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Reliability Analysis of the PR012 Distribution Substation of PT. PLN ULP Praya Through Temperature Measurements

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Abstract
The reliability of distribution transformers plays a crucial role in maintaining the continuity of electrical energy distribution. This study aims to analyze the reliability level of the PR012 distribution substation at PT PLN ULP Praya through temperature measurements using the *thermovision* method. Measurements were conducted using a FLIR T400 thermal camera on several transformer components, including the transformer body, transformer top packing, TM bushing, TR bushing, rack handle, fuse, and cable. The measurement results showed the highest temperature was 50.5°C in the transformer body, while the lowest temperature was 44°C in the rack handle. All components remained below the normal operating temperature limits according to the IEC 60076 and IEEE C57.91 standards. However, a temperature difference was found at the fuse, indicating a load imbalance. Based on the analysis, the PR012 distribution transformer at PT PLN ULP Praya still has a good level of reliability, but regular load equalization is required to maintain the transformer's performance and operational life.

Keywords: distribution transformer, thermovision, reliability, temperature, FLIR T400

1. Introduction

In modern era, electrical energy has become a fundamental necessity, supporting nearly all aspects of human life (Zohuri, 2016; Zohuri & McDaniel, 2019) [13]. The use of electrical energy spans various sectors, including household appliances, industry, healthcare, telecommunications, and information technology (Kahsar, 2019; Li et l., 2023) [6]. Beyond supporting daily activities, the availability of reliable, high-quality, stable, and affordable electrical energy is also a crucial factor in supporting a country's economic growth and development (Strielkowski et l., 2021) [10]. Therefore, the reliability of the electrical power system must be consistently maintained through effective management and maintenance of electrical infrastructure (Al Ameeri *et al*., 2023; Alvarez-Alvarado *et al*., 2022).

In an electric power distribution system, distribution substations are a crucial component, delivering electrical energy from the main substation to customers through the distribution network (Putra *et al*., 2024; Priliani & Jenra, 2023) [8, 9]. The reliability of distribution substations significantly determines the continuity and quality of electricity service received by consumers (Kafle *et al*., 2022; Zulianti *et al*., 2019) [5, 15]. Distribution substations are generally installed outdoors, exposing them to various environmental conditions, such as changes in temperature, humidity, rainfall, dust, and air pollution (Sun et la., 2024; Hawker et l., 2024) [4, 11]. These conditions can potentially degrade the performance of distribution substation equipment and increase the risk of disruptions and damage.

One of the crucial components in an electric power distribution system is the distribution substation, which serves to channel electrical energy from the distribution network to consumers (Zhao *et al*., 2026) [12]. Most equipment in a distribution substation is composed of conductive metal materials that are susceptible to environmental influences. Continuous exposure to weather can cause corrosion of connections and other metal components, as well as dimensional changes due to thermal expansion and contraction. These conditions can increase contact resistance, trigger overheating, and ultimately reduce the reliability of the electric power distribution system.

Therefore, regular maintenance and measurement activities are necessary to detect early signs of damage (Eksan *et al*., 2025) [3]. One effective method is the use of thermovision technology, which can identify temperature anomalies in substation equipment without disrupting system operation. In this context, the Reliability Analysis of Distribution Substations PR012 Using Thermovision is an important preventive measure to maintain the reliability, safety, and efficiency of electrical energy distribution to customers.**2.**

2. Method

Equipment operating in distribution substations requires maintenance. Distribution substation maintenance is necessary to maintain equipment performance. Because there are quite a lot of operating distribution substations, their maintenance requires careful planning. Corrosion or rust is common in certain parts of distribution substation equipment maintenance, including:

1. Maintenance on distribution transformer bushings.
2. Maintenance of connection points on installations.
3. Maintenance of PHBTR (Low Voltage Distribution Board).
4. Thermovision maintenance.

