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Infrared Thermography and its Role in Evaluating Medium Voltage Overhead Line System

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Abstract: **At a temperature above absolute zero (i.e. -273^{o}C), each object emits thermal energy that can be seen and measured as a thermograph by using infrared imaging and measurement camera techniques. Infrared thermography represents this process of measuring heat emission. From a lightning arrester to a transformer, the temperature of each piece of electrical component on a distribution network system starts gradually to rise before failure. So, infrared thermography is not only a cost effective technique but also an effective diagnostic tool in increasing system efficiency and reliability, power quality, workers' safety, and averting outages, valuable equipment failure and line losses. This paper will explain the process of setting up an infrared thermography program, thermography process; and describe its advantages. The paper will also illustrate the advancements in infrared technology.**

Keywords: Infrared Thermography, Medium Voltage Overhead line, Infrared Imaging, Preventive Maintenance

1. Introduction

Nowadays, distribution utilities aim to get new technical-economical requirements to improve the profitability of the electricity distribution systems. This requires a high reliability, security and availability of the electric networks. In order to do so, it is indispensable to reduce outages and minimize at the same time their duration. This condition requires redefining the current maintenance strategies, referring to predictive actions to reduce the unavailability of the equipment and decrease maintenance costs, searching for a more cost-effective scheme of the business.

In recent years, the repair and maintenance of electrical equipment at significant facilities has been a major area of interest. Some of these facilities, the repair and maintenance of equipment at facilities of electrical distribution power are listed as a task with the high priority because new modern life depends solely on the continuous operation of these equipments in the future. Electrical distribution power, medium voltage overhead (MVOH) line is main part of distribution power, is usually located in every corner of small villages and big cities. This is because electricity has to be provided to wherever the consumers are conducting their indoor or outdoor activities, leading to tens of thousands of such facilities. Unexpected problems in MVOH line 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. An important objective for every power utility is to provide proper maintenance for much electrical equipment at these facilities in order to keep and raise the reliability and security of electricity product, but such a goal has always been a challenging one.

There are three different categories for repair and maintenance of a facility: when equipment malfunctions, time–based maintenance and condition-based maintenance (CBM). CBM is the most popular one, also known as preventive maintenance. It has been reported that maintenance cost is up to 70% of the total production cost that can be spent. Furthermore, up to33% of the maintenance cost is spent unnecessarily due to overtime cost, bad planning, limited or misused preventive maintenance and so on [1]. Everything is taken into consideration when scheduling predictive maintenance actions, autonomously or in interaction with humans. With the implementation of condition based maintenance, investigations indicate that it can be reduce high cost in insuring equipment availability.

Utilities have adopted new methods of CBM to improve the condition based maintenance scheme in evaluation their medium voltage overhead (MVOH) network. Infrared thermography (IRT) is one of those new methods. IRT scanning is an important method of non-contact inspection, which has become an indispensable predictive maintenance tool throughout the utility industry. Loose connections, unbalanced load and overload conditions, deteriorating insulation, component deterioration, and many other potential problems can be detected by IRT inspection. The cost of electrical expenses can be minimized by using this method that is left undetected by the naked eye.

2. Background

Sir Frederick-William Herschel, an astronomer by profession, was the person who discovered infrared rays in 1800. He measured the temperature next to the spectrum's red area where no sunlight could be seen. To his astonishment the region had the highest temperature recorded in terms of spectrum colors. Subsequently, the first thermal image was noted by his son John Herschel. He contributed to knowledge by adding a new perspective to the temperature measurement post 1960, whereby an American company used it to create a single feature detector capable of scanning scenery coupled with the development of the images. [2]

At a specific temperature above absolute zero (i.e. -273^{o}C), every object releases energy as a form of electromagnetic waves which may vary in their frequency and wavelength depending on the temperature, emissivity and the radiating region of the object. This relationship is quantified by Stefan-Boltzmann equation:

$$P = \sigma \varepsilon A(T^4 - T_s^4) \quad (1)$$

Where P is the emitted power rate (W), A is the emitting surface area (m^2), T is the absolute temperature (K) of the radiating object, T_s is the absolute surrounding Temperature and σ is Stefan–Boltzmann's constant(σ = 5.676×10^{-8} Wm^{-2} K^{-4}) and ε is the emissivity of emitting surface for a constant wavelength and absolute temperature.

Emissivity (ε) is the ratio of the radiation released by a surface to the radiation released by a blackbody with same temperature. A perfect black body would have ε = 1 whereas real object would have ε < 1 [3].

