# INTELLIGENT THERMAL CONDITION MONITORING OF ELECTRICAL EQUIPMENT USING INFRARED THERMOGRAPHY

**by**

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ANN | Artificial Neural Network |
| BR | Bayesian Regularization |
| CB | Circuit Breaker |
| CCD | Charged Coupled Device |
| DA | Discriminant Analysis |
| DIP | Digital Image Processing |
| FN | False Negative |
| FP | False Positive |
| GLCM | Grey Level Co-occurrence Matrix |
| IRT | Infrared Thermography |
| ITADA | Infrared Thermography Anomaly Detection Algorithm |
| LM | Levenberg Marquardt |
| LVQ | Learning Vector Quantization |
| MLP | Multi-Layered Perceptron |
| MSER | Maximally Stable Extremal Region |
| MSB | Main Switch Board |
| NDT | Non-destructive |
| PCA | Principal Component Analysis |
| PdM | Predictive Maintenance |
| PM | Preventive Maintenance |
| RBF | Redial Basis Function |
| RNN | Recurrent Neural Network |
| ROI | Region of Interest |

| | |
|---|---|
| RP | Resilient back Propagation |
| SCG | Scaled Conjugate Gradient |
| SVM | Support Vector Machine |
| TN | True Negative |
| TP | True Positive |

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1. **A. S. Nazmul Huda**, Soib Taib, Mohd Shawal Jadin, Dahaman Ishak, A semi-automatic approach for thermographic inspection of electrical installations within buildings, Elsevier, Energy & Buildings, 55 (2012), pp. 585-591 (ISI cited publication)

2. **A. S. Nazmul Huda**, Soib Taib, A comparative study of MLP networks using back propagation algorithms in electrical equipments thermography, Springer, Arabian journal for science and engineering, 2012 (Accepted, article in press) (ISI cited publication)

3. **A.S.N. Huda**, S. Taib, M.S. Jadin, K.H. Ghazali, A new thermographic NDT for condition monitoring of electrical components using ANN with confidence level analysis, Elsevier, ISA Transactions, 2013 (Revision submitted) (ISI cited publication)

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5. **A.S.N. Huda**, S. Taib, Suitable features selection for monitoring thermal condition of electrical equipment using infrared thermography. Elsevier, Infrared Physics & Technology, 61(2013), pp. 184-191 (ISI cited publication)

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1. Mohd Shawal Jadin, Kamarul Hawari Ghazali, Soib Taib, **Nazmul Huda** (2013) Finding ROIs in Infrared Image of electrical installation for qualitative thermal condition evaluation, IEEE International Conference on Control System, Computing and Engineering, 23 - 25 Nov. 2012, Penang, Malaysia.

2. **A. S. Nazmul Huda**, Soib bin Taib and Dahaman bin Ishak (2012) Analysis and prediction of temperature of electrical equipment for infrared diagnosis considering emissivity and object to camera distance setting effect, Progress in Electromagnetics Research symposium, 28-30 March, 2012, Kuala Lumpur, Malaysia.

3. **A. S. Nazmul Huda**, Soib bin Taib and Dahaman bin Ishak (2012) necessity of quantitative based thermographic inspection of electrical equipments**,** Progress in Electromagnetics Research symposium, 28-30 March, 2012, Kuala Lumpur, Malaysia.

**PEMANTAUAN PINTAR KEADAAN TERMA PERALATAN ELEKTRIK MENGGUNAKAN TERMOGRAFI INFRAMERAH**

## ABSTRAK

Sistem pemantauan termografi inframerah telah digunakan secara meluas untuk mengesan kecacatan pada peralatan elektrik. Pemeriksaan lazim berdasarkan tafsiran data suhu dan penilaian keadaan peralatan adalah subjektif dan sangat bergantung kepada kepakaran manusia. Namun begitu, sistem diagnostik automatik berdasarkan rangkaian neural tiruan dapat mengurangkan masa operasi, tenaga manusia dan juga meningkatkan kebolehpercayaan sistem. Maka, dalam kerja-kerja ini, sistem klasifikasi pintar yang mengandungi ciri-ciri automatik yang diekstrak daripada kecacatan imej haba dan klasifikasi pintar keadaan haba berdasarkan rangkaian neural adalah dicadangkan. Sistem yang dicadangkan mengekstrak ciri-ciri berasaskan turutan histogram dan ciri-ciri matriks kejadian-bersama tahap kelabu dari kawasan yang dibahagikan dan membuktikan keberkesanan ciri-ciri ini untuk pencirian kecacatan. Seterusnya, tiga teknik pemilihan ciri-ciri iaitu analisis komponen utama, analisis pembahagian dan analisis prestasi secara individu yang digunakan untuk mengetahui ciri-ciri yang penting dan berguna. Dalam kajian ini, rangkaian perseptron pelbagai lapis dicadangkan untuk mencirikan keadaan haba. Rangkaian neural perseptron pelbagai lapis dilatih menggunakan pelbagai latihan algoritma. Sebagai tambahan, penyelidikan terkini memperkenalkan sistem pendiagnosis kecacatan dengan bantuan komputer. Sistem ini digunakan untuk membahagikan kawasan kecacatan dan mengekstrak enam ciri-ciri intensiti secara automatik dari rantau yang dibahagikan. Keputusan membuktikan ciri-ciri statistik mampu untuk mengklasifikasikan keadaan haba dan rangkaian neural sehingga mencapai ketepatan sekitar 73-78%.