2.1. Distribution Substation Maintenance

There are several things that need to be done for the maintenance of portal pole distribution substations, including:

1. Maintenance of bushings on the primary and secondary sides.
2. Maintenance of nuts & bolts from chemical properties (Corrosion and loosening).
3. Maintenance of grounding resistance, especially on the electrodes.
4. Maintenance of transformer oil, radiator and conservator.

2.2. Maintenance of Distribution Substation Installations

Distribution substation installations that have been installed for a long time will experience damage, especially at the connection points where the bolts are loose and corroded, so that the performance of the installed equipment will not be in accordance with its design. To prevent this from happening, maintenance of various systems is carried out, including:

- **Preventive Maintenance:** Maintenance to prevent further damage to equipment.
- **Routine maintenance:** Maintenance work is carried out periodically and continuously to maintain the condition of the network so that it remains in good and prime condition.
- **Predictive maintenance:** Condition-based maintenance system by monitoring equipment/network conditions online and offline.
- **Special/Emergency maintenance:** Maintenance work to repair equipment/networks damaged by natural disasters, fires, riots, etc.

2.3. Distribution Transformer Maintenance

Transformer maintenance is carried out on a schedule and in operating/voltage conditions or not. As is generally known, the electricity distribution system to customers of electricity sources is supplied by only one transformer unit, so that when transformer maintenance occurs with a blackout, it means a blackout for customers too, this is certainly something unpleasant for customers, both small power customers and large power customers for industrial purposes, the impact of blackouts can affect production and cause losses.

Some measures intended to reduce the negative impact of the blackout include:

1. Implementation of planned blackouts and notification of blackouts is conveyed to customers before the blackout is implemented through various mass media or direct notification by letter.
2. Implementation of effective maintenance, namely planning and implementing maintenance using the appropriate equipment and competent personnel.
3. Using a mobile substation unit or mobile generator means replacing the electricity supply to the transformer to be maintained with replacement equipment in the form of a distribution substation unit or generator that can be moved.

In maintaining a transformer in an unvoltage state, it means performing a power outage. There are things that need to be considered when powering off/disconnecting the circuit on the transformer, as much as possible, the transformer load should not be too large, especially transformers installed outside or often called portal pole substations or hangers, where the primary circuit breaker is only a Fuse Cut Out, so that when removing it there will be an arc that is difficult to avoid.

Another impact of a circuit break under high load conditions on a transformer is that the reduction in induced current in the transformer windings can cause movement that can damage the transformer's structure. Meanwhile, in the overall network system, the sudden loss of a large load can cause a voltage surge.

Distribution transformer maintenance activities in the field are of course related to the presence of potentially dangerous electrical voltages, so the issue of work safety for personnel, the suitability of work equipment and the safety of electrical equipment that is the object of work are things that need to receive serious attention.

2.4. Themorvision

Most electrical equipment is electrically conductive, meaning it can conduct electricity because it's made of metal. When an electric current flow through the equipment, it naturally generates heat. Temperatures exceeding the tolerance limit during operation are considered a problem or abnormality for the equipment. This can lead to further damage if not addressed promptly.

To prevent this, regular checks and maintenance are performed, including monitoring component temperatures using a thermal camera or Thermovisi. This measurement utilizes infrared light emitted by thermal imagers, allowing the thermal imager's display to show the temperature of the device being measured.

The working principle of this measurement is to measure the ratio of the energy radiated by an object (electromagnetic waves) to the energy radiated by a black body at the same temperature and wavelength. Radiation is an electromagnetic wave produced by the heat of an object, consisting of photons. These photons will excite electrons in the object they hit, causing them to have a higher energy level.

The following is a calculation table for evaluating thermovision measurements, so that the measured device can be classified into several conditions and will be followed up for maintenance:

Table 1: Parameters & Recommendations for the movement on the clamp

No	ΔT	Recommendation
1	<10 C	Normal conditions, the next measurement will be carried out according to schedule.
2	10 C - 25 C	Measurements need to be taken in one month
3	25 C - 50 C	Repairs need to be planned
4	50 C - 70 C	Needs immediate repairs
5	>70 C	Emergency conditions

2.5. FLIR Camera

The FLIR T400 is a T-series thermal camera from FLIR Systems, the world's largest commercial company specializing in the design and production of thermal imaging cameras, components and imaging sensors.