Based on Electromagnetic spectrum, radiated energy can be categorized which contains all electromagnetic waves arranged according to their frequencies and wavelengths. The wavelength band of electromagnetic radiation that can be perceived by naked human eye is ranging from 400nm (violet) to about 700nm (red). This range is known as visible spectrum. The term "infrared" is derived from Latin, which means "below-red." The frequency spectrum of infrared region extends from 3x 10^{12} Hz to 4 x 10^{14} Hz (red) which is the low frequency end of the visible spectrum. The naked human eye is unable to see the infrared energy but it can be perceived as heat.

Thermography is the process in which heat that emitted by an object is transformed into a visible image. So this makes all objects with temperatures above absolute zero recordable and visible by thermography instrument which termed as "thermogram."

Firstly, we should realize the problems that may occur in electrical apparatus due to improper usage, bad installation, deterioration or surrounding conditions in order to appreciate the performance of infrared thermograph. Every electrical device usually has its own specifications of rated power, which indicates the energy amount that this device can operate without being damaged [4]. If operated power of the device exceeds its specifications, the excess power causes the device's material atoms to resonate and resist the flow of electricity. This resistance produces heat, which in turns overheats the device and then by time reduces its efficiency and life cycle. Loose connection is another major problem that affects electrical equipment which causes change in electrical resistance. The loose connection makes area of the defective connection used by electricity smaller than required or intended for proper flow and thus increases the resistance which in turn overheats the connection. Any problem, which accompanies a change in resistance of the equipment, causes it to consume more power than the intended load. The following relationship shows the change in a material resistivity with respect to the change in temperature:

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

Where α is coefficient of resistivity, different for different materials, T_1 and T_2 are temperatures in °C or K, ρ_1& ρ_2 are resistivity of a conductor at T_1& T_2 respectively. There are many standards and temperature ratings for electrical component that are published by equipment manufacturers and authorized organizations; ANSI, IEEE and IEC [3]. The life and reliability of electrical component will be improved by following such standards.

3. Setting up an Inspection Program using IRT Technique

3.1 Selecting Inspection Personnel

In using IRT technique, any good utility must have planning to setup a thermography program. Therefore; it is required the need to having well practiced and qualified inspection personnel who are strongly committed. A thermographer who has the appropriate certification and experience is not only indispensable to get accurate and meaningful measurements, but it may also ensure the safety of the equipment being inspected, and individuals directly or indirectly involved. A program without qualified, trained and experienced personnel is doomed to failure.

3.2 The MVOH Line Components of Interest

The second step in setting up an active thermography program is to prepare a list of all MVOH line components that need to be inspected:

a. Substations

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

b. Overhead Components

They are Suspension and Pine Type Insulators, Fused Cut-outs, Conductor Connections, Breakers, Lightning Arrestor, Auto Circuit Reclosers, Load Break Switches, Distribution Transformer, Air Break Switches and Capacitor Banks.

3.3 Severity Index System

An active and successful thermography program requires appropriate severity standard of IRT based inspection for electrical equipment in order to determine the criticality level of incipient faults to take a proper action. For example, an IRT severity standard which is applied by Tenaga Nasional Berhad (TNB), utility of electricity in Malaysia, on MVOH line system is International Electrical Testing Association (NETA) [5]. If temperature difference (ΔT) was between similar components under identical loading, the severity level will be shown as following:

1) Critical [ΔT > 15°C]
   Major discrepancy, repair immediately.
2) Minor [ΔT= 4–15°C]
   Indicates probable deficiency, repair as time permits.
3) Low [ΔT= 1–3°C]
   Possible deficiency warrants investigation.

3.4 Selecting the Right IRT Camera

IRT inspection instrument (IRT camera) is also vital and necessary to the success of the thermography program. It must satisfactorily meets all the requirements and expectations to be active in getting critical targets. The accuracy of the program depends significantly on the performance of the camera. There are three factors that need to be considered in choosing a camera; sensitivity, resolution and signal processing speed.

3.4.1Sensitivity

The higher sensitivity of IRT camera, the higher accuracy of measurements can pick. IRT camera with high sensitivity to the target image temperature can enable inspection personnel to conduct scanning even under bad conditions.

3.4.2Resolution

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.

3.4.3Signal Processing Speed

It is the speed of processing the data resulted from thermography signal that emits from the suspected component in which the camera interprets the signal generated by its Focal Plane Array (FPA). The faster the processing speed the sharper will be the image.

3.5 Using proper reporting and database system

Using a proper reporting and database system is also very important for setting up a successful thermography program. Time management is a challenging issue for thermographers. Manufacturers of IRT camera have set up several changes in cameras and have evolved several software platforms In order to handle the "time management" problem faced by thermographers. The modern imaging systems blend features such as analysis functions, text, and voice commands etc. The combination of modem imaging systems, and widows-based software and packages has made it possible for even infrequent users to create effective thermography reports [6].

