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ANALYSIS OF ELECTRICAL AND THERMAL CHARACTERISTICS OF LOAD-RELAY CIRCUIT USING THERMAL IMAGING

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Abstract

Condition monitoring and maintenance of electrical equipments are very important matters as it has an enormous influence on daily life. Temperature inflation is a significant factor which concerns the performance of electrical equipment. In this paper, a method is proposed to compute a temperature of any point from acquired thermal image. Thermal camera is used for image acquisition which is a non-contact device. For the experiment, temperature profile of high-wattage resistors was analyzed. Current, voltage, power dissipation was measured theoretically and practically. The relation between electrical characteristics and thermal profile is analyzed by using thermal image processing. The results achieved from this study explains how electrical characteristics affect the temperature distribution. The results presented in this work can be helpful to estimate the safety limits so that electrical equipment can be protected from overheating and helps to diagnose the faults at early stages. This method can be valuable in preventive maintenance and it is safer than other contact methods.

Keywords: - *condition monitoring, electrical equipments, hotspots, high-wattage resistor*

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1. INTRODUCTION

In last few decades, there is a modern rapid evolution in advanced electrical power industry which involves electrical equipments with higher voltage and greater capacity. Electrical substations consist of transformers, conductors, insulators, lightning arresters etc. which operates continuously at all time all days at higher voltage. Most of equipments used in daily life solely depend on the continuous operation of these equipments [1]. Therefore, it is necessary to have safe and reliable operations in electrical substations.

Heat energy is a significant factor which has its impacts on operational reliability and performance of electrical equipments. Electrical current (I) passes through the resistive component and heat is produced. Therefore, as electrical resistance increases, a temperature of the component increases. Electronic component also generates heat as a result of their operation. Over the years, the condition of these equipments gets worsened due to several causes such as loose connection, corrosion and missing insulation etc. As component deteriorates, its resistance increases and causes a surge in heat. The rise in heat energy can cause the failure of electrical equipment and also fire may break out [2]. Another reason is that if the electrical device is operated at a much higher level than its admissible power level, it results in overheating leads to decrease in its lifespan and its working capability [3].

It is essential to take preventive care of electrical equipment so that undesired outages can be shunned and equipments will have a stable life. Regular condition monitoring of instruments has become a crucial factor because it gives benefits such as early warning about fault occurrence, defects detection and collecting data for thermal analysis. It offers budgetary maintenance, expands equipment's lifespan, improving safety and power handling capacity.

There are different methods and approaches which are used for condition monitoring such as surface analysis techniques, stress tests to detect deterioration of equipments. Different non-destructive techniques like X-ray tomography, Spectroscopy, Frequency response analysis, Vibration analysis and Acoustic sensor are employed [4]. Thermal imaging is one of the best non-contact, non-destructive method which can be used for fault detection. Also, thermal analysis can be performed based on data gathered during a regular examination, which gives valuable insights about equipment’s power handling capability and other fault-prone areas based on equipment’s heating patterns.

Thermal imaging has become effective, reliable and globally accepted method due to its numerous advantages. It is less susceptible to electromagnetic interference. With the thermal camera, we can visualize target equipment instantly, locate hotspots, can decide problem seriousness and save the images to a database for future reference. Thermal inspection can be done during regular working of a power station, complete shutdown of a power station is not required [5]. In power stations, temperature measurement of some interest points can be tricky to access or electrical instrument may be rotating, very hot, large or electrically live. As thermal imaging is non-contact technology, so it can work remotely. Therefore, thermal imaging is a well-adapted method for fault diagnosis and thermal analysis [6]. Several approaches have been used previously by authors

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for fault detection and thermal analysis. Different fault diagnosis methods like anomaly detection algorithm [1], color-histogram based feature extraction [9], K-means algorithm [10] and using segmentation methods for monitoring of electrical equipments [11]. Different feature extraction methods and neural networks are used for diagnosing faults of electrical equipments [3], [5]. Different thermal analytical studies were done based on thermal images [8], [12-15].