Fig 1: FLIR T4000 Camera

Like a thermometer, this device can measure an object's temperature without having to touch it. This is possible because the device receives or captures infrared radiation from the object being measured, which is then processed into an image along with a temperature measurement. For specifications of the FLIR T400 thermal camera, see Table 2.

Table 2: FLIR T400 Camera Specifications

Feature	
Temperature range	-4°F to 2192°F (-20°C to 1200°C)
Image Storage	1000 radiometric JPEG images (SD card memory)
Imaging Performance / Image Presentation	
Frame Rate	30Hz
Field of view / minimum focus distance	25° x 19° / 1.31 ft (0.4 m)
Focus	Manual / Automatic
Thermal sensitivity (NETD)	<0.05°C at 30°C
Detector Type - Focal plane array (FPA) uncooled microbolometer	320 x 240 pixels
Spectral range	7.5 to 13µm
Picture mode	Thermal / Visual / Fusion / Panorama
Screen	Built-in 3.5" color touchscreen LCD
Lens	25° (available lenses 6°, 15°, 45°, 90°, Close up 100, 50, 25µm)
Video Light	Bright LED lights
Image annotation	Voice (60 seconds); text commentary, Sketch, image markers on IR / Visual
Laser Classification / Type	Class 2 / Semiconductor AlGalnP Diode Laser: 1mW / 635nm (red)
Control settings	Mode selector, color palette, configure info to display in images, local unit adaptation, language, date and time format, and image gallery
Battery Type / operating time	Li-ion /> 4 hours, Screen shows battery status
Charging system	On camera AC adapter / 2 bay charging system
Dimensions / Weight	4.2x7.9x4.9" (106x201x125mm) /1.94lbs (0.88kg), including battery

3. Results and Analysis

3.1. Results

The following are the results of thermal tests on the ULP Praya PR012 distribution substation using the FLIR T400 Thermal Camera.

- **Transformer Body**

In the distribution transformer body measurements carried out during the day at 13.47 WITA, the measurement results obtained can be seen in Figures 2 and 3.

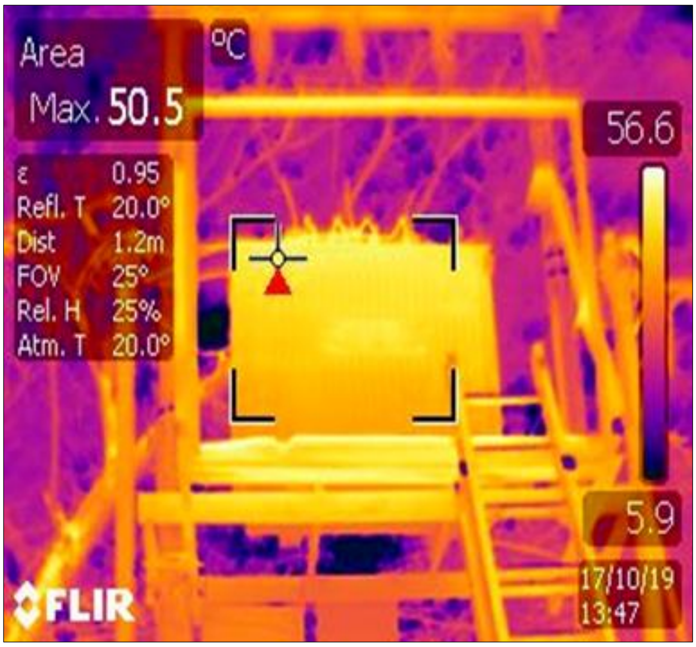

Fig 2: Transformer Body Thermal

Fig 3: Visualization of the Transformer Body

Based on the thermal measurement results above in Figure 5.2.(a) with a Temperature scale between 5.9°C-56.6°C, the temperature measurement on the transformer body was 50.5°C. It can be seen from the color of the measured transformer body which is orange. This is because the distribution transformer body contains coils and an iron core where these components function as a voltage and current transformation tool. Because of this, heat is generated on the transformer body.

