Electrical Power and Energy Systems 63 (2014) 753–759

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Design of early fault detection technique for electrical assets using infrared thermograms

Zainul Abdin Jaffery, Ashwani Kumar Dubey *

Department of Electrical Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi, India

A R T I C L E I N F O

Article history:
Received 4 September 2013
Received in revised form 23 May 2014
Accepted 16 June 2014
Available online 16 July 2014

Keywords:
NIOLVIS
NIRTVMS
Power transformer
Segmentation
SOI
Thermogram

A B S T R A C T

Infrared thermography is a non destructive temperature measuring technique, widely used in agriculture, process industries, manufacturing, pharmaceutical industries, and construction industries to detect anomalies, to predict possible faults, or to check the quality of the object. In this paper, two systems, real time and off line, are proposed to monitor the temperature variations and analyze hot regions in the electrical assets using infrared thermograms. This novel technique helps to prevent the electrical assets before any catastrophe would happen in the future. The color based segmentation technique is used to blotch hot regions in the thermograms of electrical systems. A redness area based algorithm is also proposed to analyze the hot regions and also to estimate rate of change of hotness in electrical assets for early detection and prediction of faults.

Introduction

Recently, the infrared (IR) thermograph technology has gained more recognition and acceptance due to its non-contact and non-destructive features of inspection. It is a fast and reliable inspection system that operates without interrupting the running operation of power system. In IR thermograph based technique, fault diagnosis is performed through the analysis of thermal image captured by infrared camera. It is implicit that the life of electrical equipment is radically reduced as temperature rises. Thermogram based temperature measurement technique offers many advantages such as prompt response times, ample temperature ranges, highly reliable, harmless, high spatial resolution, and very lucrative approach for the monitoring of electrical power systems.

The thermogram is solely based on the heat distribution in the system. The image segmentation from the thermograms becomes complex due to its low intensity contrast and over-centralized intensity distribution. The extraction of the hot region within a thermogram is an exigent task, particularly if the image has low signal to noise ratio (SNR) and complex background.

In this work, the non invasive infrared image based visual monitoring and controlling systems are developed for both, real time and off line applications. The real time application may include the continuous monitoring of electrical machines such as power transformers, induction motors, and synchronous motors. Whereas, off line monitoring includes: inspection and analysis of electrical contacts, excessive current drawn, fuse cabinets, imbalance loads, inductive heating, corrosion, defective components, feeder poles, capacitor banks, generator controls and transfer switches, main incoming line electrical panels, motor control centers, cables and bus bars. The off line monitoring of the electrical systems can be done through regular thermographic inspections under operational conditions to identify problem early and avoid expensive equipment failure.

Related works

As an upshot of liberalization, investments in new electrical power system equipment have radically declined over the past 20 years. Many transformers are working well beyond their anticipated life and are operating under escalating stress. As load is growing, new generation and economically aggravated transmission flows push equipment to work beyond the specification. As a consequence, new techniques must be explored to allow electrical equipment to better fit under such circumstances and also be economically acceptable and reliable [1,2]. The major flow of cost involved in the monitoring of power grid to ensure quality and uninterruptable supply of electricity [3]. The equipment on which whole grid system depends is transformer and the monitoring of transformer in efficient way is still a big task. In most of the existing systems, monitoring of transformer is done through the dissolved gas analysis (DGA) technique [4,5]. But this technique requires an

* Corresponding author. Tel.: +91 9953289235.
E-mail addresses: zjaffery@jmi.ac.in (Z.A. Jaffery), dubey1ak@gmail.com (A.K. Dubey).

http://dx.doi.org/10.1016/j.ijepes.2014.06.049
0142-0615/

exhaustive and costly procedure to detect faults. Few mathematical models [6] and fuzzy rule [7] based techniques are also proposed to identify the faults, but, these techniques are also requires some measured data to interpret and predict. Therefore, the non invasive temperature monitoring of transformers [8] and electrical assets with less complexity and high reliability is a prime requisite with existing system to overcome the maintenance cost and revenue loss during break down of the system. The infrared (IR) imaging technique makes non invasive type monitoring systems more reliable for prophecy of temperature of electrical assets [9,10]. The IR techniques are also being used to monitor house hold electrical equipment and wirings [11], determination of hydro generator efficiency [12], real-time thermal monitoring of induction machines [13], measurement of excitation winding temperature in synchronous generator [14], and real time high temperature measurement in control industry [15]. The design of visual inspection system (VIS) [16–20] based on charge-coupled device (CCD) and complementary metal oxide semiconductor (CMOS) cameras are already into existence for the monitoring of different processes, objects, sorting, and quality check but designing VIS based on IR camera are very less.

In most of the papers discussed above, only invasive or pointed temperature is observed or measured and no non-invasive monitoring and controlling systems were proposed or developed. But, in our work, two IR imaging based visual monitoring and controlling systems: Non Invasive Off Line Visual Inspection System (NIOLVIS) and Non Invasive Real Time Visual Monitoring System (NIRTVMS), are proposed for off line and real time applications respectively. The proposed systems have capability to estimate area of the hotspots in the electrical assets and take decisions accordingly to keep other part of electrical systems healthy. The proposed algorithms are simulated for a large number of thermogram images of electrical assets and their performance are analyzed using statistical and geometrical features. The simulation is done on MATLABR2012a.