In this paper, a novel approach is proposed to compute a temperature of hottest points from a thermal image and presents results of experiments performed to find out a relation between temperature, current, power dissipation, resistance, voltage, time and hotspot area. This analysis can be helpful to understand the effects of overloading on electrical equipment. It may help to decide ideal current-voltage values depending upon measured temperature values so that electrical equipment can be protected from complete failure due to overloading incidents.

2. METHODOLOGY

The main goal of the work is to analyze the variations in temperature values with changing resistance. As resistance varies the amount of current flowing will also change. Variations in resistance have its effects on power dissipation and also on the area of hotspot. If the user discovers hotspot at a particular part on electrical equipment, it may be due to rise in resistance or voltage. The rise in temperature also symbolizes the increase in power dissipation. Therefore, user can take precautionary measures so that voltage, resistance, current and power dissipation should not exceed the predetermined level and equipment malfunction can be avoided.

2.1 Experimental Setup and Test Procedure

Thermal inspection is often carried out at electrical substations, building's meter room etc. But in this experiment for analysis the load-relay circuit was investigated. The circuit consists of four power relays, relay driver integrated circuit (ULN2803) and power supply port. Four different loads can be connected to four relays. When power supply gets on, relay gets energized and load will get current supply. Here, 100-watt bulb was used as a load. Before the load, high wattage resistor was connected in series. As current is supplied to load, it also flows through a resistor. The variation in temperature at resistor was observed. The schematic diagram of the circuits is shown in Fig. 1.

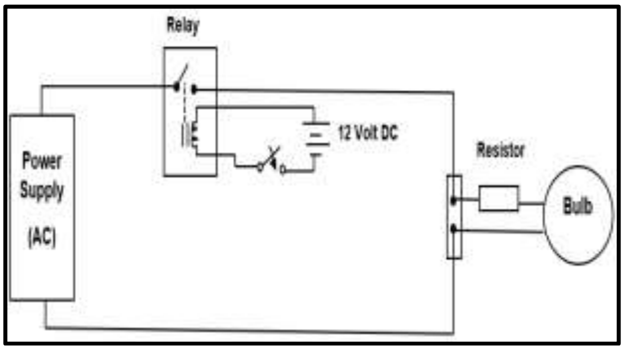

Fig 1: Schematic diagram of relay circuit

In the testing procedure, three different high-wattage resistors were used for the experiment:
1) 6.8 Ω, 10 watts 2) 25 Ω, 10 watts 3) 50 Ω, 10 watts.

Initially 6.8 Ω, 10 watts resistor was connected in series with the bulb. Three images were taken at 1 min, 2 min and 5 min respectively. Similarly, for other two resistors, images were acquired. Thermal camera FLIR E-40 was used to capture the thermal images. This camera has infrared resolution of 160×120 pixels with thermal sensitivity of 0.07^0 Celsius. Frame rate is 60 Hz and spectral range is 7.5 - 13 micrometer. FLIR E-40 can measure temperature values between -20^0 C to + 650^0 C range. Some camera setting needs to be done so that better pictures can be taken by thermal camera. Emissivity was set at 0.95 and reflected temperature was 20^0 C as advised by camera manufacturer [16]. Images taken during acquisition process are shown below:

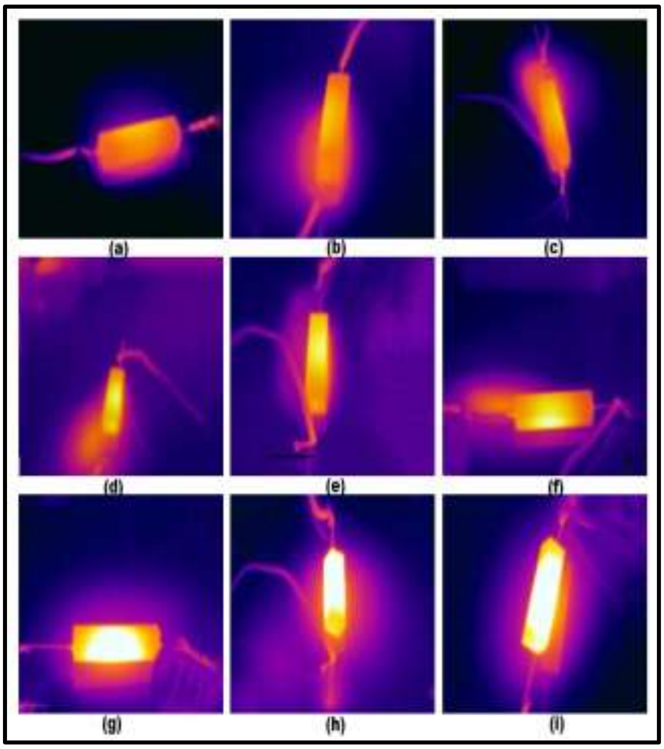

Fig 2: Thermal images acquired for each resistor

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In above Fig. 2(a), 2(b) and 2(c), resistor 6.8 Ω is shown. It shows temperature profile of resistor 6.8 Ω at 1 minute, 2 minutes and at 5 minutes respectively. Similarly, Fig. 2(d), 2(e) and 2(f) shows thermal profile of 25 Ω resistor and Fig. 2(g), 2(h) and 2(i) shows thermal profile of 50 Ω resistor. In the thermal images shown in fig. 2, black color indicates minimum temperature, whereas white spot indicates maximum temperature.

3. TEMPERATURE MEASUREMENT

One of the aim of this work is to provide a method for calibrating temperature at any point in given thermal image. This was achieved by image processing using MATLAB 2017a. First, color-based image segmentation was carried out using image processing methods. Image segmentation is used to split the image into smaller meaningful regions which are of more interest. The benefit of segmentation is that it lessens the complexity in further image processing steps and also helps to locate objects, patterns, textures or boundaries. Color image segmentation makes use of color features of image pixel. It indicates that similar color in the image resembles to separate clusters therefore, it helps to find out objects. Color segmentation is based on color space used. Different color spaces like Red-Green-Blue (RGB), Hue-Saturation-Value (HSV), and Cyan-Magenta-Yellow (CMY) etc. can be used based on images chosen for processing [17].

In this experiment, RGB color space is used. Manual thresholding is used for segmentation so that only resistor part is kept as foreground and other than resistor is background. The original thermal image and color-segmented image is shown in Fig. 3.

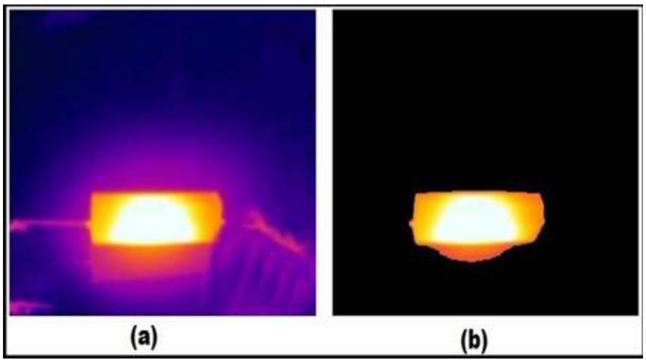

Fig 3: (a) Original thermal image (b) Color segmented image

Thermal image comes up with the color-temperature palette. It consists of a range of temperature which provides a brief idea about maximum (T_{max}) and minimum temperature (T_{min}) in that particular scene. The color palette is subdivided into 255 levels, this level resembles each RGB color to a particular temperature. The temperature of each level of the palette can be calculated as,

$$T_{level} = (T_{max} - T_{min}) / 256 \qquad (1)$$

The temperature of each pixel is measured by finding a matching color in the given palette. The matching color level is designated as D_{RGB}. The temperature of each pixel is measured as,

$$Temp = T_{min} + (D_{RGB} \times T_{level}) \qquad (2)$$

From equation 2, temperature of any point in an image can be calculated [7]. From hotspots, we can get an idea about possible inflation in heat and by calculating temperature values from this method, a possible fault condition can be confirmed. By setting reference temperature and maximum acceptable temperature level, user can easily decide extent of problem and can take necessary actions.