**INTELLIGENT THERMAL CONDITION MONITORING OF ELECTRICAL EQUIPMENT USING INFRARED THERMOGRAPHY**

## ABSTRACT

Infrared thermographic inspection system is widely being utilized for defect detection in electrical equipment. Conventional inspection based on the temperature data interpretation and evaluation the condition of the equipment is subjective and depends on the human experts. Implementation of an automatic diagnostic system based on artificial neural network reduces operating time, human efforts and also increases the reliability of system. In this thesis, an automatic features extraction system from thermal image of defects and the intelligent classification of thermal condition based on neural network are proposed. The proposed system extracts first order histogram based features and grey level co-occurrence matrix features from the segmented regions and evaluates the effectiveness of these features for defect characterization. Three feature selection techniques namely principal component analysis, the discriminant analysis and individual feature performance analysis are employed to find out the useful and important statistical features. In this study, multilayered perceptron network is proposed for classifying thermal condition into two classes namely normal and defective. The multilayered perceptron neural networks are trained using various training algorithms. Additionally, the present research introduces a computer aided defect diagnosis system where the defected region is found by manual thresholding and intensity features are extracted from each segmented region. The results prove that the statistical features are capable to classify thermal condition and the neural networks achieve the accuracy around 73~78%.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Infrared thermography is one of the popular non-destructive testing (NDT) and condition monitoring tool. The technology is generally used to investigate the invisible defects in various fields such as industrial, electrical, structural and medical etc by congregating and analyzing of data from non-contact thermal imaging devices (Maldague, 2000).

Heat energy is an important factor in electrical equipment for increasing operational reliability. Electrical current passes through a resistive component and generates heat. Thermal energy generated from an electrical component is directly in proportional to the square of the current passing through it and resistance ($I^2R$ Loss). Therefore, an increase of resistance results in an increased in heat. Over the time condition of the electrical components will begin to deteriorate due to various reasons such as loose connection, corrosion, insulators crack, etc. As components deteriorate, their resistance increases and also generate more heat (Braunovic et al., 2007; Fournier & Amyot 2001; Korendo, & Florkowski 2001; IESR, 2011). The increase in heat energy, can cause electrical equipment to fail and also fire may break out. The faults due to the abnormal heating effect is largely preventable if heat is detected at the early stage by an effective screening and then adequately necessary steps are taken.

## 1.2 Necessity of IRT as Condition Monitoring Tool of Electrical Equipment

The infrared camera is an equipment to display surface temperature of an object by detecting the infrared energy radiated from the surface of an object. Infrared thermography technique is an early faults diagnosis system of electrical equipment. It can detect the internal and external faults by monitoring the thermal condition of electrical equipment and provides various advantages over the conventional thermal condition and faults diagnosis tools (Kregg, 2004). Some of the advantages of IRT are described below:

### a) Preventive /Predictive Maintenance

Typically for maintaining electrical equipment, two types of approaches, either run-to-failure or preventive maintenance are used. The run-to-failure approach is simple and straightforward, where there is no outflow of money on maintenance purpose before equipment eventual failure. The approach waits for equipment failure before any maintenance action is taken. Therefore, the method is more expensive. Thermography based diagnosis system allows preventive/predictive maintenance for early prevention of equipment failure without interrupting running operation and thus saves money (Epperly et al., 1997; Salisbury, 2000).

According to the historical data in USA (TBPPM, 2011), effective use of the preventive/predictive maintenance will reduce about 33% to 50% of the maintenance cost that are wasted by the most manufacturing and production plants.

### i) Preventive Maintenance (PM)

Maintaining electrical equipment according to the statistical or historical information of operating capacity, failure history, mean-time-to-failure (MTTF) instead of tracking equipment performance is referred as preventive maintenance. Preventive maintenance program schedules the repairing and rebuilding activities for electrical equipment. Suppose, an electrical equipment normally runs 10 months before needed any repair. Using preventive technique, the equipment will be removed from service and rebuilt after 10 months of operation. In this example, the schedule of repairing of equipment is predefined which is determined by maintenance personnel. Now, if there is no need to rebuild after 10 months. Then, there would be wasted of labour and material. Again, if the equipment fails before 10 months, then it is necessary to fix problems after failure which is usually more expensive than schedule maintenance. This is a just random decision, not supported by any kind of realistic data.