Non Invasive Off Line Visual Inspection System (NIOLVIS)

The process flow block diagram of NIOLVIS is shown in Fig. 1. This NIOLVIS includes an infrared image acquisition system, threshold and color based segmentation, feature extraction and marching, and generation of control signals according to characteristics of image.

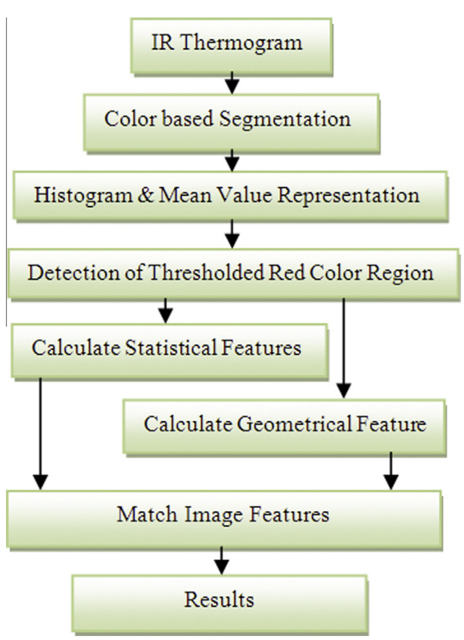

Fig. 1. Process flow block diagram of NIOLVIS.

Thermogram image segmentation

In NIOLVIS the thresholding with smoothing technique is applied for segmentation [19–26] of surface of desire from thermograms to explore the regions with abnormalities in the electrical systems. The mathematical representation of thresholding is given by (1):

$$L(i,j) = \begin{cases} 1; & \text{if } T(i,j) > \rho \\ 0; & \text{if } T(i,j) < \rho \end{cases} \tag{1}$$

where $T(i, j)$ and $L(i, j)$ represents original and thresholded images respectively and ρ is the specified threshold value. This segmentation results the image into binary form, where, 1 represents the desired color region and 0 the undesired color region. Otsu method [27] is used for automatic selection of threshold value for effective segmentation of infrared image colors because this method does not depend on modeling the probability density functions and assumes a bimodal distribution of gray-level values. Also, in this method, only zeroth and first order cumulative moments of the gray level histograms are used and integration based optimal threshold is selected. The optimal threshold value is estimated using (2) as follows:

$$\rho_{OT} = \arg\max\left\{\frac{P(\rho)[1-P(\rho)][\mu_1(\rho)-\mu_0(\rho)]^2}{P(\rho)\sigma_1^2(\rho)+[1-P(\rho)]\sigma_0^2(\rho)}\right\} \tag{2}$$

where ρ_{OT} = optimal threshold value, μ_1 = mean values of desired foreground image, μ_0 = mean values of undesired background image, σ_1 = standard deviation of desired foreground image σ_0 = standard deviation of undesired background image. Also, $P(\rho)$ used in (2) is calculated by (3) and (4).

$$\text{Cumulative probability } P(\rho) = \sum_{k=0}^{\rho} p(k) \tag{3}$$

$$p(k) = \frac{f_k}{n} \tag{4}$$

where $p(k)$ = probability distribution of image histogram, f_k = frequency of gray level k, n = total number of pixel in the image.

In NIOLVIS, RGB color vectors [28] are used to get desired color range by estimating average from the RGB color space and the objective is to classify each RGB pixel in a given image having a color in the specified range.

Consider the average color as RGB vector $\boldsymbol{r}$ and $\boldsymbol{q}$ as any point in RGB space. The $\boldsymbol{q}$ will said to be analogous to $\boldsymbol{r}$, if, the distance between them is less than a specified threshold value $\boldsymbol{\rho}$. This similarity measure is estimated using Euclidean distance between $\boldsymbol{q}$ and $\boldsymbol{r}$ as given in (5).

$$\begin{aligned}\rho(\boldsymbol{q},\boldsymbol{r}) &= ||\boldsymbol{q}-\boldsymbol{r}|| = [(\boldsymbol{q}-\boldsymbol{r})^T(\boldsymbol{q}-\boldsymbol{r})]^{1/2} \\ &= [(q_R-r_R)^2+(q_G-r_G)^2+(q_B-r_B)^2]^{1/2}\end{aligned} \tag{5}$$

where subscript R, G, and B denotes the RGB components of vectors $\boldsymbol{q}$ and $\boldsymbol{r}$.

The smoothing [28,29] filter is used to remove noise and artifacts from an image prior to object extraction. This bridges the gap between curves and lines [30–32]. Smoothing filter is the average of the pixels contained in the neighborhood of the filter mask given by (6). As the mask is slid across the image to be smoothed, each pixel is replaced by the average of the pixels in the neighborhood defined by the mask. Consider, P_{ij} denotes the set of coordinates defining a neighborhood centered at (i, j) in an RGB color