4. EFFECT OF CHANGE IN RESISTOR

To understand the importance of resistance in temperature measurement, it is essential to know how the temperature rises at the equipment. To measure power loss, first calculate current flowing through the resistor by using Ohm's law,

$$I = V / R \qquad (3)$$

As supply voltage is constant (240 volts), we can calculate current through resistor. To find the power dissipated at resistor, we use

$$P = I^2 \times R \qquad (4)$$

From equation (3) and (4), it is clear that as resistance increases, power dissipation at resistor increases. When current flows through them, power will be dissipated at any current carrying load. Deterioration and loose connections are the main factors behind the high resistance path to any electrical circuit which increases power dissipation.

Another reason is if load increases, it draws excessive current and temperature increases. Most of equipment works continuously, therefore current passes through them over longer duration, eventually they are at higher temperature than other surrounding equipments. These factors have direct impact on temperature rise and area of heat spread. Therefore, all these factors are important to consider for analysis which can be useful for preventive maintenance.

5. RESULTS AND DISCUSSIONS

After following the steps of test procedure from subsection 2.1, thermal images were obtained and used for analysis. Resistors were connected in series with load one by one. Power supply used in this experiment was 240 volts, 50 Hz. Initially, bulb resistance was calculated and added to the external resistor value. Current and power dissipation across resistor were computed using equation (3) and (4). Maximum temperature of the particular resistor was calculated using method mentioned in section 3. From the thermal images, the highest temperature regions i.e. hotspots were indicated by yellow and white colors. The results obtained are shown below.

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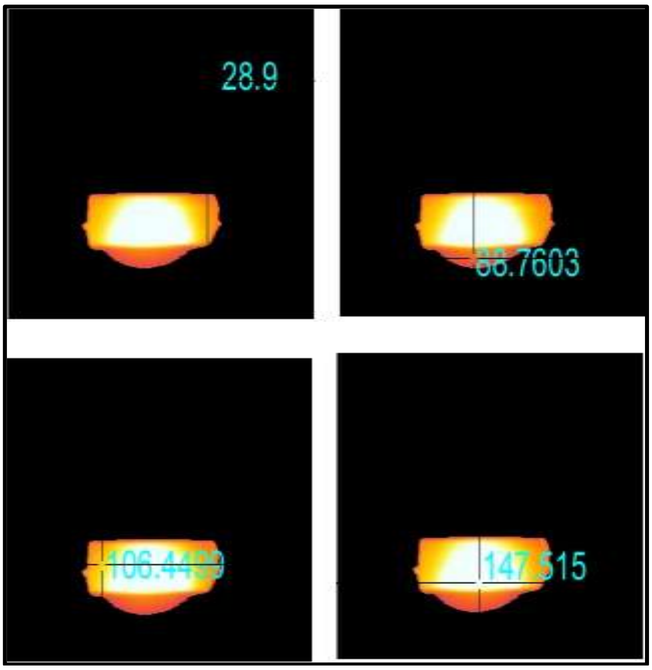

Fig 4: Temperature at different points on resistor

In Fig. 4, temperature at different points of a resistor is shown. By clicking at any point, temperature of that point can be determined using image processing techniques mentioned in section 3. It is evident in Fig. 4 that, the black region is a background (not part of resistor) at a minimum temperature (28.9^0 C). Orange color point out temperature (66.76^0 C) higher than black color region. Yellow (106.44^0 C) and white colors are considered as the area associated with possible fault and white color shows the highest temperature (147.51^0 C) in a scene.