### ii) Predictive Maintenance (PdM)

Maintenance of electrical equipment based on the direct monitoring of the actual operating condition, regularly collecting measurements, efficiency, heat distribution and other indicators instead of depending on statistical or historical data is called predictive maintenance. The program schedules all maintenance activities based on the factual data and if necessary, repairs before the equipment failure (Epperly et al., 1997). Early detection of imminent equipment failures and preventing them can significantly reduce downtime, costs for maintenance and maximize uptime.

**c) Fire Prevention**

According to the reports of Fire and Rescue Department of Malaysia about the causes of fire in buildings (STAT, 2012), about 2,317 fire related incidents have occurred between January 2012 and June 2012, making the average number of incidents around 387 a month. In this report, 1049 fires were caused by electrical problems. This was about 46% of the total causes of fire in building and mainly involved the electrical wiring problems (809 cases) and failure of electrical equipment (240 cases). Failure of electrical distribution equipment can potentially produce an ignition and fire. One of the causes of ignition is excessive ohmic heating in electrical distribution. The causes of excessive ohmic heating can be subdivided into gross overloads, excessive thermal insulation, stray currents, ground faults, overvoltage and poor connections (Coutin et al.,2003, TMEFP, 2011). These conditions can occur especially for old buildings with outdated electrical wiring that is deteriorating, inappropriately amended or insufficient for the electrical load. However, the new constructions are also not excluded from these conditions (Babrauskas, 2001; Plumecocq et al., 2011).

**d) Reduction of Energy Loss**

Frequent monitoring of thermal condition of electrical equipment is also necessary for reducing the heat loss which occurs by elevated surface temperatures. The thermal insulation survey of a 460 MW thermal power station in India reveals that about 0.426768 million KJ/hour heat losses was occurring due to bare surfaces, inadequate/damaged insulation or open cladding condition in all four units. This is equivalent to a coal loss of about 1847 MT per annum. Further analysis shows that if these faulty insulated areas are attended by monitoring their thermal condition, there would be financial saving of around 59,052 USD per annum giving a simple payback period of about one month (Garnaik, 2011).

### e) Reduced Maintenance Cost

Identifying fault quickly before critical condition, scheduling the follow-up inspection, repair and diagnosis the fault within appropriate period is the most efficient and cost effective way to increase the reliability of system. By thermographic inspection, it is easy to identify the potential problems, quantify potential energy savings, schedule interventions and set priorities for preventive and predictive maintenance or the need for immediate service to minimize the risk of failure and maintenance cost.

### f) Avoiding Unnecessary Repair

Thermographic inspection can see the actual area of defect in equipment. Thus, it reduces disassembling, rebuilding, repairing or unnecessary replacement of good components which is pointless, expensive, time consuming issue. By applying infrared thermographic inspection, the extent of the defect or failure could be identified and this enables repair to be undertaken quickly. Thus maintenance costs are reduced and the revenue is increased.

### g) Increased Production & Safety

The diagnosis system allows early avoidance of equipment failure which significantly decreases unscheduled outage and equipment damage. The system can diagnose the faults without interruption or shutdown of the service which results in an increase of production. Additionally the failure of electrical components could be catastrophic, injuring or even killing employees, maintenance personnel or the public.

### h) Increased Life Time

The power rating of equipment indicates the amount of energy the equipment can conduct without being damaged. Before the equipment failure, it is operated at excess power level which resists the electricity flow and generates heat. Therefore, the equipment is overheated and operating efficiency is decreased. Utilization of thermography can increase the life time and efficiency of equipment by pinpointing the heat earlier (Braunovic et al., 2009).

## 1.3 Scope of the Research Work

Infrared thermography senses the heat produced in the electrical installations. The thermal profiles of different electrical installations and connectors are captured by using thermal imager. The thermal profile which is called thermogram consists of a thermal picture and a temperature scale. The different colors of temperature scale represent the different temperature spots of the equipment.

Power system consists of many kinds of electrical equipments such as circuit-breaker, transformer, lightning arrester, capacitor, bushing, bus bars and insulator and so on. However in the present study, we will concentrate on the defect occurring in circuit breaker. Line and load side conductor heated, loose/dirty bolted connection and internal CB contact problems on three phase circuit breaker are considered as the problems of CB.

Abnormal heated component is generally detected as red or brighter coloured area in an infrared image. In the grey image, the abnormal heated area of equipment will be illustrated as either a cluster of bright pixels and the area is defined as hot defect. Although infrared inspection can detect cold defect indicating dark pixels, in this thesis, the inspection will focus only the hot defects, which are very common effect in the equipment.

In the current practice, the interpretation of the thermal image for detecting defect and classifying the defect condition level are done manually. However, manual heat detection and thermal condition classification technique do not show good performance due to the slow process and human errors. Some experiments on automated or semi-automated thermographic screening using computer aided visualization and intelligent diagnosis have already been developed to increase the electrical system diagnostic performance. But most of the existing studies use manual feature extraction technique and unattractive features for interpretation of defect. Therefore, further interpretation is required to extract more useful information from the defect of equipment. In this study, the feasibility of some automatic extracted statistical features for identifying defect in breaker will be evaluated.

