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Condition Monitoring of distribution transformer: A case study on 500 kVA distribution transformer of Jigme Namgyel Engineering College (JNEC) using Thermal Imaging method

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Abstract

Uninterrupted electrical supply is critical for the smooth operation of JNEC, supporting laboratories, research facilities, and educational infrastructure. Even brief outages can disrupt critical activities, leading to data loss, research delays, and educational setbacks. To mitigate these risks, continuous condition monitoring is essential. Condition monitoring of electrical machines, including generators, motors, and transformers, ensures reliable operation and prevents unexpected failures in industrial settings. The increasing reliance on automation and the economic importance of continuous operation underscores the need for effective monitoring techniques. This study investigates condition monitoring strategies for 500 kVA distribution transformer of the campus using thermal imaging method. By capturing thermal images, we evaluated the operating status of transformer without interrupting college operations. The color distribution in the thermal images provides a clear indication of equipment health, enabling proactive maintenance and preventing potential failures. This case study focuses on the condition monitoring of transformers within an JNEC's electrical distribution system using a thermal imager. The results demonstrate the effectiveness of thermal imaging as a valuable tool for assessing transformer status and ensuring reliable power supply in a demanding engineering education environment.

Keywords— Uninterrupted electrical supply, thermal imaging, thermal imager, condition monitoring, color distribution

1 Introduction

Understanding the condition of a transformer is paramount, as it indicates the likelihood of failure due to various system faults. This assessment is a crucial factor in ensuring the optimal operation of every component within the power system. Consequently, power engineers prioritize maintaining

transformers in good working order. While traditional offline monitoring techniques like Dissolved Gas Analysis (DGA) [1] have been used for a long time, they can be less reliable and delay the restoration process. This highlights the increasing importance of adopting more advanced monitoring techniques. Specifically for distribution transformers (DTs), which require careful attention to guarantee uninterrupted power supply to customers, various monitoring approaches are being developed. Monitoring these DTs presents a challenge due to their widespread distribution and the prevalence of faults affecting them. Different methodologies are employed for assessing transformer condition based on various parameters [2], each with its own set of advantages and limitations.

Transformers can be modeled based on the specific parameters intended for analysis or monitoring. To analyze electrical characteristics such as current, voltage, and resistance, an equivalent electrical model is developed. Similarly, for the analysis of thermal parameters like temperature, an equivalent thermal circuit must be constructed to mathematically derive and evaluate parameter variations [3]. This thermal model aids in a deeper understanding of a transformer's thermal behavior under different operating conditions. The international standard for thermal modeling of transformers is IEC 60076-7: 2005, while various IEC standards like IEC 60076-1 and IEC 60076-2 exist for different electrical modeling scenarios [4]. Transformers typically rely on insulation systems made of pressboard and kraft paper immersed in insulating oil, which dissipates heat through convection. These materials degrade when operating temperatures exceed their thresholds, causing insulation failures and transformer faults. Several studies proved that insulation degradation is the primary cause of transformer failure.

This study focuses on the application of Fluke TiS75+ Thermal imager and Fluke Connect software for advanced condition monitoring of transformers. Given that all losses resulting from any transformer fault dissipate as heat, any internal or external anomaly will significantly impact its thermal characteristics. By measuring temperature rises at windings, the oil tank, and other critical points. This technology enables the establishment of thermal baselines and the tracking of temperature trends over time, facilitating the early detection of faults such as loose connections, overloading, insulation degradation, or cooling issues. By providing a means for severity assessment and supporting condition-based maintenance strategies, this approach offers the potential for predictive maintenance insights. This review of transformer condition monitoring techniques offers valuable insight for selecting an appropriate method based on factors like cost, operating environment, transformer application, and surrounding conditions. Temperature monitoring, a widely used technique, is performed using integrated TiS75+ Thermal imager and analysis for fault diagnosis and condition monitoring of a 500 kVA distribution transformer located in the JNEC campus.