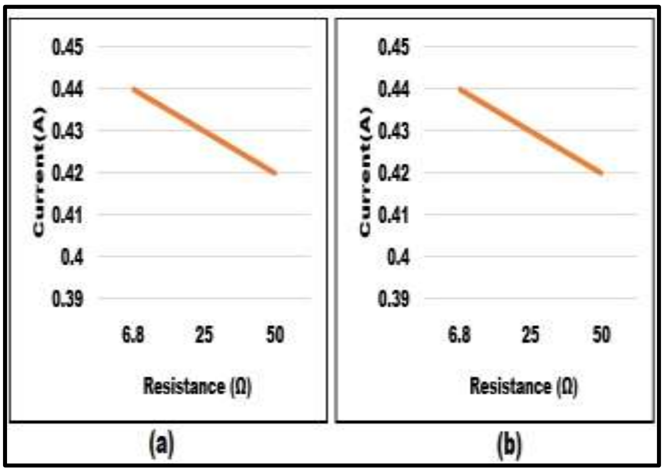

Fig 5: Current plot for all three resistor (a) Theoretical (b) Experimental

Fig. 5 shows as a value of resistance increases, current value decreases keeping supply voltage constant. It means if there is a decrease in current at load, it may be due to high resistance path. Current is inversely proportional to resistance.

Table 1: Power dissipation and Voltage data

R1 (Ω)	R2 (Ω)	P_{R1} (W)	P_{R2} (W)	V_{R1} (V)	V_{R2} (V)
533.33	6.8 Ω, 10 watts	105.41	1.34	237.10	3.02
533.33	25 Ω, 10 watts	98.54	4.60	229.25	10.74
533.33	50 Ω, 10 watts	90.28	8.44	219.19	20.57

In above table, R1= Resistance of bulb, R2= External high wattage resistor, P_{R1} = Power dissipation at bulb, P_{R2} = Power dissipation at high wattage resistor, V_{R1}= Voltage across bulb and V_{R2}= Voltage across high wattage resistor.

From above table, we can analyze power dissipation and voltage values for a given circuit. Total voltage across the circuit is sum of voltage across bulb and voltage across the external resistor. From table it is clear that as value of resistor increases, voltage across the resistor increases. In series circuit, power dissipation across each individual resistor is different. Every resistor in a circuit has a voltage drop across it and dissipates electrical power. This electrical power is converted into heat energy. From the table it is clear that, as value of external resistor increases, power dissipation at resistor also increases, therefore heat generation also increases. Temperature of resistor depends upon power dissipation at resistor.

When temperature increases, a thermal image displays hotspots with yellow and white color. Hotspot area is a sign of heat spread. If the hotspot area is bigger in size, it implies that heat is expanded to a larger area of resistor. Every resistor has a power rating which indicates about maximum amount of power that can be dissipated from the resistor safely without any damage. All the resistors used in this experiment have maximum power rating of 10 watts. 6.8 Ω resistor dissipated only 1.34 watts power, therefore resistor can handle power dissipation and it results in very small amount of heat. Hence, hotspot area on resistor is also small. 25 Ω resistor dissipated 4.60 watts of power. Therefore, moderate amount of heat is generated and hotspot area is larger than hotspot area in 6.8 Ω resistor. 50 Ω resistor dissipates 8.44 watts of power which is close to maximum power rating, therefore 50 Ω resistor heated up quickly and shows largest hotspot area amongst all three resistors.

Fig. 6 is a graph of temperature of different resistors at different time intervals. It indicates that as a value of resistance increases, temperature value also increments. Temperature of individual resistor was observed at different time intervals. Fig.6 shows, as time duration increases temperature of resistor also increases. Also, from fig. 7, it is clear that as resistance increases, hotspot area also increases over the time period.