Applying intelligent condition monitoring of equipment could improve the defect detection technique with quicker and accurate reading even expert or experienced personnel are not present. This thesis proposes a semi-automatic and computer aided approach for defect detection. It is also embedded with an intelligent thermal condition monitoring of equipment through automatic feature extraction technique.

## 1.4 Objectives of Research

The main objective of this research is to develop an intelligent thermal condition monitoring system of equipment using infrared thermography technology. The system uses multilayered perceptron neural network and image processing technique. As a result, the system would be automatic, precise, reliable, robust and easier to use. In order to implement intelligent monitoring system, the proposed automatic features extraction system investigates the suitable features from thermal image of equipment. After that the condition monitoring system classifies condition of electrical hot component using neural network. The objectives of this research can be given as follows:

- To detect the hot defect of circuit breaker and extract first order histogram based statistical and grey level co-occurrence matrix features automatically from the segmented defected area of that equipment. This introduces a new application for statistical features in the analysis of hot defect in electrical equipment.
- To find out the useful and important features for thermal condition monitoring of components using two feature selection techniques namely principal component analysis (PCA) and discriminant analysis (DA). Then classify the condition using neural network.
- To analysis the individual performance of each extracted feature and select suitable features for classifying the condition using neural network.
- To develop a computer aided intelligent condition classification system that contains computer aided ROI segmentation, automatic intensity features

extraction and intelligent classification using multilayered perceptron networks.

## 1.5 Thesis Outlines

This thesis consists of five chapters. Chapter 1 presents an introduction of the infrared thermography and the necessity of IRT as the thermal condition monitoring of electrical equipment is mentioned, followed by the scope, objectives and outline of the thesis. In Chapter 2, a comprehensive literature review on the principle of infrared thermography, advantages and disadvantages of IRT, inspection modes and various applications of IRT will be discussed. The defects in electrical equipment and their monitoring and the methodology of classification are explained. In addition, a brief description of the image processing and intelligent classification system in infrared thermographic inspection of equipment will be reviewed at the end of this chapter. In the Chapter 3, the methodology of the proposed defect detection, feature extraction and suitable features selection will be described. In the Chapter 4, a semi-automatic approach for thermal condition monitoring of circuit breaker will be proposed. The system uses suitable features chosen by using PCA, DA, individual feature performance analysis. After that an intelligent thermal condition classification using multilayered perceptron networks is proposed. Finally, Chapter 5 highlights the conclusions and contributions of this research. Some of the future works are also suggested at the end of thesis.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

The chapter begins with the history and basic principles of IRT, its inspection modes, advantages, disadvantages and some applications of IRT in various fields. The defects in equipment and manual diagnosis system are also described. Then the chapter deals with a literature study on the applications of image processing and intelligent condition classification in existing thermographic inspection techniques.

## 2.2 Principles of Infrared Thermography

In 1800, Sir John Hershel conducted an experiment and found that the area having the highest temperature contains the most heat in a form of light beyond red light. Thus he discovered infrared radiation. The experiment was essential, not only due to discover infrared radiation, but also it showed that this form of light is visible to human eyes.

Electromagnetic radiation propagates from the intermolecular oscillation between electrostatically charged particles (i.e. electrons and neutrons) of a object having temperature above absolute zero (-273°c or 0k) (Azmat & Turner, 2005). Electromagnetic spectrum can be classified according to the wavelength and distance between the successive peaks of oscillations of electromagnetic fields as radio transmissions, microwaves, infrared, visible, ultra-violet lights, x-rays and gamma rays (Griffith et al., 2001).

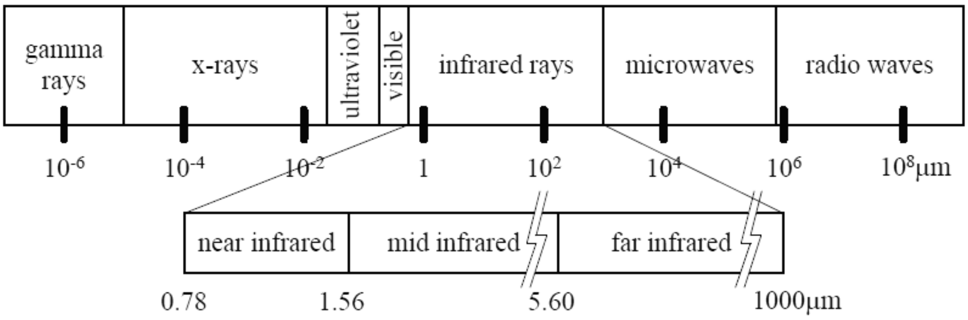


Figure 2.1 Electromagnetic spectrum (Braunovic et al., 2007)

Actually the heat transfer in an object is caused by thermal radiation. Intensity of thermal radiation emitted from an object determines the temperature of that object. The warmer the object, the more infrared radiation it emits. The wavelength of infrared radiation falls in the region of 0.78 to 1000μm (microns). This wavelength range can be further sub-divided into three regions: near infrared (wavelengths 0.78 to approximately 1.56 μm), middle infrared (wavelengths 1.56 to approximately 5.60 μm) and far infrared (wavelengths 5.60 to 1000 μm). Figure 2.1 shows the spectrum of electromagnetic radiation.

