Infrared Thermography and its role in Rural Utility Environment

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***Abstract*— The thermal energy emitted from an object can be seen and measured as a thermograph with the help of infrared imaging and measurement camera. This process of measuring heat emission is known as Infrared thermography.**

From a line arrester to a transformer, nearly every piece of equipment on a Utility System gets hot before failure. This makes infrared thermography not only a cost effective mean but also a valuable diagnostic tool in improving system efficiency, power quality, workers' safety, and averting outages, valuable equipment failure and line losses. This paper will look at the process of setting up an infrared thermography program, thermography process; describe its advantages, and its usage by Rural Cooperatives. The paper will also accentuate the advancements in infrared technology.

***Index Terms*— infrared thermography, predictive maintenance, rural utility maintenance tools, infrared imaging**

I. BACKGROUND

Nearly all objects emit energy in the form of electromagnetic waves which may vary in their frequency (ν) and wavelength (λ) based on the temperature, emissivity and the radiating area of the object. This relationship is quantified by Stefan-Boltzmann equation:

$$P = e\sigma A(T^4 - Ts^4) \qquad (1)$$

Where

P = Power emitted

e = emissivity, where $0 < e < 1$ (e = 1 for ideal blackbody)

s= Stefan's constant = 5.669×10^{-8} W/m^{2}K^4

A = radiating area of the body

T = Temperature of the radiating object in K

Ts = Temperature of the surrounding

Emissivity is a measure of the thermal emittance of a surface with respect to a thermally black surface, having the same wavelength. The black surface, also known as blackbody, does not reflect heat and has an emissivity value of 1.

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Energy radiated can be classified based on Electromagnetic spectrum, which contains all electromagnetic waves arranged according to their frequencies and wavelengths. The normal unaided human eye is capable of perceiving electromagnetic radiation that has a wavelength in the range from 400 nm (violet) to about 700 nm (red). This range is referred to as visible spectrum. The term "infrared" is derived from Latin, which means "below-red." The infrared region extends from 3×10^{12} Hz to the low frequency end of the visible spectrum, which is about 4×10^{14} Hz (red) and hence the term "infrared." The infrared energy is invisible to the human eye and is perceived as heat.

Thermography is the process of transforming heat, emitted by an object, into a visible image. All objects with temperatures above absolute zero emit heat, which makes them recordable by thermography equipment. Sir. John Herschel, the son of William Herschel, is commemorated with the creation of an image using solar radiation, which he termed as "thermogram."

In order to appreciate the process of infrared thermography let us first understand the problems that may arise in electrical equipment due to deterioration, improper usage or surrounding conditions. Electrical devices are usually rated for Power, which indicates the amount of energy the device can conduct without being damaged. If the device is operated at a Power above its specifications, the excess power causes the atoms present in the device's material to resonate and resist the flow of electricity. This resistance to the flow of electricity generates heat, which in turns overheats the device and reduces its life cycle and efficiency. Another major problem that affects utility equipment is the change in resistance due to loose connection. The loose connection causes electricity to use smaller area of the defective connection than required or intended for proper flow and therefore increases the resistance and temperature of the connection. Any problem, which accompanies a change in resistance of the equipment, causes it to consume more power than the intended load. The change in resistivity of a material with respect to the change in Temperature can be shown by the following relationship

$$\rho_2 = \rho_1[1 + \alpha(T_2 - T_1)] \qquad (2)$$

Where

α= coefficient of resistivity, different for different materials

T_1 and T_2 are Temperatures in °C or K

$\rho 1$ = Resistivity of a conductor at T1

$\rho 2$ = Resistivity of a conductor at T2

Equipment manufacturers, ANSI, IEEE and IEC publish standards and temperature ratings for electrical component. Following such standards help increase the life and reliability of electrical component.

II. INTRODUCTION

WHEN Sir. Frederick William Herschel, who is well known for his discovery of Uranus, discovered Infrared rays in the year 1800, he was not aware of the diversity of his findings. While gazing at the stars in search of new nebulae on a clear night with shimmering stars sounds like a viable option, what Herschel never could have fathomed was that on the same night, there would be another set of curious eyes gazing not at the stars but the radiant heat of Utility equipment through something called infrared camera.

In this competitive era of deregulation and changing economic conditions it has now become more than essential for utilities to be not only cost conscious but also proactive in their customer relations. By providing efficient, reliable, continuous and improved power along with some value added services such as inspections of customers' facilities to insure the elimination of inefficient consumption costs, utilities seek to build a solid and winning relationship with their customers. Unexpected problems in utilities' components can not only be costly but can also be damaging to a healthy customer relationship. It has therefore become necessary for utilities to have some sort of preventive, predictive or precision based maintenance strategy that would help them analyze, monitor and solve their problems.