- **Transformer top packing**

In the measurement of the distribution transformer's top packing which was carried out during the day at 14.10 WITA, the thermal measurement results were obtained which can be seen in Figure 4 and visually in Figure 5.

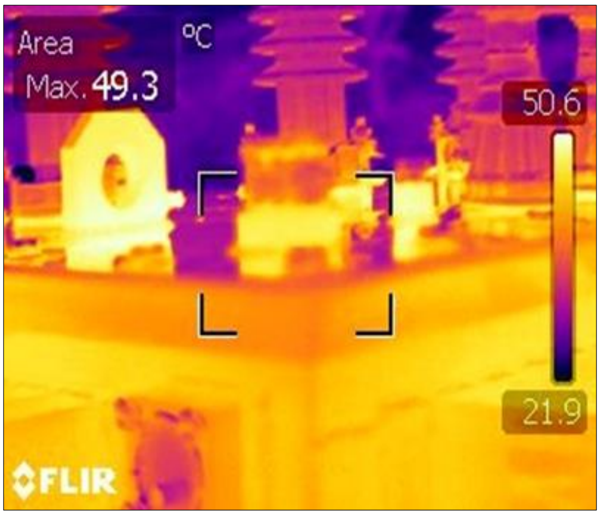

Fig 4: Transformer Top Packing Thermal

Fig 5: Visual of the Top Transformer Packing

Based on the thermal measurement results of the transformer's top packing in Figure 5.3.a with a temperature scale of 21.9°C-50.6°C, the temperature measurement on the top packing of the transformer was 49.3°C, which is seen in orange. This is because there is a current flowing in the transformer, namely in the coil, which causes heat in the transformer packing.

- **TM Transformer Bushing**

In the measurement of the TM bushing of the distribution transformer which was carried out during the day at 14.15 WITA, the thermal measurement results were obtained which can be seen in Figure 6 and visually in Figure 7.

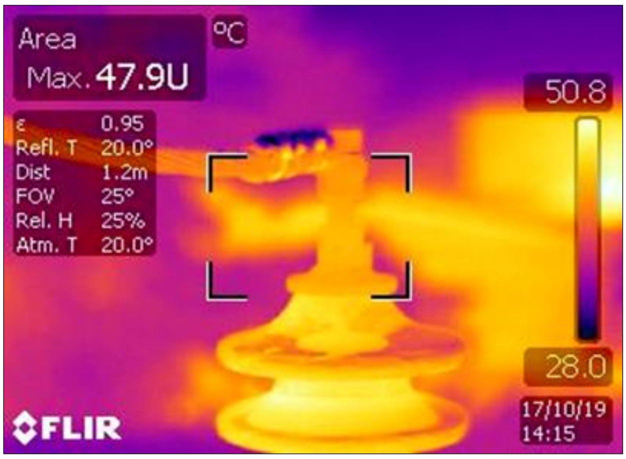

Fig 6: Thermal Bushing TM Transformer

Fig 7: Visual Bushing TM Transformer

Based on the results of thermal measurements on the medium voltage transformer bushing in Figure 5.4.a with a temperature scale of 28°C-50.8°C, the temperature measurement value of the medium voltage bushing was 47.9°C. This is because the bushing is a conductor coated with an insulator which then receives a 20-kV voltage supply from the JTM so that a current flow in the bushing. This continuous current flow which causes heat to arise in the bushing.