The characteristic of diagnostic system depends on the basic thermal radiation laws namely Kirchhoff's radiation law, Plank's law and Stefan-Boltzmann law. Kirchhoff's thermal radiation law describes the relationship between absorption and emission of thermal energy of an object is proportional i.e. in thermal equilibrium for an object emissivity equals to absorptivity. A blackbody is an imaginary perfect absorber having no property of reflecting thermal radiation and the spectrum of blackbody radiation can be described by Plank's law. Thermography is based on the emission of radiant energy which is described by emissivity. Emissivity is defined as the ratio of radiation intensity of a non-black body to the intensity of a blackbody (Lindquist & Bertling 2008) which is expressed as

$$\varepsilon = \frac{E_0}{E_b} \quad (2.1)$$

where, $\varepsilon$ is the emissivity of the object surface, $E_0$ is the non-blackbody radiation intensity and $E_b$ is the blackbody radiation intensity. Stefan-Boltzmann law describes the amount of emitted radiation per unit surface area and is given by

$$R(t) = \sigma\varepsilon T^4 \quad (2.2)$$

where $R(t)$ is emitted energy per unit surface area of equipment in W/m$^2$, σ is Stefan-Boltzmann constant (= $5.67\times10^{-8}$ W/ (m$^2$·K$^4$)), $\varepsilon$ is the emissivity and $T$ is the absolute temperature of the equipment in Kelvin. So, the temperature of the object depends on the emitted energy. The IR energy emitted by the object is sensed by infrared detector and converted it into electrical signal. The monitor displays the object thermal image with a temperature scale. This image is commonly known as thermogram. Thermal image is captured using an infrared camera.

## 2.3 IRT Inspection Modes

There are two modes for capturing thermogram of an object. One is active thermography and another is passive thermography. In active thermography, during capturing the thermogram, an external heat source (generally flash lamp or pulse generator) is supplied. The active thermography is required in many applications where the inspected parts are typically in equilibrium with the surroundings. Therefore, by applying the external heat source, the infrared camera can distinguish the difference between two surface areas. On the other hand, in passive thermography, no external heat source is supplied when capturing the thermogram since the temperature difference between defective and sound area is so obvious. Figure 2.2 shows the configuration for the two modes of IRT.

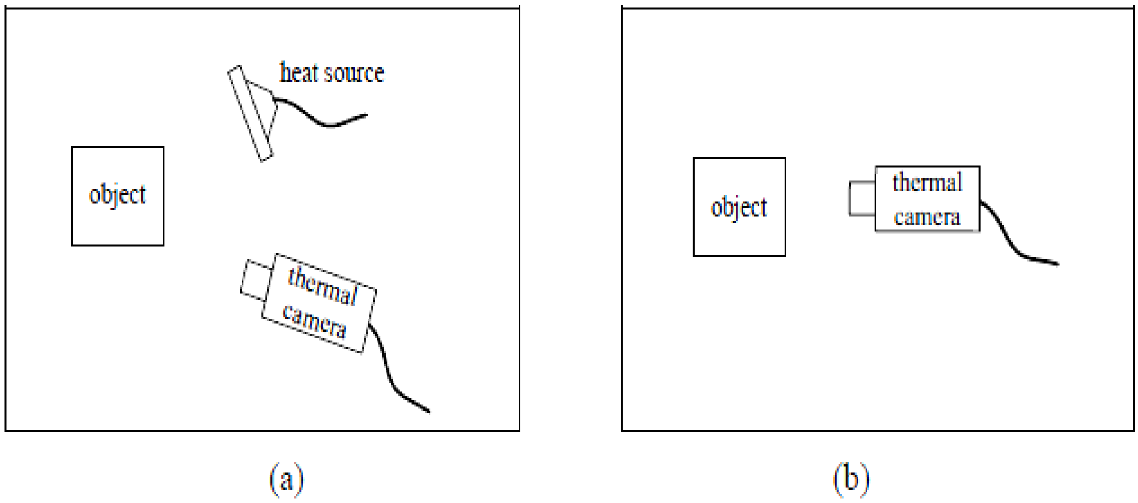


Figure 2.2 Thermographic inspection modes (a) active (b) passive

## 2.4 Advantages and Limitations of IRT

Now-a-days infrared thermography is being utilized in many applications due to its various advantages. Some of the advantages and also limitations are described in this section.

i. Time saving fast thermal condition monitoring system (in the ms range). Thermographic inspection can identify the defect of equipment quickly and accurately under normal loading condition.