1.1 Causes of Distribution Transformer Faults

A detailed analysis of distribution transformer failures reveals several key contributing factors, with electrical issues emerging as the most significant, accounting for 29% of failures. This category includes winding faults, short circuits, and voltage stresses, all of which place undue electrical stress on transformer components. Lightning strikes are the second leading cause at 25%, as high-voltage transients from lightning can severely damage insulation systems. Insulation failures represent 15% of failures and are typically caused by thermal stress, material aging, or contamination, leading to reduced dielectric strength and eventual breakdown. [1]

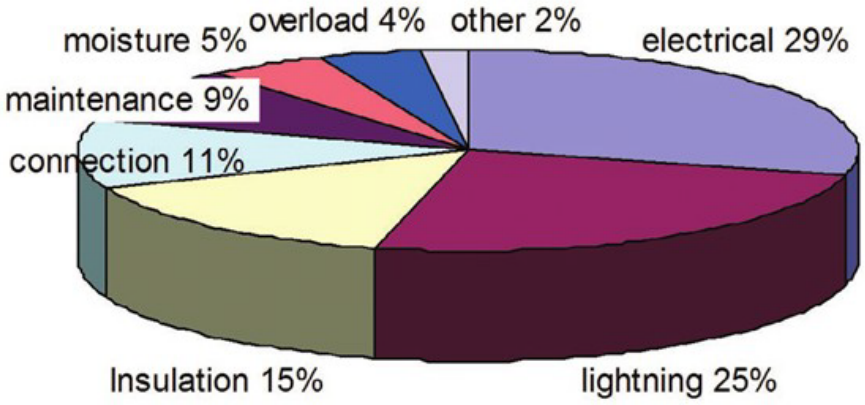


Figure 1: % wise distribution of causes faults in distribution transformer [1]

Connection problems contribute to 11% of failures, emphasizing the importance of proper installation and maintenance. Loose or corroded terminals can lead to localized heating and mechanical degradation. Maintenance-related issues, comprising 9%, underscore the need for regular upkeep such as monitoring oil levels, cleaning breathers, and addressing minor issues before they escalate. Moisture ingress, responsible for 5% of failures, contaminates insulating oil and degrades solid insulation, increasing the risk of electrical discharge [1]. Overloading accounts for 4% of transformer failures, as operating beyond rated capacity generates excess heat, accelerating insulation deterioration and potentially damaging windings [1]. The remaining 2% is attributed to other less frequent or uncategorized causes. This breakdown highlights that electrical faults, lightning surges, and insulation degradation are the primary drivers of transformer failure. Enhancing transformer reliability therefore requires robust electrical design, effective surge protection, the use of high-quality insulation materials, secure electrical connections, consistent maintenance practices, and avoiding the overloading conditions.

One of the most important aspects of transformer design is the insulation. As transformers age, their insulation's capacity to tolerate changes [10]. The commonly used insulation technique for transformers includes oil-impregnated paper. Insulating life decreased substantially because of aging-related degradation. The aging factor is influenced by five primary processes including Thermal aging, Electrical aging, Chemical aging, Impulse aging and Environmental aging. The principal aging element stems from thermal exposure that produces alterations to the insulation material's chemical and physical properties through changes to both polymerization and depolymerization and modifications to the fiber order of solid insulation. Insulation size displays two possible changes because of thermal aging either through elongation or contraction. CIGRÉ working Group found that failure records show that the On Load Tap Changer component causes 41% of transformer malfunctions while windings account for only 19% of cases [11]. The failure initiation rate for electrical transformers occurs in two ways: mechanical failures make up 53% while dielectric failures account for 31% [12].

Without Tap changing type of the transformer, it consists of 26.6% winding faults and 6.4% magnetic circuit problems. The data shows 33.3% of failures occur from connection lead-outs while tank and dielectric fluids lead to 17.4% of failures and other accessories combined with 11% and 4.6% due to tap changer [12]. Furthermore, the failure probability of transformer throughout the world is 26/1000 [14]. O.N. Grechko discovered that transformers experienced 51% of their failures within their initial five years of service period [15]. The primary causes for transformer failures include (a) decreased dielectric insulation strength by aging by-products and (b) short circuit-generated damage or decomposition to windings; damage of the bushing on transformer [16].