Similar to reporting, using a proper database is also very decisive in tracking IRT data. Relational database with the capability to search data with respect to different factors such as date, problem type, location etc. is necessary in tracking historical trends. Open Database Connectivity (ODBC) feature of a database will allow it to communicate with other programs and databases in future.

4. Infrared Thermography Process

IRT camera detects infrared energy (heat) emitted from the target object which is then focused by the optics (lens) onto an infrared detector. The detector converts it into an electrical signal that varies with the intensity of the infrared radiation. This signal will be send to the electronics circuits to amplify, digitize, and then will be electronically transmitted for further processing into a visible image and displayed on the monitor as a thermograph by the image processing unit. The video image is designed to show temperature levels on the monitor because infrared energy is directly proportional to the fourth 'power of temperature according to Stefan-Boltzmann equation. Different temperature levels throughout the selected temperature range are represented by 256 shades of gray from black to white. 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.

Using the IRT process requires specific corrections to be made for variables such as Survey Load Level (SLL) and Wind Speed because Measured Temperature Rise (MTR) can be different under different conditions. 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 expressed as:

CRT = MTR x LCF x WSCF (3)

5. Infrared Thermography Advantages

A good infrared thermography program has several advantages, which include:

a. Minimize Outage Costs

The costs of unplanned outages are much higher than planned outages. As well as unplanned outages could cost utilities, it also could cost their customers. Utilities lose revenue from unused Power as well.

b. Increased Revenue

Utilities also experience increased revenue from continuous uptime. Utilities will be able to concentrate on components that have more potential of failure by using infrared thermography technique and thus reduce their maintenance cost. Nipping the evil in the bud also helps reduce the costs of damages that would have otherwise occurred.

c. Reducing Downtime

IRT technique is non-contact and non-destructive method which does not cause any disturbance to the usual operating routine of the system being inspected. Therefore; equipment with incipient fault, which has a significant impact on production, can be tested while being in service and need not be taken out. Incipient faults can be detected during routine operation because all electrical equipment turns hot before it fails.

d. System Reliability and Power Quality

As well as faulty equipment can cause unexpected outages, it can also result in a poor quality of service. If incipient faults left undetected, they can also cause some unplanned outages and thereby reducing reliability. Using IRT technique, System Average Interruption Frequency Index can be improved.

e. Increase Safety

The voltage range of MVOH line system is from 11-66kV, so on-line inspection can be dangerous on maintenance personnel. Therefore; by using IRT inspection method, the personnel can avoid hazardous regions and catastrophic

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failures.

f. Identification of Chronic Faults

The maintenance history and thermographic trends can help indicate chronic faults and their root reason.

6. IRT Technology Developments

In recent years, IRT technology has developed and reached new levels. The need to decrease the time spent on the scanning and reporting has encouraged manufacturers to seek developing imaging systems and get new and easy to use software packages and databases. Infrared detectors of older imaging instruments required liquid nitrogen for cooling [7]. The new imaging devices either have some electrical cooling solution or do not require cooling at all. Increase requirement of mobility has motivated the need for small and portable equipment, which has been addressed by several manufacturers. Efforts have been made to bring infrared thermography cameras up to the same level of performance as modem video camcorders.

The use of mosaicked multispectral image acquisition along with cascade laser has not only augmented the battery life and mechanical sturdiness, but it has reduced instrument cost and physical size of the camera as well.

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

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Author Profile

Ahmed Abdelmajeed Hameed was born in Iraq in 1976. He received the B.S. degree in Electrical Engineering from Almustansiria University, Iraq in 2000. During 2002-20011, he employed in Almuthanna Cement Plant in Iraq. He worked in Electrical Maintenance Department. Then in 2012 Iraqi government sent him to Malaysia to study M.S. digree in Electrical Power engineering- Uniten University. Now he is doing a dissertation and its topic: "Condition Based Maintenance of medium voltage overhead lines using ultrasonic detection and infrared methods".

Azrul Mohd Ariffin was born in Malaysia in 1981. He received his B.Eng in Electrical Engineering (First Class Honors) from University of Southampton, UK in 2004. He then pursued his doctorate at the same university and was awarded the Ph.D degree in 2008. His thesis investigated the electroluminescence phenomenon in insulating polymers subjected high electric field. Currently, he is a Senior Lecturer at Universiti Tenaga Nasional (UNITEN), Malaysia and also a member of Board of Engineers, Malaysia (BEM), Institute of Electrical and Electronics Engineers (IEEE) and The Institution of Engineering and Technology (IET).