International Journal on "Technical and Physical Problems of Engineering" (IJTPE)
Published by International Organization of IOTPE
ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com
March 2024 Issue 58 Volume 16 Number 1 Pages 182-189

MODERN APPROACHES TO ELECTRICAL EQUIPMENT DIAGNOSTICS

S.V. Rzayeva N.A. Ganiyeva N.M. Piriyeva

Department of Electromechanics, Faculty of Engineering, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, sona.rzayeva@asoiu.edu.az, nigar.atakisiyeva75@mail.ru, necibe.piriyeva@mail.ru

Abstract- This article provides a comprehensive overview of modern electrical equipment diagnostic methods used to identify and prevent possible malfunctions and damage in power transmission and distribution systems. The authors reviewed various methods and approaches based on advanced technologies, such as vibration analysis, infrared thermography, ultrasonic flaw detection, resonant frequency diagnostics and others. The article focuses on the importance of using modern diagnostic methods in order to ensure the reliability and safety of electrical power systems. The article highlights the main advantages of each method, reveals its scope and identifies limitations. The main objective of this study is to expand the reader's understanding of the capabilities of modern diagnostic methods and their contribution to ensuring the efficient operation of electrical power equipment. The results of the study and practical recommendations presented in the article provide valuable information for energy specialists, technical services of enterprises and all interested parties seeking to minimize the risk of accidents and increase the efficiency of electrical equipment.

Keywords: Diagnostics, Electric Power Equipment, Methods, Visual Inspection, Tests and Measurements, Condition Analysis, Thermal Diagnostics.

1. INTRODUCTION

During the war years, bulky thermal imagers served mainly for military purposes, so the development of thermal imaging equipment accelerated after 1940. The Germans discovered that by cooling a photo resistive receiver, its performance could be improved.

After the 60s, the first portable thermal imagers appeared, with the help of which they carried out diagnostics of buildings. These were reliable devices, but with poor quality images. In the 80s, thermal imaging began to be introduced not only into industry, but also into medicine. Thermal imagers were calibrated so that they gave a radiometric image - the temperature of all points in the image.

The first gas-cooled thermal imagers displayed images on a black-and-white kinescope screen with a cathode ray tube. Even then, it was possible to record from the screen onto magnetic tape or photographic paper. Less expensive models of thermal imagers worked on the basis of vidicon tubes, did not require cooling, and were more compact, although the thermal image was not radiometric.

By the 1990s, matrix infrared receivers became available for civilian use, including arrays of rectangular IR receivers (sensitive pixels) mounted in the focal plane of the instrument lens. This was a significant advance over the first IR scanning receivers.

The quality of thermal images continues to improve and spatial resolution is systematically increased. The average modern matrix thermal imager is equipped with receivers that provide resolutions of up to 640×480 - which is 307.200 micro-IR receivers. Professional devices demonstrate even higher resolution, exceeding 1000×1000.

IR array technology has undergone significant development in the 2000s. The advent of long-wave thermal imagers capable of detecting wavelengths from 8 to 15 μm, as well as mid-wave thermal imagers optimized for wavelengths from 2.5 to 6 μm, has presented new opportunities.

The best thermal imager models have full radiometric functionality, support image overlay and are characterized by high sensitivity, not exceeding 0.05 degrees or even less. Over the past ten years, the cost of these devices has decreased by more than 10 times, while their quality characteristics have improved. All modern models are capable of interacting with computers, automating data analysis and providing convenient reports in various formats.

Electric power equipment plays a key role in ensuring the reliable operation of electric power systems. However, over time, it is subject to wear, damage, and other problems that can lead to system failures or even crashes. Therefore, the diagnostics of electric power equipment is an important step in its maintenance and reliability [1]. Power equipment diagnostics is the process of checking, analyzing and evaluating the condition of various components and systems used in power installations. The purpose of diagnostics is to detect possible problems, defects, damage or abnormal equipment, and to determine the need for repair, replacement or service.

Diagnostics of electrical power equipment may include the following steps [2-3]:

• Visual inspection: Visual inspection is the first step in the diagnosis and allows you to detect visible defects,

Registered: 230722 Article Info: 1719 Accepted: 240205
Reserved: 231031 Available: 240331

damage or non-compliance with safety requirements. This may include checking the condition of the insulation, connections, corrosion, and overall cleanliness of the equipment.