- **TR Transformer Bushing**

In the measurement of the TR bushing of the distribution transformer which was carried out during the day at 14.13 WITA, the thermal measurement results were obtained which can be seen in Figure 8 and visually in Figure 9.

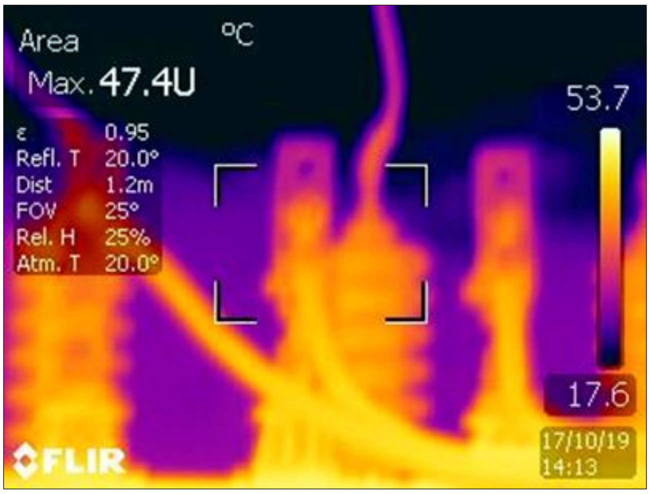

Fig 8: Thermal Bushing TR Transformer

Fig 9: Visual Bushing TR Transformer

Based on the results of thermal measurements on the low-voltage bushing of the transformer with a temperature scale of 17.6°C-53.7°C, the temperature measurement value on the low-voltage bushing was 47.4°C. This is caused by the transformer supplying a voltage that has been stepped down from 20 kV to 220 v, so that in the bushing on the low-voltage side there is a current flowing which then causes heat in the bushing.

- **TR Rack Handle**

In the measurement of the distribution TR rack handle which was carried out during the day at 13.57 WITA, the thermal measurement results were obtained which can be seen in Figure 10 and visually in Figure 11.

Fig 10: Thermal Handle of TR Trafo Rack

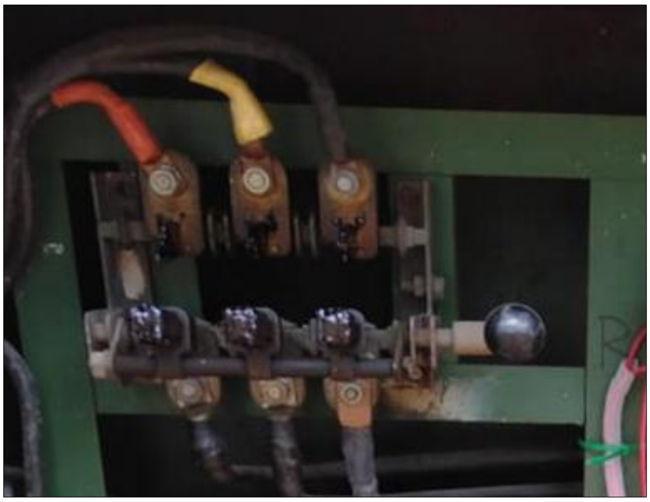

Fig 11: Visual Handle of the TR Trafo Rack

Based on the results of thermal measurements on the TR rack handle with a temperature scale between 45.5°C-38.3°C, the temperature measurement value on the low voltage rack handle is 44°C. This is because there is a current flowing in the TR rack handle. However, there is a difference in color on the incoming and outgoing sides where there is a difference in temperature color, this is because the switch on the TR rack handle is turned off. It can be seen that the incoming side is brighter in color with a temperature of around 44°C than the color on the outgoing side with a temperature of around 41°C because the current is stopped on the incoming side and there is no current flowing on the outgoing side.

- **Fuse TR**

In the distribution TR fuse measurement carried out during the day at 13.57 WITA, the thermal measurement results were obtained which can be seen in Figure 12 and visually in Figure 13.

