".

2.2 Background and Execution of the Plan

Since the beginning of the 90´s, Edenor has been carrying out IR scans of their HV/HV and HV/MV transformer substations, initially by outsourcing the service and not in a systematic way as a part of a maintenance annual plan. In 1998, the decision of performing this task systematically in a programmed way by developing its own know-how and with in-house personnel was taken, incorporating this task as part of the PdM annual plan of its facilities.

With the information related to the tasks to execute, the available bibliography [4], [7], the contribution of infrared cameras manufacturers and the own knowledge regarding the facilities and the equipment to be scanned, thermal criterions to apply categorizing the thermal abnormalities detected and diagnosing their condition were set.

For the classification of thermal abnormalities, three critical levels and their corresponding recommended maintenance actions were defined:

I- Overheating ≥ 130°C (Serious): immediate outage of the equipment affected for the repairing of the anomaly.

II- Overheating between 100°C and 130ºC (Priority): repairing of the anomaly as soon as possible.

III- Overheating between 75°C and 100º C (Programmed): repairing of the anomaly when possible

Correction factors considering the effects of variables such as emissivity, environment temperature and relative humidity, wind influence and distance to the object were established to be considered in the measuring.

Maximum admitted loadability for the whole facilities to be scanned were set and tabulated (for instance identifying the equipment with the lowest load capability of the bay). Therefore, the overheating measured at any level of load could be referred to such maximum admitted loading level, so as to consider the most unfavorable conditions that could be present during their operation.

The information provided by infrared cameras manufacturers, the bibliography related and the experience available among the energy utilities in general, agreed on highlighting that thermographic registers obtained in equipment loaded with less than 30% of its admitted load, must not be taken into account, since in such cases correction factors normally used are not applicable. Likewise, in case of equipment loaded just before being scanned, minimal time to let the temperature reach its highest value prior scanning was established. These data was also considered when performing IR scans.

So as, to follow the technical management to perform, were developed a data base with all the information related to the facilities and the associated equipment to be scanned, data registers forms, a support computing system for the recording and processing of the obtained information and a form to submit to the maintenance personnel Thermographic Reports of the thermal abnormalities detected.

Thermographic Reports, provide information that identify with certainty the item on which a thermal abnormality has been detected (*e.g. T.S. 047 - Agronomía, feeder 634, circuit-breaker, phase S, connection accessory, side busbar*), together with a picture and a thermographic image of the abnormality detected, to facilitate the repairing tasks for the maintenance personnel. Besides, they add additional information, such as over-temperature registered and temperatures of reference, load level at the time of the scan and maximum admitted load, overheating above the environment temperature referred to the maximum admitted load and thermal classification of the abnormality.

Finally, a Technical Procedure was drawn up, where guidelines of the tasks to perform were defined, setting the technical criterions to use, the administrative management for the registering and processing of the information and the treatment to give the thermal abnormalities detected for the performing of the corresponding corrective actions.

2.3 Lessons Learned and Improvements Implemented to the Plan.

As the plan was being developed, types and characteristics of thermal abnormalities related to the different kind of equipment scanned were determined. The contribution made by the maintenance personnel, allowed the categorization of the abnormalities detected. Thanks to the feedback obtained after the repairing performed "*typical heating patterns*" were established and "*hot spots*" that were determined not being real abnormalities were identified.

By the analysis of the gathered information and the acquired experience, a higher flexibility in the criterion used to classify the thermal abnormalities detected could be applied. The practice and the obtained knowledge, led to apply a number of improvements in the execution of the plan:

- The items of all the equipment of every bay to be scanned were identified as a whole, parameterized and registered in the data base (*e.g. in a disconnector, contacts, heads, terminals, connection accessories*). In each next inspection, the inventory of the data base was inspected as a routine, to update the information related to the equipment to be inspected.
- The optimal frequency to perform the inspections was defined in twice a year per substation.
- Due to the difficulty to take out of service critical facilities of the network, in case of items with an overheating *referred to their maximum admitted load*, corresponding to *Serious Level*, it was determined that prior analysis of degree and characteristics of the abnor-

mality (location of the "hot spot"), load level and potential risks made by maintenance specialists, such criticality could be reclassified as *Priority Level*, avoiding the immediate outage of the equipment affected.