2 Methodology

2.1 Electrical Machine

The system under observation is a 500 kVA, 11000/400 V, Dyn11, ONAN transformer located in the JNEC campus, selected for thermal condition monitoring. This transformer is feed from 11 kV incoming feeder from 132/33/11 kV Dewathang substation. The secondary side of the transformer is fed to the lower part of the campus which comprises of mixed load of residential and academical.

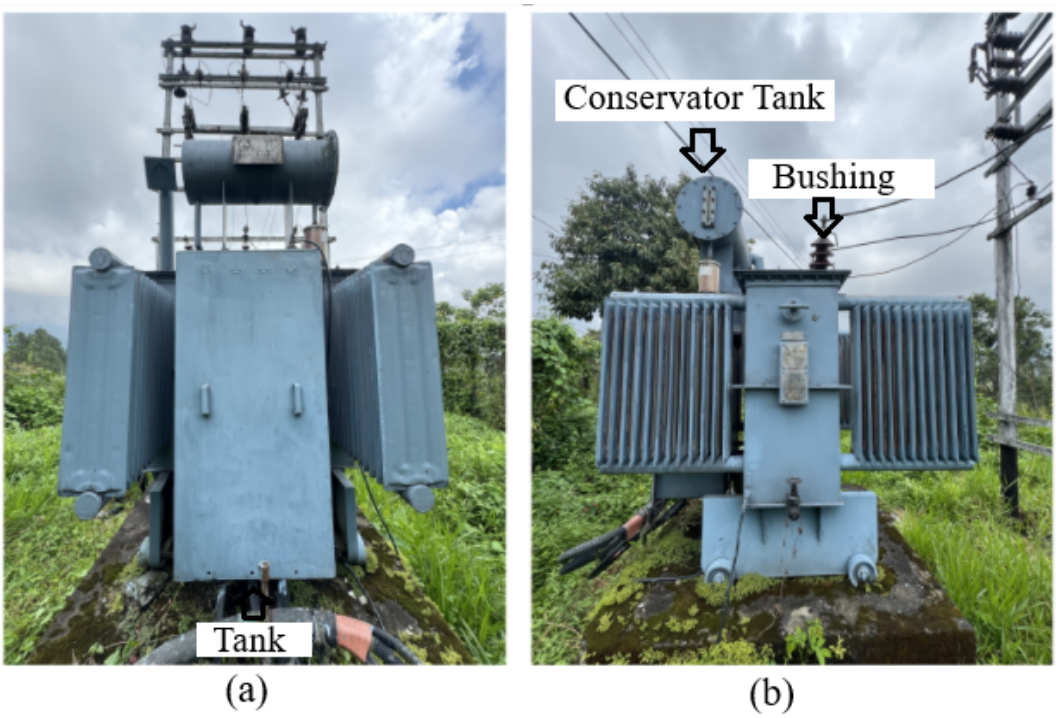


Figure 2: Transformer under observation, (a) Front view (b) Side view

2.2 Data Acquisition



Figure 3: Fluke TiS75+ Thermal imager

Thermal images were captured under normal load conditions using a *Fluke TiS75+* thermal imager (infrared resolution: 384 × 288 pixels [110,592 pixels]; accuracy: ±2 °C or ±2% of the reading, whichever is greater, at an ambient temperature of 25 °C), as shown in Figure **??**, to ensure accurate thermal signatures.

As shown in Figure 2, thermal imaging was used to evaluate critical components of the transformer. The scrutiny focused on electrical connections and bushings, which were assessed for thermal anomalies revealing of corroded or loose contacts. Tank walls were studied for uneven temperature distributions that could indicate internal faults. Radiators and cooling fins were examined for thermal uniformity to guarantee effective heat dissipation. Moreover, the cable terminations and tap changer were checked for signs of confined overheating, which may compromise working integrity. All imaging procedures were directed in accordance with strict safety protocols due to the proximity to energized equipment, thereby lessening risk to personnel and warranting data reliability.