- Tests and measurements: For a more detailed assessment of the condition of the equipment, various tests and measurements are carried out. For example, measuring parameters such as voltage, current, resistance, capacitance, and inductance can determine whether they comply with regulations and standards. Tests for load, insulation and other characteristics are also carried out.
- Condition Analysis: Modern data analysis techniques are used to interpret measurement results and detect anomalies or faults in equipment operation. For example, thermal diagnostics can detect overheating or inhomogeneities in the temperature distribution, and vibration analysis can indicate defects or inconsistencies in bearings or other mechanisms.
- Visualization and documentation: Diagnostic results are recorded in the form of reports, graphs, photographs and other formats. This allows you to save data for further analysis, comparison and action plans. Visualization also helps to visualize the state of the equipment and its changes over time.

Examples of application of diagnostic methods:

➢ Transformer diagnostics: Thermal diagnostics are used to detect overheating and evaluate the thermal state of transformers. Measurements of parameters such as insulation resistance and magnetic induction help to determine the condition of the insulation and the magnetic circuit.

➢ Generator Diagnostics: Vibration testing and spectrum analysis help detect defects in bearings and other mechanisms in generators. Harmonic distortion analysis allows you to evaluate the quality of the electricity produced.

➢ Diagnostics of high-voltage transmission lines: Measurement of parameters such as insulation resistance and capacitance allow you to determine the condition and wear of transmission lines. Strength and load tests are also carried out to evaluate their reliability and safety.

Thermal imaging diagnostic method, also known as instrumental terrorism, is known from modern approaches to identifying and analyzing faults in electrical power equipment and equipment. It is based on measuring the thermal effect, or infrared vision, that objects emit depending on their temperature. This method can be used to detect overheating, inhomogeneities, leak selection and other anomalies that relate to problems with the operation of the equipment. Comparison of the results of the thermal imaging method with a similar diagnostic method makes it possible to determine its effectiveness and efficiency.

Let's compare with other common diagnostic methods:

- Visual Inspection: Visual inspection of equipment is the most common method. However, it is limited to cases of identifying identified problems that occur only with thermal imaging diagnostics.
- Vibration Analysis: This method is used to identify mechanical faults in equipment such as uneven rotation, unbalance, bearing wear, etc. e. In the case of the thermal imaging method, the condition of the equipment can be better assessed.
- Ultrasonic flaw detection: This method allows you to detect food defects, cracks, leaks and other manifestations in materials. Together with the thermal imaging method, it is possible to more accurately determine the location and nature of the malfunction.

An analysis of the results of the thermal imaging method with the above similar methods shows its advantages and specific verification to identify problems related to temperature and thermal radiation. The thermal imaging method detects high sensitivity to small temperature changes, which allows you to identify problems and prevent accidents.

However, it is important to note that for more frequent diagnostics and equipment condition, an integrated approach is often used, combining several methods, including a thermal imaging scheme. This allows you to reduce the likelihood of false attacks and get more reliable results.

Assessing the technical condition of electrical equipment is a key component in all aspects of electrical equipment operation.

One of its main goals is to identify the serviceability or malfunction of equipment. Equipment that meets all requirements established by regulatory documents is considered to be in good working order. Otherwise, it is considered faulty.

The transition from a serviceable state to a faulty state occurs due to defects. The term "defect" is used to refer to any single non-conformity of the equipment.

Defects in electrical equipment can occur at different stages of its life cycle: during manufacturing, installation, configuration, operation, testing and repair. These defects can have different consequences. There are many types of defects in electrical equipment.

Let's start with assessing the condition of defects using thermal imaging diagnostics, which is most often used in infrared inspection. There are usually four main categories or degrees of development of the defect:

- Normal condition of the equipment (no defects). Defect in the initial stage of development (defect that does not clearly affect the operation of the equipment).
- A highly developed defect (a defect that limits the ability to operate equipment or shortens its service life). A defect in the emergency stage of development (a defect that makes the operation of equipment impossible or unacceptable).

Depending on the degree of development of defects, appropriate decisions and measures are taken to eliminate them:

- Replacement of equipment, its part or element. Repair of equipment or its element (after which an additional check of the quality of the repair performed is carried out).
- Continued operation with increased inspection frequency. Carrying out other additional tests.

When identifying defects and making decisions about the further operation of electrical equipment, one should also take into account the reliability and accuracy of the information received about the condition of the equipment.

Any non-destructive testing method does not guarantee complete reliability of the assessment of the object's condition. Measurement results always contain errors, which can lead to false control results:
- A serviceable object is considered unusable (false defect or error of the first type).
- A faulty object is considered acceptable (undetected defect or error of the second type).

Errors in non-destructive testing can have various consequences and, therefore, it is very important to take them into account in the process of diagnosis and decision-making about repair and replacement of equipment.