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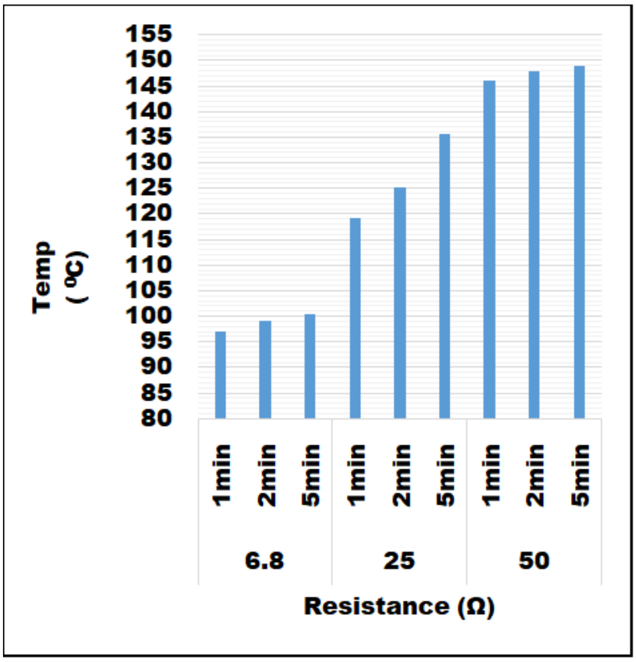

Fig 6: Temperature plot with resistance and time

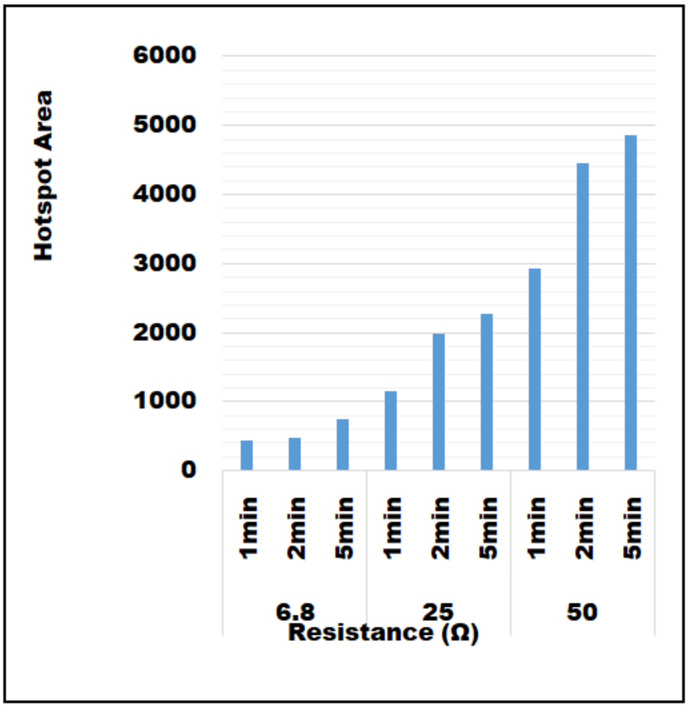

Fig 7: Hotspot area plot with resistance and time

6. CONCLUSION

In this paper, we have addressed the importance of routine condition monitoring of electrical equipments and how thermal imaging is a beneficial technique for preventive maintenance. The suggested method will be very useful for temperature measurement of load resistor. As it can measure temperature of any point in given image, it can also be useful to find out relative temperature rise and for qualitative analysis. The thermal images of different resistors taken during image acquisition process shows detail temperature distributions. The experimental study shows how change in resistance value, changes current, power dissipation, temperature and also the hotspot area. The analysis based on theoretical and practical values will be helpful for understanding the relationship between power dissipation and hotspot area (temperature).

It is important to understand the influence of temperature on electrical equipments for its stable working for long period. From all the results, it can be stated that temperature plays an important role in working of electrical equipments and also on their lifespan. Thermal imaging camera and image processing methods can be helpful to examine the condition of electrical equipment. From the thermal image, possible occurrence of a fault can be predicted. The early prediction of fault can be helpful to prevent the accidents.

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