2.3 Signal Processing (Fluke Connect)

Captured images were uploaded to Fluke Connect software, where they were organized, enhanced, annotated, and securely stored for analysis. Measurements can now be stored in the cloud, where teams can always access the data on their smart device or computer. Whether your maintenance and reliability team are gathering data from condition monitoring sensors or from portable test tools, they now have all the data they need to make critical decisions and complete necessary jobs.

2.4 Feature Extraction

Analysis of thermal data was carried out to derive key diagnostic metrics, as demonstrated in Figure 4. This comprised the extraction of point and area temperatures, capturing minimum, maximum, and average values to analyze thermal performance across components. Temperature differences were determined by comparison of localized component readings with ambient conditions, allowing the location of potential overheating or inefficiencies. Moreover, thermal patterns were inspected to detect anomalies and uneven heat distribution that may show underlying degradation or faults. Baseline measurements were methodically recorded to facilitate trend analysis and longitudinal comparisons in future inspections.

2.5 Fault Detection Severity Assessment

Present thermal data were systematically compared with established baseline temperature ranges of 5–20 °C for the bushings, 40–70 °C for the conservator tank, and 45–75 °C for the middle section of the transformer tank. These reference values, obtained from industry standards, were used to classify the detected thermal conditions into three categories: *normal*, *caution*, and *alarm*. This classification enabled targeted diagnostic assessments and prioritized maintenance actions. Furthermore, trend analysis was performed to identify faults developing over time by examining the relationship between varying load conditions and thermal deviations, thereby enhancing operational reliability and supporting predictive maintenance.

2.6 User Interface

The Fluke Connect interface enables well-organized diagnostics by presenting glossed thermal images along with temperature trend data with time. This dual-display feature improves the immediacy and clarity of thermal valuations, permitting operators to monitor evolving conditions and locate anomalies with precision visually. The incorporation of historical temperature profiles and real-time imaging supports fast identification of developing issues and updates communication among maintenance teams, thereby enhancing operational decision-making and response times.

2.7 Maintenance and Predictive Insights

Thermal assessment plays a crucial role in improving transformer asset management by allowing condition-based maintenance methods that prioritize interventions in accordance with to the health status of individual components. This method agrees for targeted reviews, concentrating efforts on zones exhibiting degradation or thermal anomalies. Additionally, the incorporation of trend data enables predictive failure investigation, presenting early warnings of possible faults before they intensify into critical issues. By identifying and mitigating causes of thermal stress, thermal diagnostics also present to operational optimization, eventually expanding the service life of the machinery and enhancing overall system reliability.