- However, some absolute temperature limits were incorporated. In case of detecting an item with an overheating ≥100ºC by direct scan, it was defined that the abnormality should be qualified as *Serious Level* with no need of referring the obtained value to the highest admitted load capability and in principle, the equipment involved should be taken out of service immediately.
- Cases of thermal differences of around 10ºC were detected between an item belonging to a phase of an equipment and those belonging to the other phases where, when performing later maintenance tasks, damage of components were found. Consequently, in case of thermal differences <75°C as the above described, a fourth critical degree was established, defining that the anomaly should be registered and followed its evolution.
- Regarding the evolution of such abnormalities for temperatures <75°C, experience indicated that generally by the time of the next inspection, critical levels get worse.
- Since an important number of "hot spots" in items such as thermal-magnetic circuit-breakers, fuses, terminal boxes and battery terminals was detected, it was emphasized the importance of scanning a.c. and d.c. LV auxiliary services panel-boards, control cabinets (transformers, circuit-breakers) and batteries.

From the experience obtained during the execution of IR scans, the update of the Technical Procedure in use was made, collecting the improvements arisen from the implementation of the plan, introducing besides improvements in the scheduled Preventive Maintenances (PM).

2.4 In-Depth Approach to the Use of the Technique.

From the acquired knowledge, the use of this technique was extended to the evaluation of the state of some items which contacts or conductor parts are not visually exposed to the thermographer view. In such situation, to detect any internal thermal abnormality, the overheating caused by the "hot spot" has to reach the external surface of the item scanned, which means that the heat has to be "transferred" to that external surface by any means (oil, air, gases).

These enclosed points in some cases even when out of service, do not allow a maintenance routine and/or an effective check of its true state. It is the case of HV surge-arresters, where slight thermal differences of around 3°C detected between different component units of a phase and those belonging to the other phases, made it possible to identify important internal damages in the affected arresters, originated by entry of moisture due to sealing defects between flanges and the external insulator, causing tracking and discharges that affected non-linear resistors, capacitors and gap elements (Fig. 1). As a result, similar models of this equipment were carefully scanned, leading to settle the need of replacing several of them.

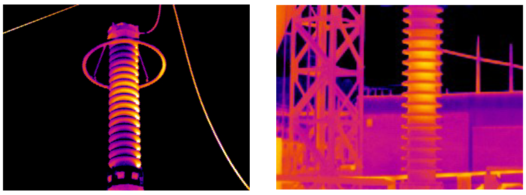

Fig. 1 - Thermal anomalies in HV surge arresters.

In wall-bushing current transformers, internal anomalies for overheating were also found, just as in oil HV circuit-breakers, where thermal differences of around 10ºC between a pole of a phase and the other poles allowed the detection of anomalies caused by an abnormally high resistance of contact between their fixed and moving main contacts (Fig. 2).

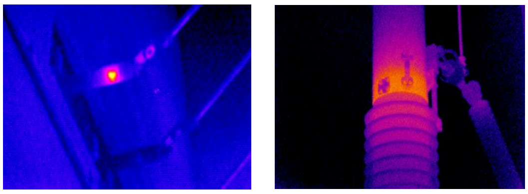

Fig. 2 - Thermal anomalies in current transformers and HV circuit-breakers.

In all the anomalies above described, characterized as "*out of sight situations*", which causes were "hidden" from the direct view of the IR camera, "typical" fail patterns for the different type of equipment scanned that cause thermal abnormalities when an internal failure is developing were identified, and the occurrence of further and worse damages and probable unscheduled outages could be prevented.

2.5 Obtained Results.

From the results of IR scans performed during the period 1999-2005 (Fig. 3), arose that most of problems were found

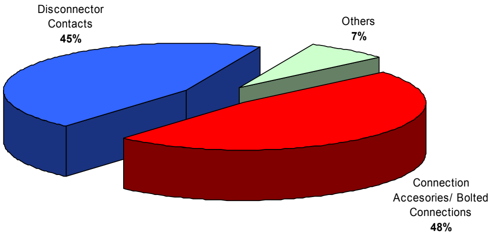

Fig. 3 - Distribution of thermal abnormalities by component Period 1999-2005.

in conductor connection accessories and bolted connections (48%), mainly derived from deficiency of adjustment and/or materials (anomalies in bimetallic surfaces joints, rust, non adequate use of inhibitory grease).

Besides, an important number of thermal anomalies appears in disconnectors contacts (45%), from mainly of defected contacts by deformations, deficient pressure of contact, incorrect alignment of arms and dirtiness (Fig. 4).

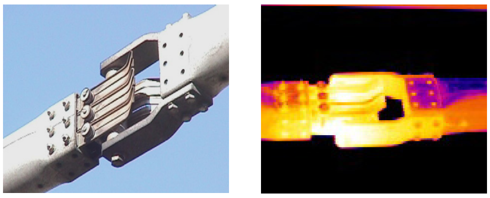

Fig. 4 - Disconnector contact and Infrared Thermography of thermal anomaly detected on this item.