It is important to note that when carrying out any type of non-destructive testing (NDT), there are a number of factors that influence the measurement results and analysis of the data obtained. These factors can be divided into three main groups:
- Environment: Meteorological conditions (air temperature, humidity, cloudiness, wind force, etc.), time of day.
- Human factor: Qualification of personnel, professional knowledge of equipment, skills in thermal imaging control.
- Technical aspect: Information base about the equipment being diagnosed (material, passport data, year of manufacture, surface condition, etc.).

In fact, there are many other factors that can influence NDT results and data analysis. However, this topic is so vast that it deserves a separate voluminous study. It is for this reason that each type of non-destructive testing is regulated by appropriate regulatory documentation.

These documents define the goals of non-destructive testing methods, procedures for its implementation, control tools used, analysis of results, types of possible defects and recommendations for their elimination.

2. PROBLEM SETTING

The main aspect in the operation of power plants and substations is the assessment of the technical condition of the equipment. In this case, the main task is to identify the fact of a malfunction or serviceability of the equipment. [4]. It is customary to consider equipment serviceable, the condition of which meets all the requirements established by regulatory documents, otherwise it is faulty. The transition of the product from a good state to a faulty one occurs due to defects. To date, there are many modern diagnostic methods that allow you to determine the real state of the equipment with a high degree of probability and predict its change in the near future. Thermal imaging inspection is one of such modern and highly effective methods of diagnostics [5].

Thermal imaging inspection of electrical equipment is the most effective preventive measure to prevent accidents during its operation. It is carried out in order to identify visually imperceptible defects in various parts of the power network. Moreover, a malfunction is detected at the stage of its formation, which allows you to respond in a timely manner and take appropriate measures. Thermal imaging surveys are very effective in identifying defects in existing electrical equipment, including contact connections, cable overload areas; they allow to assess the thermal state of transformers for various purposes, electric motors, arresters, reactors, and other electrical equipment during their operation without removing the voltage. Thus, avoiding potential accidents, the safety of electrical equipment operation increases, and significant financial resources are saved. Burnt insulation of a cable or electrical wire and a short circuit as a result, for example, can cause enormous damage to an enterprise.

The thermal inspection method is one of the non-destructive testing methods used to detect defects, changes or inhomogeneities in materials or structures by measuring thermal characteristics. The main idea of the thermal control method is that defects or anomalies in materials or objects have different thermal conductivities, heat capacities, or other thermal properties compared to the surrounding areas. When applying thermal control, the object under study is heated or cooled, and then the distribution of heat on its surface or inside it is measured. By analyzing the data obtained, it is possible to identify inhomogeneities, defects, cracks, voids or other problems.

There are several different methods of thermal control including:

- IR thermography (infrared thermography): This method uses an infrared camera to measure the thermal radiation of objects. It is often used to detect problems in buildings, electrical systems, and in medicine to detect disease or damage.
- Ultrasonic Thermal Inspection: This technique combines ultrasonic testing with heating/cooling of an object to detect internal defects such as cracks, inclusions, or weld defects.
- Thermal current monitoring (TCM): This method uses current pulses to heat an object and then measures the thermal distribution on its surface to detect defects or changes.
- Radiographic Thermal Inspection: This technique combines X-ray or gamma radiography with thermal inspection to detect defects and inhomogeneities within objects, such as welded joints or complex structures.

The control principle is as follows:

1. Heat Generation: First you need to create a difference in temperature between the areas of interest. This may be due to the use of a source or system, or an external heat source.
2. Thermal vision measurement: A special infrared camera or thermal imager is used to measure the infrared vision emitted from the surface of an object. Different materials and defects can have different thermal characteristics, which allow anomalies to be detected.
3. Preview and analysis: The infrared camera creates images in which the display temperatures of colors or shades vary. After obtaining the map, analysis can be carried out to identify areas where abnormal heat generation occurs, which may indicate the presence of defects, deficiencies, or problems.

There is a wide variety of instruments for thermographic photography. The most common and affordable are the means of thermal imaging control BALTECH and TESTO. The technical characteristics of these devices allow you to perform a large amount of thermal imaging measurements. Thermal imagers of the

BALTECH TR-0170 series are a new unique solution for thermal non-destructive testing at any distance to the object with great accuracy. A wide measurement range and a set of interchangeable lenses allow you to use them to diagnose equipment or perform an energy audit of any objects. The thermal imager TESTO 875 is ideal for professional industrial and building thermography, while at the same time allowing you to work quickly and easily. It is easy and versatile in operation and can be used, for example, in the maintenance of industrial and mechanical equipment, to detect defects in building envelopes, as well as to monitor the technical condition of various operating electrical equipment.