ii. Thermography is a non contact remote sensing diagnosing system and does not have any risk to be injured of living body or damaged of target equipment. Since infrared rays are harmless to living body (Inagaki et al., 1999).

iii. Temperature measurement of the moving objects

iv. No risk of contamination and no mechanical effect on the surface of the object

v. Temperature measurement of hazardous or physically unreachable objects (high-voltage equipment)

vi. Non-contact inspection, no heat energy is transferred from the object to camera. Also it does not interfere the system operation.

vii. View of defect in equipment and results relatively easy to interpret (image format)

On the other hand, limitations are as follows:

i. Cost of the thermal cameras are very high

ii. Target object must be optically (infrared-optically) visible to the IR thermometer. High levels of dust or smoke make measurement less accurate.

iii. Equipment inside of the container or box cannot be measured from the outside

iv. Unable to detect the inside temperature if the medium is separated by glass/polythenematerial etc.

## 2.5 Applications of IRT

For several years, IRT technology has been successfully utilized in various fields. Some of the applications of IRT are briefly described below.

### 2.5.1 Medical Applications

IRT is being utilized as an early diagnostic tool for diseases due to abnormal temperature pattern of different organs. In medical thermography, IRT is widely used for diabetic neuropathy, vascular disorder breast cancer detection, thermoregulation study, fever screening, brain imaging (thermoencephaloscopy), dentistry and dermatology, muscular pain and shoulder impingement syndrome study, diagnosis of rheumatologic diseases, dry eye syndrome diagnosis, treatment of parasitic liver diseases, detection of metastatic liver disease, bowel ischemia, renal transplantation, heart treatment, and gynecology. IRT has been used in acupuncture treatment, cryotherapy, forensic medicine and assessment of radiation damage to human body also. A details description of medical thermography will be found in (Lahiri, 2012).

### 2.5.2 Building and Infrastructure

The IRT technology has been applied to the buildings for enhancing the building performance by monitoring early age temperature of different construction and building materials. IRT can be used to examine the heating system and to detect insulation defect, air leakage, heat loss through windows, dampness and defects in subsurface pipes, flues, ducts, wall ties, etc. (Balaras & Argiriou, 2002; Barreira & de Freitas, 2007). Some examples include the location of missing, improperly installed or damage cable, thermal bridge, costly air leakage around opening, moisture damage and detection of crack in concrete structure etc (Azenha et al., 2011; Clark et al., 2003).

### 2.5.3 Mechanical Inspection

The IR inspection is used to identify the defects in HVAC installations and rotating equipments. For instance, the defects in mechanical couplings on rotating equipment, bearings, compressor heads, friction in drive gears and drive belts, air ducts, heat distribution pipes, air supply inlets and outlets are monitored. Thermal fluid installations such as boilers, vapour lines, valves, reactors, heat exchangers of refrigerating systems can be monitored and diagnosed with IRT to ensure proper operating system (Al-Kassir et al., 2005; Chunli et al., 2005; Ge et al., 2011). Also thermography is applied to detect defect in thermal barrier coating which is used in gas turbine and diesel engine applications.

### 2.5.4 Electrical Equipment Inspection

Infrared thermography can detect the thermal defect of electrical equipment (Jadin & Taib, 2012). Some common defects in electrical system will be described in Section 2.6 .

Moreover, IRT technology is being utilized to test materials such as cables, wires, resistors, printed circuit boards etc during production in a closed and controlled environment (Kaplan, 1999). The technology is used to detect the defects in crack on square steel bars in the automotive industry. Various applications such as the defects detection of polyethylene pipe welding, for inspection of airport pavements, non-destructive evaluation of joints, quality monitoring of AWJ cutting, defect assessment on radiant heaters, fatigue evaluation, damage assessment and diagnosis of orthopaedic diseases of animals are also being conducted using IRT.

## 2.6 Defects in Electrical Equipment

Electrical installations such as transformer, circuit breaker, fuse, capacitor etc can cause faults when its internal temperature reaches at abnormal level (Cao et al., 2008; Hou, 1998). According to the thermographic inspection performed during the period from 1999 to 2005 (Lizak & Kolcun, 2008), it was found that most of the problems (48%) were associated with conductors connection accessories and bolted connections including problems in bimetallic surface contacts, dirt, oxidization and non-adequate utilization of inhibitory grease. It is also shown that 45% of the anomalities emerged in disconnectors arising from defected contacts by deformations, deficient pressure of contact, incorrect alignment of arms and dirtiness. Only 7% of the anomalities were found due to other reasons in the electrical equipment.