Anyway, a significant number (7%) grouped in Others validates the efforts of scanning all the equipment identified.

These determinations allowed to focus the tasks developed during the scheduled PM, introducing improvements in the maintenance practices carried out. Besides that, an increased awareness by the maintenance working teams in the actions executed to solve the abnormalities detected was achieved, resulting this in an important contribution for the decrease of the critical "hot spots" found.

By analyzing the evolution of the abnormalities detected during the period 1999-2005, we see that in the period as a whole, a growing tendency to the reduction of thermal abnormalities related with the total number of item scanned for all critical levels is presented (Fig. 5).

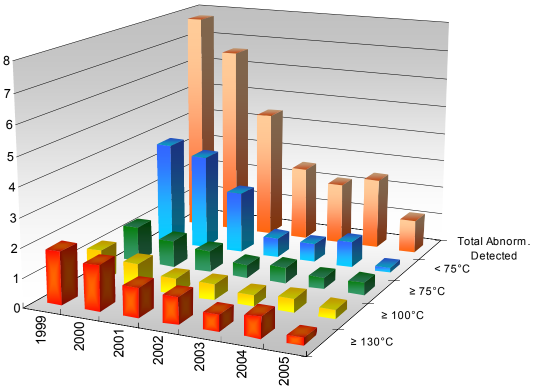

Fig. 5 - Evolution of thermal abnormalities by critical levels Period 1999 - 2005 (in per thousand of items scanned).

The decrease of thermal abnormalities with higher critical level is attributed to its early detection and their addressing by means of programmed outages, taking corrective actions to prevent the abnormality could evolve to a worse critical level. On the other hand, the decrease of thermal abnormalities with a lower critical level can be attributed to an improvement in the practices of the maintenance working teams since the experience acquired.

In all the cases, along the development of the plan as the experience and the knowledge acquired in the application of the technique were used in the improvement of the maintenance practices, thermal abnormalities were decreasing in number and critical level.

Additionally, by applying this technique an important number of maintenance activities were modified. It is the case of HV busbar disconnectors and busbar section disconnectors, which maintenance, originally time-based, could be turned into condition-based. In such cases, IR scans performed together with other tasks, went to constitute an important tool for the PdM of these equipments. This change carried out on an important part of items, reduced maintenance costs and unavailability of facilities.

Looking ahead, is foreseen to reinforce the inspections frequency on strategic substations for the operation of the network (for both, power installed or criticality in the system) or that for being located in areas with high pollution level, present repetitive thermal abnormalities, and reducing such frequency on facilities that do not have a background of an important level of anomalies in number and criticality.

As a consequence, the use of this technique went to constitute a core part for the transformer substations maintenance annual plans of the company.

3. CONCLUSIONS.

At Edenor, thermographic inspections are performed as part of a PdM program of its HV/HV and HV/MV transformer substations, which have shown to be an effective method to detect thermal abnormalities in electric distribution systems.

The use of this technique as a non-intrusive maintenance tool in a systematic way, has allowed the achievement of an important reduction of thermal abnormalities, not only in number but also in criticality. This has contributed to prevent non planned outages of facilities (for both, failures happened or abnormalities whose criticality did not let them remaining in service), and emergency repairing, letting besides to identify additional problems to be solved during the routine PM, minimizing deterioration of items.

The obtained results are highly influenced by the early detection of abnormalities, preventing their evolution to higher critical levels. In addition, from performing thermographic inspections, improvements in the maintenance practices have been introduced, as well as in the performance of the maintenance teams.

BIBLIOGRAPHY.

[1] J. Douglas, The Maintenance Revolution, *EPRI Journal, Vol. 20 Nº 3*, May-Jun, 1995.

[2] H. Röshler et al, Experience with Systems for Condition Based Maintenance, paper 23-103*, 37th Cigré Session* (Paris, 1998).

[3] R. Matusheski, et al, *Predictive Maintenance Guidelines*, EPRI Technical Report TR-103374, Aug, 1994.

[4] R. Hudson, Jr., 1969, *Infrared System Engineering*, Wiley & Sons Inc.

[5] M. Eby, R. Bush, Maintenance Management Techniques for the Future, *Transmission & Distribution World*, INTERTEC Publ. Corp. USA, Aug. 1996.

[6] Mc Adams, 1954, *Heat Transmission*, 3rd ed. Mc Graw Hill.

[7] W. Wolfe, G. Zissis, 1985, *The Infrared Handbook* (*revised edition)*, Infrared Information Analysis Center, Environmental Research Institute of Michigan.