Both of these thermal imagers can be used to implement both active control methods and passive thermography methods. The former is based on preheating and subsequent measurement of the temperature field of the surface of an object and are used to detect defects, changes in the structure and physicochemical properties of objects associated with the anisotropy of thermal conductivity, heat capacity, and the magnitude of the absorption coefficient. They are also widely used in the construction and repair of buildings, when using thermal imagers, walls, roofs, ceilings are examined to identify places of heat leakage, moisture accumulation, and the state of hidden communications is assessed. Passive methods involve the use of the controlled object's own radiation and are used to detect deviations from the specified shapes, geometric dimensions and thermal regime of objects.

3. SOLUTIONS TO THE PROBLEM

The essence of the thermal (thermal imaging) diagnostic method is the remote recording of the temperature field on the surface of the controlled equipment by measuring equipment, the construction and analysis of thermograms using a PC to detect and classify defects and make a decision on the further operation of the equipment [7-8]. The presence of a defect in such diagnostics is characterized by an anomalous change (as a rule, an increase) in the temperature in the defective zone compared to the qualitative areas. As a means of measuring surface temperature, it is planned to use a thermal imager or an IR scanner that registers IR radiation along the scanning line, the position of which is controlled on the monitor from the visible image of the object [6].

The advantages of thermal imaging diagnostics of electrical equipment in comparison with other methods of non-destructive testing are:

➢ Inspection of objects during operation without stress relief;

➢ The possibility of classifying defects according to their degree of danger;

➢ The possibility of objective documentation of the detected defects.

The main technical requirements for the parameters of these tools are:

- Spectral range – 2.5-5.0 or 8.0-14.0 microns;
- Temperature measurement error – ± 2.00 °C;
- Sensitivity – 0.20 °C;
- Range of measured temperatures –20 °C to +150 °C;
- Image format - at least 320×240 elements for thermal imagers and at least 100 elements for scanners;
- The number of saved images - at least 30;
- Temperature conditions of work –15 °C to +50 °C.

As criteria for assessing the technical condition of current-carrying connections, the following are provided:

• Temperature rise - the difference between the measured heating temperature and the ambient air temperature;

• Excess temperature - the excess of the measured temperature of the controlled node over the temperature of similar nodes under the same conditions;

• Defectiveness coefficient (K_d) - the ratio of the measured temperature rises of the contact connection to the temperature rise measured on the entire section of the bus (wire), separated from this contact connection at a distance of at least 1 m.

An indispensable condition for calculating these criteria is the knowledge of the current load I_{work} of the controlled equipment and the value of the rated current I_{nom}. The allowable temperature rise values given in the normative documentation are calculated for the rated current I_{nom}, therefore the measured temperature rise value T_{meas} should be reduced to the rated current through the ratio: $T_{nom}=T_{meas}\ (I_{nom}/I_{work})^2$. This ratio can be used when measuring the temperature rise of contacts and bolted contact connections (CC) at load currents (0.6-1.0) I_{nom}. At load currents (0.3-0.6) I_{nom}, the temperature value $T_{0.5}$, recalculated to $0.5I_{nom}$, should be used as a standard: $T_{0.5} = T_{meas}(0.5I_{nom}/I_{work})^2$.

Thermal imaging inspections of electrical equipment at load currents less than $0.3I_{nom}$ are not recommended, since such a load does not contribute to the detection of defects, especially at an early stage of their development. The calculated values of temperature rise T_{nom} and $T_{0.5}$ allow for contacts and bolted CC to assess the degree of failure, using a criterion called "excess temperature". If the excess temperature is in the range of 5-10 °C, then this is assessed as the initial stage of the malfunction and measures should be taken to eliminate it during the planned repair. An excessive temperature of 10-30 °C is assessed as a developed defect, which should be eliminated at the next withdrawal of electrical equipment from operation. If the excess temperature exceeds 300 °C, then this is assessed as an emergency situation requiring immediate elimination of the defect.

The assessment of the thermal state of power cables is recommended to be carried out according to the criterion "defectiveness coefficient K_d". This allows you to determine the degree of failure. If K_d<1.2, then this is estimated as the initial degree of malfunction. If K_d=1.2-1.5, then this is an already developed defect. As an emergency, the situation is assessed when K_d>1.5. The use of thermal imagers and scanners makes it possible to diagnose not only such fairly simple assemblies as contact connections, but also to assess the technical condition of such types of equipment as transformers, electric motors, etc.