Most of the anomalies are due to various reasons such as contact problems, unbalance current distributions, cracks in insulators, defective relays and terminal blocks, etc. Some of the examples of the defects in electrical system which can be revealed by thermographic technology are as follows:

**a) Transformers**

Heat is generated due to the losses in transformer and temperature increases within the core and windings. The transformers are generally cooled by either oil or air and the operating temperatures are higher than ambient. The cooling system helps to maintain the rise of temperature within tolerable limits. Actually thermographic inspection is utilized for thermal defects diagnosis of oil-filled transformers instead of dry transformers. Since the coil temperatures of the dry transformers are so much higher than ambient, it is not easy to identify the internal defects before it becomes serious. Therefore, other monitoring tools including built-in temperature and pressure gauges can perform more accurate measurement for the dry transformer. In the oil-filled transformers, thermographic inspection usually detects the defects occurring at primary and secondary bushing connections, cooling fins, cooling fans, internal bushing connections, etc.

**i) Primary and Secondary Bushing Connections**- The loose or dirty connections, unbalance and overloading problems can cause overheating in the connections. Thermographic inspections show hotspots at the defected phase connection compared to other phases.

**ii) Cooling Fins-** In an oil-filled transformer, cooling is provided by the circulation of oil. The oil gets heated due to the heat generated in the core and windings. Therefore, cooling fins normally appear warm compared to the inactive cooling fin. From the thermal image, if it is seen that one or more fins have comparatively low temperature or cool compared to other warm fins, then it can be concluded that the circulation of oil is being limited in those fins, probably due to the low oil level.

**iii) Cooling Fans-** In higher rating transformer where more heat will be generated, cooling fans are used to increase the cooling rate. In general, the fan in action is normally warm and thus thermogram will show whether it is working or not.

**iv) Internal Bushing Connections-** If there is any defect in the connections, it will be higher temperature than surface temperature.

**b. Defects in Circuit Breaker**

A circuit breaker (CB) always senses the fault current, instantly opens the circuit automatically and protects the electrical installations from damage. Thermographic inspection has the advantages to find the abnormalities by analysis the surface temperature variations of circuit breaker and can prevent these abnormalities earlier.

**c. Fuse Connection**

Fuses are used to protect the system against overloading condition. Overloading condition in a system can increase fuse connection heating and moreover, the fuse clips can be overheated due to the loose and dirty connections.

**d. Defects in Contacts**

Electrical connection switches, breakers and other reclosing devices operate with contacts. If these contacts become loose, oxidized, dirty or anyhow increase in resistance, then the defect can be occurred in the contacts.

**e. Insulation Problems**

Insulation failure can cause short circuit current between two conductors. Overcurrent generates overheating and allows the circuit breaker or fuse to open. Poor insulation can also cause overheating.

**f. Utility Connection Box Break Elbows**

In residential areas, many underground connection and switching locations are in utility box enclosures. Normally break elbows provide a point of disconnection and if these break elbow connections are not installed properly or connection resistance increases and faults can occur.

**g. Surge Arrestors Problems**

Problems with surge protection and lightning arrestors leaking to ground and current tracking over insulators can also be detected using thermography. However, finding such problems requires the capture of subtle temperature differences which are often too difficult to be monitored.

## 2.7 Overheating Monitoring Using IRT

Thermographic inspection technique for electrical equipment is a fast and safe in identifying the faults. However, the present study concentrates about general faults overheating diagnosis system of circuit breaker. The major causes of overheating in circuit breaker are loose or oxidized connections, load imbalance, overloading, contact problems, wiring mistakes, insulation faults, harmonics etc.

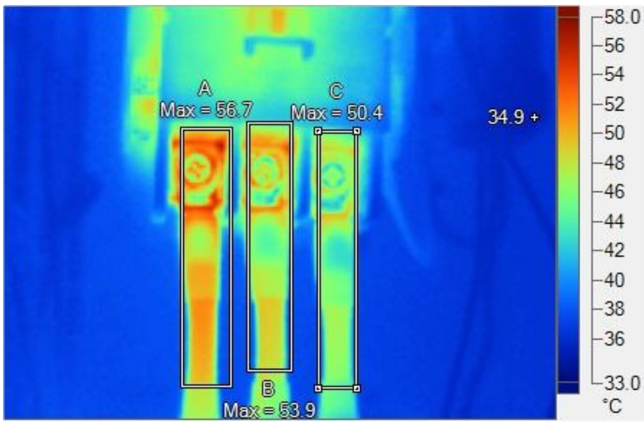


Figure 2.3 Circuit breaker having problems in connections ( Phase A)

The main causes of loose or poor connections include the continuous loading, vibration and aging. Various environmental conditions such as high surrounding temperature, dirt in the air and chemicals reaction can increase the speed of corrosion. However due to the connections problem, there is an increase in resistance at the faulty spot. Increasing resistance also increases the heat at the connection. Thermographic inspections can easily reveal the faults. In a three phase system, under the same loading condition, all the phases should show the same thermal characteristics. Abnormal or dissimilar thermal characteristics at the connections of phases identify the poor or corroded connection. Figure 2.3 shows a circuit breaker having poor or rust connections problem. Through the inspection, it reveals the connection at phase A is warmer than other phases.