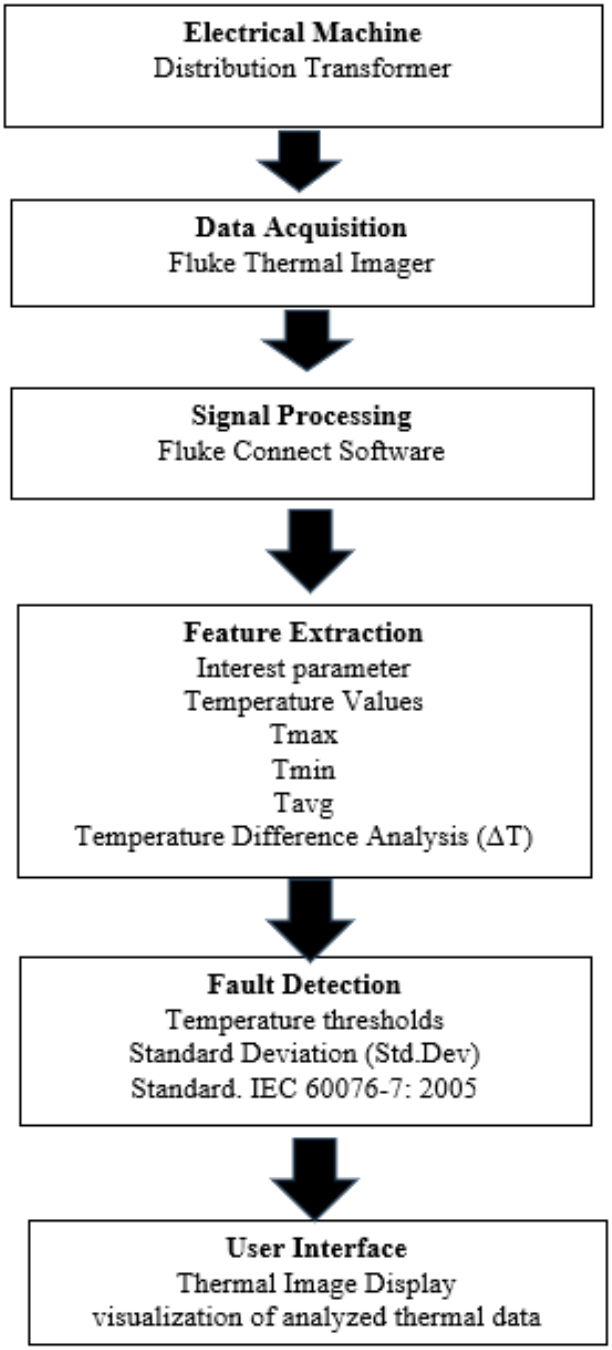
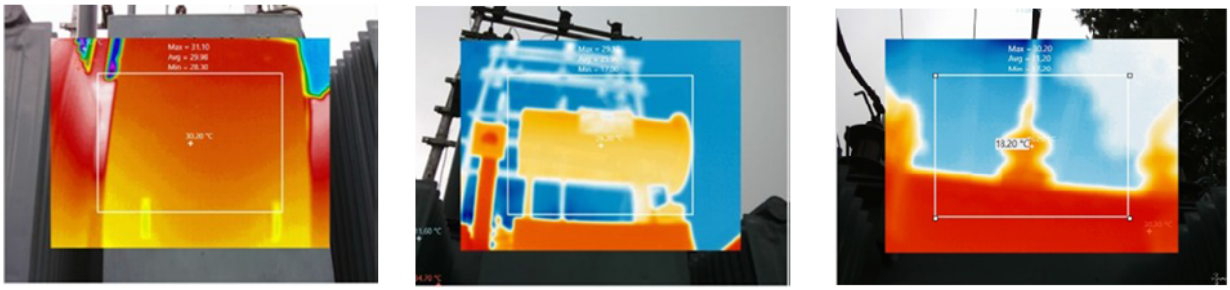


Figure 4: Methodology flowchart

3 Results and Discussion

The final thermal images captured by Fluke TiS75+ Thermal imager from the middle tank, conservator tank and bushing of Distribution Transformer are shown in Figure 4.



(a) (b) (c)

Figure 5: Thermal image of, (a) Middle part of transformer tank, (b) Conservator Tank, and (c) Bushings

Figure 5(a) shows the thermal profile of the middle section of the transformer tank. The maximum temperature recorded in this region was 30.20 °C, with an average temperature of 29.90 °C. These values indicate a relatively uniform and moderate temperature distribution with a slight temperature gradient from the bottom to the top of the tank. No significant hotspots were observed, suggesting that heat dissipation was occurring effectively through the sides of the transformer tank.

Figure 5(b) presents the thermal profile of the conservator tank. The maximum and average temperatures recorded were 26.20 °C and 23.56 °C, respectively. As the conservator tank serves as a reservoir for transformer oil, its temperature generally reflects the overall thermal condition of the oil system. The relatively low and uniform temperatures indicate that the transformer was operating under a light load without significant internal heat generation. Furthermore, the stable temperature distribution suggests that the transformer oil was not undergoing substantial thermal expansion, indicating normal operating conditions.

