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Induction motor inter turn fault detection using infrared thermographic analysis

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HIGHLIGHTS

- Infrared thermography (IRT) is used to detect inter turn fault in induction motor.
- Transient rise in temperature during initial start of the motor is carried to detect inter turn fault.
- At steady thermal state, pseudo-coloring technique is proposed to extract hot region on the motor surface.
- Pseudo-coloring technique is in compliance with NETA thermographic standard.
- Comparative analysis has been carried under healthy and faulty conditions.

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ABSTRACT

Induction motors are the most commonly used prime movers in industries. These are subjected to various environmental, thermal and load stresses that ultimately reduces the motor efficiency and later leads to failure. Inter turn fault is the second most commonly observed faults in the motors and is considered the most severe. It can lead to the failure of complete phase and can even cause accidents, if left undetected or untreated. This paper proposes an online and non invasive technique that uses infrared thermography, in order to detect the presence of inter turn fault in induction motor drive. Two methods have been proposed that detect the fault and estimate its severity. One method uses transient thermal monitoring during the start of motor and other applies pseudo coloring technique on infrared image of the motor, after it reaches a thermal steady state. The designed template for pseudo-coloring is in acquiescence with the InterNational Electrical Testing Association (NETA) thermographic standard. An index is proposed to assess the severity of the fault present in the motor.

1. Introduction

Induction motors are considered as workhorses of industries as it is the most commonly used prime mover. However, failure of motor in critical applications can lead to high production loss and in some cases can results in fatal accidents. Faults in induction motors lead to poor efficiency i.e. more energy consumption [1,2]. According to a survey report, the failure percentages of various components in induction motors are: bearing (41%), winding (37%), rotor faults (10%) and others (12%) [3].

Majority of faults are bearing and winding related, therefore, its early diagnosis is essential. However, out of the two, the winding failure is considered serious. It increases stress on the winding insulation, which has a potential to completely damage the motor, if left untreated. As a rule that states, with every 10 °C rise in temperature leads to reduction of insulation life to half [10]. Once failure due to winding damage occurs, it requires more time to repair increasing downtime and production loss. Therefore, early detection of winding faults is very essential.

Predictive maintenance of induction motors using condition monitoring techniques has gained its importance in detecting various incipient faults. It is an effective tool in the present industries for reducing downtime and production losses. Presently, the most common condition monitoring techniques for fault diagnosis of induction motors are vibration and current based. Both these techniques are effective in detecting various electrical and mechanical related faults [3–5]. However, both these techniques, requires costly setup like sensors, data acquisition systems and consumes a lot of time in computing and diagnosing the fault.

Winding short circuit impress a clear pattern into the stator currents. Bellini et al. [13] discussed the use of online current and voltage based advance diagnosis technique and offline partial discharge (PD) test to diagnose winding fault. These techniques

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Table 1
NETA standard for electrical machines.

Priority	Temperature difference between object and ambient (ΔT) (°C)	Action recommended
3	1–10	No exception likely
2	10–20	Possible exception
1	>20	Exception likely

are very effective in diagnosing the fault. It requires additional setup or relays to diagnose the winding fault therefore, its application is restricted only to high tension or critical motors due to it high cost. PD test is an offline test that requires motor shutdown which can leads to production loss. Therefore, the need for a non contact and online monitoring is necessary.

Infrared thermography (IRT) is an online and non contact type condition monitoring technique, which has been used widely for inspection of electrical installations and transformers. However, IRT has been left underutilized for health monitoring and fault diagnosis of motors [6,7].

Manana et al. [8] proposed a thermal model and an infrared monitoring test method for field winding fault detection during manufacturing of DC machines. Temperature estimation based on thermal model is flexible and accurate, but it can't respond to the changes in motor thermal characteristics [10].

Garcia Ramirez et al. [9] presents a methodology based on thermographic image segmentation for detecting broken bar, bearing, misalignment, mechanical and voltage unbalance faults in induction motors, and the repercussion of these faults along the kinematic chain.