Infrared scanning is an important form of non-contact testing, which has become an indispensable predictive/preventive maintenance tool throughout the utility industry. Infrared surveys can detect loose connections, unbalanced load and overload conditions, deteriorating insulation, component deterioration, and many other potential problems. The use of infrared thermography can eliminate the cost of electrical expenses that are left undetected by the unaided eye.

III. SETTING UP A THERMOGRAPHY PROGRAM

A. Choosing Right Personnel

Whether an organization is planning to setup a thermography program in house or to outsource it, it must recognize the need to having well trained and qualified personnel who are strongly committed. The proper certification and experience of a thermographer is not only necessary for accurate and meaningful results, but it may also impact the safety of the equipment surveyed, and individuals directly or indirectly involved. A program without qualified, dedicated and experienced personnel is doomed to failure.

B. Target List

The second step in setting up a successful thermography program is to create a list of all the targets that need to be inspected, e.g.

1) Substations

Transformer – Power, Buss Connectors, Bus Supports, Ground Connectors, Breakers, Isolating and Bypass switches, Air Break Switches, Station Service Transformer, Current Transformer, Potential Transformer

2) Underground Distribution

Pot-heads, Switch Contacts, Lightning Arrestors, Direct Buried Cable, Underground Splices

3) Aerial Distribution

Suspension and Pine Type Insulators, Conductor Connections, Lightning Arrestor, Fused Cut-outs, Underslung Disconnect Switches, Distribution Transformer, Air Break Switches, Capacitor Banks, Breakers.

Additional benefits can be achieved by organizing the targets in terms of their criticality

C. Problem Classification System

In order to identify the criticality of the problems and to prioritize the troubleshooting process a proper classification system is required e.g.

1) Critical [Temp > 135 deg. F]

Repair immediately (overtime). Replace component and inspect surrounding components

2) Serious [Temp 45-135 deg. F]

Repair in immediate future (1-2 days). Replace component and inspect surrounding components for probable damage

3) Intermediate [Temp 18-45 deg. F]

Repair in the near future (2-4 weeks). Watch load and change accordingly. Inspect for physical damage in the component, but not in the surrounding components

4) Minor [Temp 2-10 deg. F]

Repair in regular maintenance schedule; little probability of physical damage

D. Choosing the Right Camera

Purchasing a camera, which satisfactorily meets all the requirements and expectations for all critical targets, is also vital to the success of the program. The accuracy of the program relies heavily on the performance of the camera. While choosing a camera, three factors need to be considered.

1) Sensitivity

A camera which is highly sensitive to the target image temperature can enable thermographer to conduct surveys even under bad conditions.

2) Resolution

It is the ability of a camera to accurately measure the temperature of the smallest target spot of a certain diameter at a maximum distance away from the camera.

3) Signal Processing Speed

It is the speed with which the camera interpret the signal generated by its Focal Plane Array (FPA). The faster the processing speed the sharper will be the image.

E. *Choosing the Right Reporting and database system*

Choosing a right reporting and a database system is also very critical for a successful thermography program. Time management is a big issue for thermographers. Infrared-camera manufacturers have made several changes in cameras and have developed several software platforms In order to address the "time management" problem faced by thermographers. The modern imaging systems incorporate features such as text, analysis functions, and voice commands etc. The combination of modern imaging systems, and widows-based software and packages has made it possible for even infrequent users to create effective thermography reports.

Like reporting, choosing a right database is also very crucial in tracking Infrared data. Relational database with the ability to search data with respect to various factors such as date, problem type, location etc. is important in tracking historical trends. Open Database Connectivity (ODBC) feature of a database will allow it to communicate with other programs and databases in future.

IV. THERMOGRAPHY PROCESS

The imaging system detects the portion of the energy radiated by the object, converts into an electrical signal which is then amplified and converted into a video signal and reproduced on a monitor screen. Because infrared energy is directly proportional to the fourth power of temperature, the video image is designed to depict temperature levels on the monitor. Two hundred and fifty six shades of gray from black to white represent different temperature levels throughout the chosen temperature range. An isotherm is utilized to determine different shades of gray of the temperature being measured. The temperature can then be calculated from the documented isotherm.

Measured Temperature Rise (MTR) using the infrared process can be different under different circumstances therefore certain corrections need to be made for variables such as Survey Load Level (SLL) and Wind Speed. Using Joule's law the MTR can be adjusted to Converted Reference Temperature (CRT). The CRT is then adjusted up or down from the SLL to 50% load level, by employing Load Correction Factor (LCF), which is then multiplied by Wind Speed Correction Factor (WSCF) to obtain the correct CRT. Therefore CRT can be written as:

$$CRT = MTR \times LCF \times WSCF \tag{3}$$

V. ADVANTAGES OF INFRARED THERMOGRAPHY

There are several advantages to having a good infrared thermography program, which include:

A. *Immediate Bottom Line Result*

According to reference [3] 80% or more of the losses experienced are caused by 20% or less of the failure events. When an effort is made to identify and resolve those 20% of the problems, an immediate bottom-line result is realized.