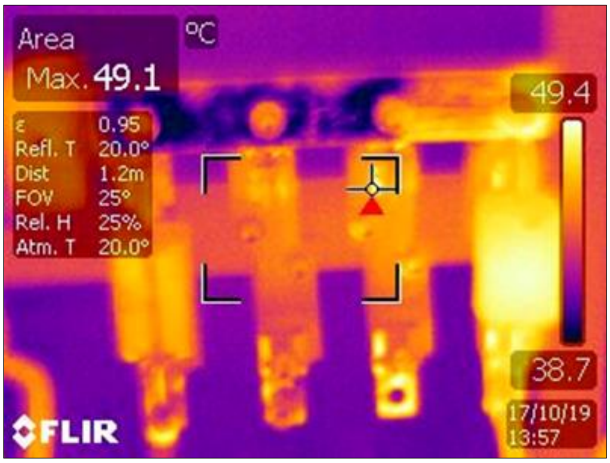

Fig 12: Thermal Fuse TR Transformer

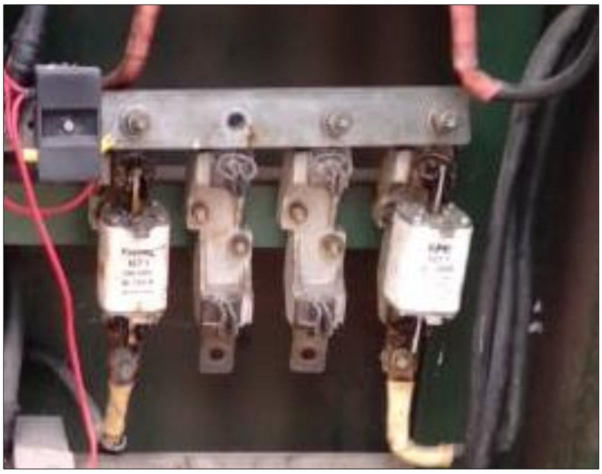

Fig 13: Visual Fuse TR

Based on the results of thermal measurements on the TR Fuse, it can be seen that the PR036 substation uses 2 routes, where the two Fuse routes have different temperatures. On Fuse Route C, the thermal measurement is bright yellow, which indicates that the Fuse C temperature is very hot and the measured temperature is 49.1°C. While on route A, the thermal measurement is orange with a temperature ranging from 43-44°C and tends to be the same as the color of the route next to it where there is no Fuse. This is because there is a current flowing which causes heat to arise in the Fuse, and this also indicates that there is an imbalance in the load in both routes so that the current flowing is not the same which causes a difference in the measured temperature on the Fuse.

1. Cable

In the measurement of the outlet cable carried out during the day at 13.59 WITA, the thermal measurement results were obtained which can be seen in Figure 14 and visually in Figure 15.

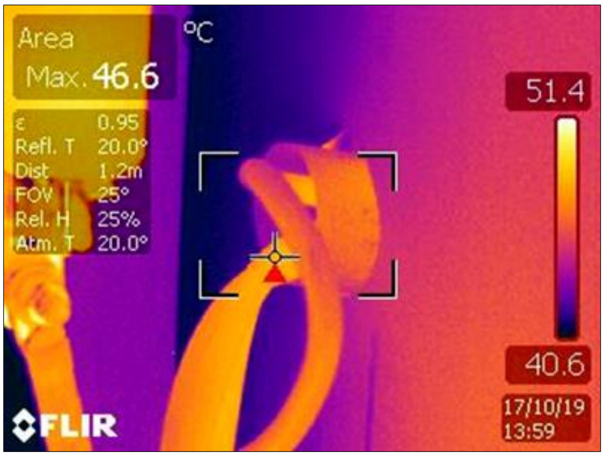

Fig 14: Thermal Fuse Cable

Fig 15: Fuse Cable Visualization

Based on the thermal measurements of the cable above, the cable's thermal color is orange with a measured temperature of around 46.6°C. This is due to the current flowing through the cable. Continuous current flow causes the cable's temperature to rise. The cable used is NYY, a cable with a PVC-insulated copper core, with a single or multiple core, and a PVC outer sheath.