Inter turn fault leads to increase in motor stator temperature due to over current. This problem can be detected by Infrared thermal image camera. Using this concept, Eftekhari et al. [12] considered three indicators: Histogram mean value, $Hull_{index}$ and Hot area, which are extracted by using image processing techniques on the obtained infrared images of the motor under test. Authors have considered only steady state temperature profile of the motor and have not considered the heating pattern during start of the motor. Winding short circuits is rapid evolving fault and can even lead to the collapse of the motor, before reaching its thermal steady state. Therefore, monitoring the temperature rise during starting period of its run is also essential for early fault diagnosis. Also, severity of the fault estimated by the authors at steady state temperature is without consideration of the commonly used Inter-National Electrical Testing Association (NETA) standard.

NETA has classified the severity of faults by measuring the temperature difference between the motor surface and ambient. NETA standard for motor core (on test bench, not in service) is presented in Table 1 [11].

The effectiveness of thermographic techniques for fault identification in induction motors is highly dependent on its accuracy in identifying the hot areas and predicting its severity level. This paper proposes an algorithm for automatic inter turn fault detection in induction motors and to estimate its severity level based on its infrared thermography images. The proposed algorithm uses simple but effective technique for extracting fault features. The proposed algorithm is in accordance with NETA standard for infrared inspection of electrical systems and rotating equipment. Authors have also analyzed the rise in the motor core temperature, during the initial period of its run and diagnose the fault severity using this transient rise.

2. Experimental setup

A 5 hp, 440 V, 4 poles, star connected three phase induction motor is used with provision for short circuit of 16.6% and 33.2% turns. The motor is run at no load condition in order to avoid rapid collapse of the motor. Its thermal images are captured using FLIR-E60 camera under both transient and steady state conditions. The obtained thermal images profile is compared under healthy as well as faulty conditions of the motor. For steady state analysis, the thermal images obtained are in gray scale format. The intensity values $I(x,y)$, in gray scale image lies between 0 and 255 and is the measure of body surface temperature. The thermal scale of the captured IRT images need to be modified, before applying image processing in Matlab. The temperature scale is adjusted such that maximum temperature (T_{max}) = minimum temperature (T_{min}) + 30 °C i.e. if temperature lower limit is 35 °C then upper limit is set to 65 °C as per NETA standard. The T_{min} is the operated ambient temperature. Obtained new thermogram $I_1(x,y)$, values lying between 0 and 255 (i.e. ΔT equal to 0–30 °C). The $I_1(x,y)$ thermal scale is equally divided into three parts. The first part indicates region with ΔT = [0–10 °C), second part has ΔT = [10–20 °C) and third part shows ΔT = [20–30 °C] or higher. This creates a temperature profile that is in compliance with NETA standard. Pseudo coloring is carried out on these three sections with green, yellow and white color[1] as shown in Fig. 1. The g, y and w indicate the intensity values of $I_1(x,y)$ at which ΔT is =10 °C, =20 °C and =30 °C respectively.

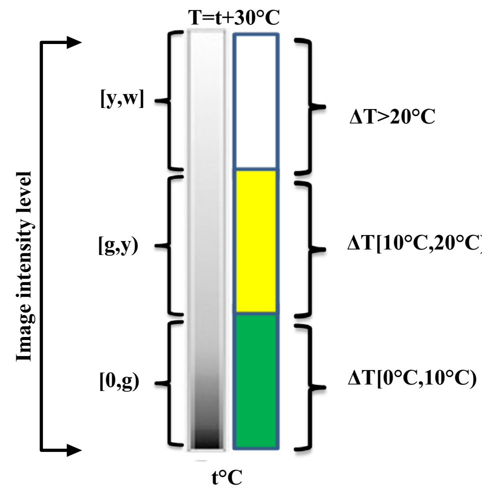

Fig. 1. Template in accordance with NETA standard.

However, in order to segregate the background and to extract the actual motor surface area or region of interest (*ROI*) from IRT images, a factor 'i_n' known as maximum background intensity level is calculated. Value less than i_n has been assigned an intensity value equal to 0 i.e. Black as shown in Fig. 2. This will easily isolate the motor from its background, however the optimal value of i_n needs to be computed.

3. Optimum value of i_n for steady state analysis

The captured thermal image and desired *ROI* are shown in Figs. 3 and 4 respectively. In order to extract the desired *ROI* form the thermal image after preprocessing of image, the following steps have been followed:

Step1: calculate the mean (μ) and standard deviation (σ) of $I_1(x,y)$ image.
Step2: calculate various values of '$\mu + n\sigma$' where n = 0, 1, 2, 3. . ..

[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.