Imbalance of current distribution to the loads is defined as load imbalance or overloading. It is found that the current imbalance is the primary reason of voltage imbalance. The major causes of electrical unbalance are caused by unequal distribution of single phase load, unbalanced incoming power supply, unequal impedance in power supply cables, insulation resistance breakdown, etc. Under the same loading condition, each phase should have same load and heating condition. But in an unbalanced load situation, the more heavily loaded phase(s) will show hotter pattern than the others, due to the more heat generated. However in most of the electrical operation, an unbalanced load, overloading, poor connection and harmonic imbalance can also create a similar temperature pattern. Thermographic inspection is a simple way to identify these kinds of faults. In a three phase system, the unbalance or overloading problem can be identified by comparing the temperature patterns of the phases. Figure 2.4 shows a circuit breaker having overloading or unbalance loading problem where the phase B is shown to be warmer than the other phases.


Figure 2.4 Circuit breaker having overloading at B phase

In some cases overheating of equipment can be caused due to the insulation problem of conductors. In this problem, two conductors are short circuited and overcurrent flows into the fuse or circuit breaker (CB) to protect the device. But if the fuse or CB fails to operate, the circuit will be overheated. Harmonics distortion and wirings mistakes in the relays and switches can also cause overheating in equipment. Therefore thermography can be the solution to find out the problem and diagnosis the faults before the ultimate failure of the equipment.

## 2.8 Classification of Thermal Condition of Equipment

For classifying the thermal conditions, three approaches are available.

Firstly, evaluating the maximum temperature for defected and reference region and determined thermal condition based on $\Delta T$ criteria, while maximum temperature region carries the highest pixel value of that region.

Secondly, using histogram or histogram distance for evaluating the similarity between defected and reference region.

Thirdly, analyzing the gradient of the segmented defect region (Smedberg, 2006).

First one i.e. classification based on the evaluation of maximum temperature is usually used for monitoring the conditions. There are two methods for measuring temperature of the component. One is quantitative method and another is qualitative method. In the quantitative method, the exact temperature value of the target object is used. This method is often affected by the environmental factors such as ambient temperature, wind, humidity and emissivity etc. Therefore, for getting accurate temperature, the surrounding variables should also be considered. On the other hand, the qualitative method accounts the relative temperature of a hotspot with respect to other normal part (reference) of the equipment with the similar conditions. The technique is widely used for electrical thermography due to its simplicity and minor influencing by the emissivity. The main drawback of this technique is that it does not work, if in a three phase system, all phases show overheating at the same time which is very infrequent condition in electrical system.

Therefore, the qualitative classification method is briefly known as ΔT (temperature difference) factor analysis (Gill, 1998). This ΔT factor is defined as the increment of temperature of the equipment with respect to a defined reference, which is typically the ambient air temperature, a similar component under the same loading condition or the maximum allowable temperature of the component (STD, 2011). ΔT factor can be calculated by comparing the hotspot and the reference spot temperature and it is widely used for condition monitoring of equipment. The hotspots support temperature of faulty components having temperature more than reference spot, where reference spot is the same type, load or same repeated component of the equipment having the minimum temperature.

A number of standards and professional organizations have established ΔT criteria for determining the necessity and urgency for preventive maintenance or repair. There are several standards for ΔT factor analysis namely InterNational Electrical Testing Association (NETA) (STD, 2011), American Society for Testing & Materials (ASTM) – E (ASTM, 2005), National Fire Protection Association (NFPA) – NFPA 70-B (NFPA, 2006) etc. Table 2.1 shows the NETA specification for electrical thermography.

Table 2.1 InterNational Electrical Testing Association (NETA) Maintenance Testing Specifications (NETA MTS-1997)

| Priority | ΔT(Similar Components) | ΔT(ambient) | Recommended action |
|---|---|---|---|
| 4 | 1-3°C | 1-10°C | possible deficiency; warrants investigation |
| 3 | 4-15°C | 11-20°C | indicate probable deficiency; repair as time permits |
| 2 | -------- | 21-40°C | Monitor continuously until corrective measures can be accomplished |
| 1 | >15°C | >40°C | major discrepancy; repair immediately |

## 2.9 Image Processing in Electrical Thermography

Image processing (Jadin et al., 2011) is the most important part for identifying defect, feature extraction and automatic classification of thermal condition of defected component of electrical equipment. Both bottom-up and top-down strategies are used to find the region of interest. But the traditional bottom-up approach is commonly used due to its simple implementation. Image processing consists of several steps including image pre-processing, segmentation and different features extraction for classifying the thermal conditions (Castleman, 1996). This section will actually discuss the bottom-up and top-down approaches that have been used in the previous works for identifying the hot defects of electrical installations.

### 2.9.1 Image Pre-processing

In the beginning of image processing, image is pre-processed by converting from color image (infrared thermal image) to greyscale image that carries the intensity information at each pixel of the image. Greyscale image is often called the monochromatic or 'black and white' image, while the black and white imply the