3.2. Analysis

The reliability analysis of the PR 012 distribution transformer of PT PLN ULP Praya was carried out using a thermovision-based temperature measurement method with a FLIR T400 thermal camera. Measurements were carried out on several main components of the transformer, namely the transformer body, top gasket, medium voltage (TM) bushing, low voltage (TR) bushing, TR rack handle, TR fuse, and output cable. The thermovision method was used because it is able to detect heat distribution non-contact so that it can identify potential disturbances early before operational failure occurs. The following are the measurement results using thermovision showed at Table 3.

Table 3: Temperature measurement results on the PR 012 distribution transformer

Component	Temperature (Celcius)	Condition
Transformer Body	50,5	Normal
Transformer top packing	49,3	Normal
TM Transformer Bushing	47,9	Normal
TR Transformer Bushing	47,4	Normal
Rack Handle Transformer	44	Normal
Fuse Transformer	49,1	Normal
Cable	46,6	Normal

Based on Table 3. The measurement results show that the highest temperature is found in the transformer body at 50.5°C, followed by the top packing of the transformer at 49.3°C, the TR fuse in the C direction at 49.1°C, the TM bushing at 47.9°C, the TR bushing at 47.4°C, the cable at 46.6°C, and the TR rack handle at 44°C. Based on the temperature distribution, it can be seen that all components experience an increase in temperature due to the flow of electric current and power losses that occur during transformer operation.

The increase in temperature in the transformer body is primarily influenced by core losses and copper losses. Core losses originate from hysteresis and eddy currents in the iron core, while copper losses are caused by the current flow in the transformer coils. The higher the transformer load, the greater the current flowing, resulting in an increase in temperature. This condition is in accordance with the theory that the amount of heat generated is proportional to the square of the current based on the power loss equation:

$$P= I^2 \times R$$

This equation shows that increasing the current will increase power losses and result in an increase in temperature in the equipment.

Based on distribution transformer loading standards referring to IEC 60076 and IEEE C57.91, the transformer operating temperature is affected by ambient temperature, top-oil temperature rise, and hot-spot temperature rise. In distribution transformers with class A insulation, the oil temperature rise limit is generally around 55°C–65°C compared to ambient temperature, while the maximum coil hot-spot temperature is in the range of 95°C–110°C.

Compared with the thermal measurements obtained, all components in the PR 012 transformer remained below the critical temperature limit. The maximum measured temperature of 50.5°C on the transformer body was still within the safe range. This indicates that the transformer's cooling system is still functioning properly and there are no indications of overheating, which could accelerate insulation degradation.

However, the measurement results on the TR fuse show a temperature difference between the A and C lines.

The C line fuse has a temperature of 49.1°C while the A line fuse is in the range of 43–44°C. This temperature difference indicates an imbalance in the load between phases or between feeders. Load imbalance can cause uneven current distribution so that one line experiences a higher load than the other.

Long-term load imbalance can cause several impacts, including:

1. Increased power losses in transformers;
2. Accelerated aging of insulation;
3. Decrease in efficiency of distribution system;
4. Reduced operating life of transformer.

In terms of reliability, a transformer is considered to have good reliability if it can operate continuously without experiencing a temperature increase that exceeds standard operating limits. Temperature is a key parameter in determining reliability because the lifespan of a transformer's insulation is significantly affected by operating temperature.

4. Conclusion

Based on the results of the thermal testing that has been carried out, it can be concluded that the PR012 distribution transformer of PT. PLN ULP Praya still has a good level of operational reliability because all measurement points are in the normal temperature range and have not exceeded the permitted temperature limit. However, there are indications of load imbalance on the TR fuse that need attention through load evaluation and load equalization between phases so that the condition of the transformer is maintained and the risk of future disturbances can be minimized.

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