Figure 5(c) illustrates the thermal profile of the transformer bushing. The maximum temperature recorded was 18.20 °C, while the average temperature was 21.20 °C. The comparatively lower temperatures observed at the bushing are consistent with its function of providing electrical insulation while conducting current with minimal heat generation. The measured temperatures were validated by comparison with the permissible operating temperature ranges specified in IEC 60076-7:2005, confirming that the bushings were operating within the acceptable thermal limits.

Table 1: Thermal readings of transformer components

Transformer Part	**Standard Average Temperature (°C)**	**Measured Temperature (°C)**
Middle part of tank	45–75	29.98
Conservator tank	40–70	23.96
Bushing	5–20	21.20

The middle section of the transformer tank recorded a temperature of 29.98 °C, indicating that the transformer was not operating at full load. This condition is likely supported by effective ventilation or external cooling. It is important to note that this measurement was obtained externally and not from internal oil or embedded sensors. The conservator tank recorded a temperature of 23.96 °C, suggesting low load operation with minimal oil heating. This reading was also taken externally. Similarly, the bushing temperature of 21.20 °C indicates light loading conditions or relatively cool ambient surroundings.

The Centerbox data for the middle tank region shows a temperature range from 28.30 °C to 31.10 °C, with an average of 29.98 °C. This relatively narrow range reflects a stable thermal profile and effective heat dissipation, supporting the operational integrity of the transformer. The Centerbox region exhibits a standard deviation of 0.48 °C, indicating minor fluctuations. In contrast, the Hot, Cold, and Centerpoint markers each show a standard deviation of 0.00 °C, reflecting uniform temperature readings at those specific points.

The highest temperature recorded in the broader transformer tank region is 35.20 °C, while the lowest is 8.50 °C, indicating the presence of a thermal gradient across the surface. In the conservator tank, the hottest point reaches 34.70 °C and the coldest point is 11.60 °C, showing a more pronounced thermal variation. The Centerpoint temperature of 22.90 °C reflects a relatively stable core condition. Within the Centerbox region of the conservator tank, temperatures range from 17.00 °C to 29.10 °C, with an average of 23.95 °C and a standard deviation of 2.36 °C.

The higher standard deviation in the conservator tank (2.36 °C) compared to the middle tank (0.48 °C) indicates greater thermal variability, likely due to oil movement, convection effects, or environmental exposure. Such variations may affect insulation performance and contribute to accelerated ageing if persistent. In contrast, the lower deviation in the main tank suggests stable thermal behavior and efficient cooling. Although Hot, Cold, and Centerpoint markers show zero deviation, the presence of a localized hotspot at 34.70 °C may indicate possible localized heating or connection-related issues that warrant further inspection.

Recommended Actions: Inspect oil circulation, clean cooling systems, check insulation integrity via dielectric tests, and conduct routine thermal imaging to detect early faults. Monitoring standard deviation trends can help identify developing issues and improve transformer reliability.

4 Conclusion

The thermal analysis of a 500 kVA distribution transformer using a Fluke TiS75+ Thermal imager and Fluke Connect software revealed distinct thermal profiles for different components. The middle of the tank exhibited a relatively uniform and moderate temperature distribution, suggesting efficient heat dissipation. In contrast, the conservator tank showed a wider temperature range and greater variability, potentially indicating oil movement irregularities or localized heating. The bushing displayed relatively low temperatures overall, with a localized hotter spot requiring further attention. Comparing measured temperatures to general guidelines and analyzing the standard deviation of temperature distributions provided insights into the transformer's operational status. The findings underscore the value of thermal imaging as a non-intrusive method for condition monitoring, enabling the identification of potential thermal inconsistencies that warrant further investigation and targeted maintenance actions to ensure the reliable operation of the transformer within the engineering college's electrical distribution system. Regular thermal inspections and trend analysis are recommended for proactive fault detection and predictive maintenance planning.

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