B. *Reduced Outage Costs*

The costs of planned outages are much less than unplanned outages. Unplanned outages could not only cost utilities but also their customers. Utilities also loose revenue from unused Power.

C. *Increased Revenue*

Utilities also experience Increased Revenue from continuous uptime. The use of infrared thermography allows utilities to focus on components with more potential of failure and therefore reduce their maintenance cost. Nipping the evil in the bud also helps reduce the costs of damages that would have otherwise occurred.

D. *Less Downtime*

Critical equipment, which can not be taken off-line without a significant impact on production, can be inspected while being in service and need not be taken out. Since all electrical equipment turns hot before it fails, problems can be identified during routine operation.

E. *Less Need For spare parts*

With predictive techniques, such as infrared thermography, problems can be identified ahead of time and therefore no immediate inventory of spare parts is required.

F. *System Reliability and Power Quality*

Loose connections and faulty equipment can not only cause outages, but can also result in blinks and a poor quality of service. Problems if left undetected can also cause some unexpected outages and there by reducing reliability. Using infrared thermography System Average Interruption Frequency Index can be improved by reducing frequency of sustained outages

G. *Customer Relationship*

Lesser power outages and improved power quality can add to consumer content. Customers' facilities can also be inspected upon request, thereby reducing the inefficient use of Power.

H. *Identification of Chronic Problems*

The maintenance history and thermographic trends can help identify chronic problems and their root cause.

I. *Safety*

Routine surveys can help avoid catastrophic failures of electrical equipment, which could cause threat to the safety of employees or general public.

VI. INFRARED THERMOGRAPHY IN RURAL UTILITIES

In researching to understand the impact of infrared thermography in the local electric cooperative areas in Arkansas and Texas, surveys were sent out to help identify how infrared thermography impacts the cooperative costs and efficiency. The survey contained questions which determined the effectiveness, if any, and the benefits of using infrared cameras to detect faults on utility equipment. Of the cooperatives surveyed, 73% acknowledged the use of infrared thermography as a preventive maintenance tool to detect troubled spots, also known as "hot spots," on their systems. Cooperatives not involved in the infrared thermography, plan to purchase one or add it to inspection/maintenance programs in future.

Out of the cooperatives, which have infrared thermography inspection program, 31% of the cooperatives use in-house solutions for predictive maintenance detection in their areas, 56% outsource the work to a certified contractor who does the work for the cooperatives and 13% use both in-house and outsourcing methods. The cooperatives, which use both in-house and outsourced work, use in-house inspection as a redundant tool. To ensure a more thorough look at problems the in-house is for follow up on problems detected by the contractor. The in-house inspection is also considered for investigation of critical loads and infrequent problems that may arise at any time of the year. Some of the thermography imaging devices that were used during inspections are FLIR model PM 290, Raytek ThermoView Ti30, Raytheon Extor and AGEMA THERMOVISION AGA 782.

A successful infrared scan was attributed to the skills and experience of the operator of the equipment. The problems, which were observed frequently, were with connections and splices in overhead distribution lines, and transmission lines and equipment, bolted connections in substations, lightning arresters due to improper sizing, fuse contacts and switches at substations and distribution line facilities, overheated transformer bushings and draw leads in power transformers, capacitor banks, elbows in underground transformers and junctions, cracked insulators, and partially insulated jumpers on substation equipment.

When asked if the cooperatives have qualified personnel to use the equipment assigned for the survey 100% of the cooperatives, which have an in-house program, believed they were qualified and 37% of them believed that they needed retraining to be able to use the equipment to function properly, when the time comes to do the survey.

Regular infrared inspections, experience in the field, and training can help personnel develop the abilities to successfully do the inspections and create reports for the cooperatives which include relevant and necessary data for the troubleshooting process.

VII. ADVANCEMENTS IN INFRARED TECHNOLOGY

Progress in infrared technology has reached new levels. The need to reduce the time spent on the surveys and reporting has prompted the industry to move with better imaging systems along with new and easy to use software packages and databases. Older imaging equipment required liquid nitrogen for cooling its detectors. The new imaging devices either have some electrical cooling solution or do not require cooling at all. Increased mobility has stimulated the need for small and light weight systems, which has been addressed by several manufacturers. Efforts have been made to bring infrared thermography cameras up to the same level of performance as modern video camcorders.

The use of mosaicked multispectral image acquisition along with cascade laser has not only increased the battery life and mechanical robustness, but it has also decreased equipment cost and physical size of the camera.

Real-time imaging systems are not just fast, compact and frequency agile but they also have greater image resolution improved imaging analysis and recording capabilities. The integration of PC with the mix has given a new edge to the technology. New PC interfaces have made it easy for even occasional users to operate with confidence.

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