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Application of infrared thermography for predictive/preventive maintenance of thermal defect in electrical equipment

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HIGHLIGHTS

- Intelligent thermal defect detection using infrared thermography.
- Use of statistical features as inputs of classifier.
- Applications of MLP network and discriminant analysis as classifier.
- Selection suitable features using discriminant analysis.
- Classification accuracy up to 82.40%.

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ABSTRACT

Internal heat of electrical equipment rises due to various reasons such as contact problems, unbalance loading, cracks in insulation, defective relays or terminal blocks, etc until eventual failure which can cause unplanned outages and possible injuries. Therefore, early prevention of thermal abnormalities in electrical equipment is necessary to avoid failure. Nowadays a fast, reliable, non-contact and cost effective infrared thermographic inspection system is being utilized widely for detecting where and how internal and external defects occur in equipment. The system collects data for investigating thermal condition through the analysis of thermal image of equipment. The image is captured by infrared camera without interrupting the running operation of system. Both preventive and predictive maintenance programs are adopted for defect diagnosis. Actually, the frequency and sequence of thermographic inspection depend on various factors including thermal condition, expense of a failure, type of production and age of equipment, etc. The objectives of this article are to discuss about preventive and predictive maintenance, thermal defects in electrical equipment and also an intelligent thermal defect identification system for accelerating the predictive defect diagnosis technique. The intelligent system proposes the application of artificial neural network and statistical features to detect the existence of defect within equipment by monitoring its thermal condition. Using discriminant analysis, the optimum features were chosen as the inputs of the neural network. The performances of the neural network were compared with the performances of discriminant analysis classifier. The comparison results showed that discriminant analysis classifier produced better performance with accuracy 82.40%.

1. Introduction

All objects with a temperature above absolute zero emit infrared radiation and cause an increase in temperature. The naked eyes cannot see the infrared energy because it is emitted as heat energy. Infrared thermography is a technique for converting invisible heat into a visual image which shows the heat picture of the object surface. The colour of the object surface in the heat picture varies with the surface temperature. An infrared camera or sometimes called thermal imager is used to capture the heat picture and measures temperature variation of the object surface [1,2]. For several years, thermographic inspection has become an important tool for preventive and predictive maintenance of surface defect in various materials due to its non-invasiveness, safety and relatively low cost approach. Therefore, numerous studies were executed to prove thermography as a useful technique in various applications [3–11].

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 proportional to the square of the current passing through it and resistance (I^2R Loss). Therefore, an increase in electrical resistance results an increase in

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heat. With the time and age, the condition of the electrical component gets deterioration due to various reasons such as loose connection, corrosion and insulators crack, etc. As component deteriorates, its resistance increases and also generates more heat. The increase in heat energy can cause the failure of electrical equipment and also fire may break out. By utilizing thermography for inspecting the equipment under loading condition, the defective component can be identified and classified by its level of severity [12].

Infrared thermography senses the heat which is produced in the electrical equipment. The thermal profiles of electrical equipment and connectors are captured by using a thermal imager. Thermal profile which is also called thermogram consists of a thermal picture and a temperature scale. The different colours of temperature scale represent the different temperature spots of the equipment. Heating components are generally detected as red or brighter coloured areas in an infrared image. A circuit breaker (CB) thermogram obtained in the present study is shown in Fig. 1. In Fig. 1a, the brighter area (R phase) indicates the higher resistance and results overheating of that phase. The probable reason of this high resistance could be a bad or dirty connection. Fig. 1b shows the temperature profile across the line L0 showing the variation of temperature in the equipment surface. Thus defects in components are identified and then recorded. Finally, the maintenance programs are planned and carried out before breakdown of equipment.

Maintenance cost of electrical equipment plays an important role for reducing the total operating cost of electrical power system. The maintenance cost can be increased due to the lack of information about the maintenance scheduling and kind of maintenance needed for the equipment. Typically, the operating performance of electrical system is not monitored periodically which can play an important role in early prevention of a fault and for increasing the life of equipment. Instead, the schedule for maintenance is determined by using the failure history of equipment or according to the experiences of maintenance personnel. Infrared thermography is used to monitor the performance of equipment which offers a complete information regarding the operating status of equipment for increasing production, decreasing or removing unnecessary repairs, preventing eventual failure and decreasing the maintenance cost of equipment.

Usually, applying infrared thermography technology, the electrical thermal defect and level of defect are identified by monitoring its Delta T (ΔT) criteria [13]. The technique is widely known as qualitative based temperature measurement system [14]. The Delta T criteria of a component is defined as an increase in temperature value above the temperature of a reference value, which is typically the ambient temperature, temperature of a similar component under the same condition or the maximum allowable temperature of the component [15]. Several standards for ΔT value are found such as Electrical Testing Association (NETA) [15], National Fire Protection Association (NFPA) – NFPA 70-B [16] and InterNational American Society for Testing & Materials (ASTM) – E [17], etc. Sometimes thermographers prefer to classify thermal condition based on their own inspection experiences instead of using the available standards.

Artificial neural networks (ANNs) are potentially powerful, robust and adaptive mathematical model for pattern recognition and classification [18,19]. Nowadays ANNs are being utilized to solve complex non-linear real world problems. Several articles about the application of artificial neural networks (ANN) for electrical fault diagnosis system using infrared thermography have been proposed in the past few years. In these articles, different features were used as inputs of ANN. Almeida et al. [20] used a neuro-fuzzy approach for fault diagnosis of lighting arrester while the inputs of the ANN were thermographic and identification variables. The system achieved resulting index of wrong diagnosis lower than 10% for classifying thermal condition into normal, suspicious and faulty classes. Shafi'i and Hamzah [21] proposed the application of multilayered perceptron network. The RGB colour scale data and temperature data were used to classify internal faults into four classes namely low, intermediate, medium and high. The result obtained 99.38% of accuracy. Rahmani et al. [22] developed an intelligent system applying support vector machine (SVM) as a classifier and 22 image features of Zernike moments for diagnosing of ground substation faults. The diagnosis was carried out on 20 thermal images and was able to obtain 68.42% of accuracy. Smedberg [23] and Wretman [24] proposed an intelligent classification system based on ANN for diagnosing three-phase fuses and different forms of connections problems. The four input parameters of ANN were used which are absolute maximum temperature, relative maximum temperature, mean temperature difference compared to the other regions of the image and histogram distance to the other regions of the image. The test error rate using all four feature parameters as input of ANN was 9.5% and the error rate using only the histogram distance as input was 31.2%. The set of data was 74 infrared images. One of the disadvantages of working with a small dataset is that the reliability of the results can sometimes be questionable.

This paper will investigate the application of infrared thermography technology as predictive/preventive maintenance program to identify the presence of thermal defect in electrical equipment. The technique uses multilayered perceptron network, statistical features and discriminant analysis classifier to characterize the thermal status of hotspot into 'defect' and 'no defect' categories. Discriminant analysis classifier was utilized to select

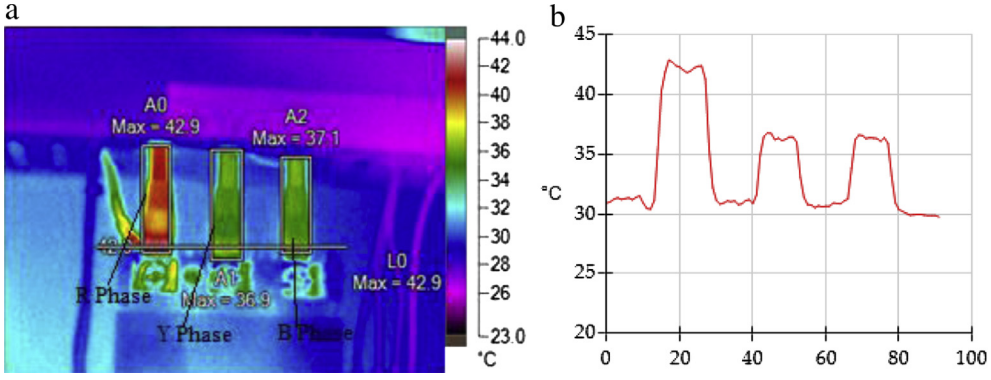

Fig. 1. a. Thermogram of R phase overheating in CB b. Temperature profile across line L0.