Transformers are part of the main equipment of power stations, step-up, step-down and distribution substations. Their importance in power systems leads to the need for a comprehensive diagnostic examination, the main purpose of which is to give an objective assessment of the state of transformers, identify defects, develop recommendations for their elimination and carry out their further trouble-free operation [9-10]. Along with traditional methods for diagnosing transformers, such as determining the level and location of sources of partial discharges, chromatographic analysis of gases dissolved in oil (CAGD), thermal imaging inspection of transformers is increasingly being used. It allows you to assess its thermal state and the health of its constituent systems and components.

The experience of thermal imaging diagnostics of power transformers shows that it can detect the following faults:

- Violations of the mechanical insulation of the windings, burnout of the turns of the winding due to short circuit currents;
- Overheating of the magnetic circuit due to short circuit currents;
- Malfunctions of cooling systems (oil pumps, fans, filters, etc.);
- Violation in the operation of voltage regulation devices under load (OLTC);
- Formation of stagnant oil zones in the transformer tank;
- Violations of the tightness of the tank;
- Overheating of internal contact connections of low voltage windings with transformer leads;

When analyzing the results of a thermal imaging survey, it is necessary to take into account the design of this type of transformer, the method of cooling the windings and magnetic circuit, the conditions and duration of operation. This requires preliminary preparation for the inspection by studying the passport and design data of the transformer, the period and operating conditions, information about the results of repairs carried out, and the degree of loading of the transformer.

The result of the thermal imaging inspection of the transformer is a report with fixation of the detected defects, the degree of their development, recommendations are given for eliminating defects and thermograms of defects and their binding to the video image are attached. This allows you to plan repair work, based not only on the standards, but also use the results of a thermal imaging survey, which reflect the real picture of the technical condition of the equipment.

Thermal imaging inspection of oil-filled current transformers (CTs) allows assessing the condition of internal and external contact connections, Figure 1. Taking into account the specifics of the operation of measuring and relay CTs at the preliminary stage of preparation, it is necessary to pay attention to the number of CC currents flowing through the windings and their magnitude, as well as to the results of measuring the insulation characteristics of the windings.

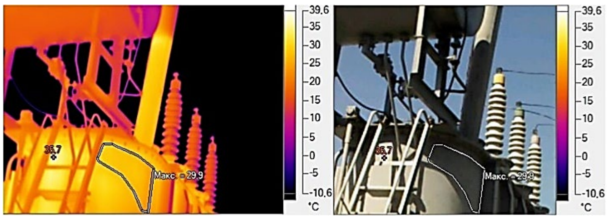

Figure 1. Thermal imaging inspection of oil-filled current transformers

It is necessary to make a phase-by-phase comparison of the temperatures measured in the same areas of the surface of the CT covers. The temperature difference should not exceed 0.3 °C. The heating of the contacts of the internal switching device on the thermogram appears as a temperature anomaly on the surface of the expander. Exceeding the temperature by more than 10-15 °C indicates an emergency state of the switch. Mass-filled voltage transformers (VT) of the NKF series operate in saturation mode, therefore, during thermal imaging, this appears on the thermogram as an elevated temperature on the porcelain cover.

During a thermal imaging inspection of circuit breakers, the assessment of the state of external contacts and CC that are in the air is assessed by the temperature rise according to the method described above for the CC. It is recommended to evaluate the contacts of arc chutes according to the nature of the temperature distribution of the phases. Comparing the measured temperatures of different phases with each other, the arc chute is faulted by the value of the excess temperature. In a similar way, during a thermal imaging survey, the thermal state of disconnectors and separators is assessed. The volume of thermal imaging inspection of electric motors depends on their power and design. The main objects of inspection are: stator housing, collector, bearings, terminal box and cooling system. Abnormal zones on the stator housing indicate the appearance of turn short circuits in the winding coils or blockage of the ventilation ducts. Checking the terminal box provides information about the state of the CC. The heating temperature of the motor bearings must not exceed the values specified in the regulatory literature or in the manufacturer's instructions.

A comparative analysis of the main performance characteristics of thermal imagers of the BALTECH TR-0170 and TESTO 875 (Figure 2) series is given in [11]. The devices under consideration have a wide range of functions that allow high-quality and safe thermal imaging control of various technical objects, buildings, structures and operating electrical equipment. The thermal imager of the BALTECH TR-0170 series has somewhat greater capabilities, but for monitoring local objects, especially in conditions of limited access, the TESTO 875 thermal imager is more functional.

Consider the studies carried out using the TESTO 875 thermal imager. Figure 3a show a general view of the ship's fire pump electric drive and its thermal imaging image (Figure 3b), obtained using the TESTO 875 thermal imager. The area under study is highlighted on the thermal imaging image, covering the lower bearing assembly and the stator of the electric motor.

Figure 2. TESTO 875-1 thermal imager

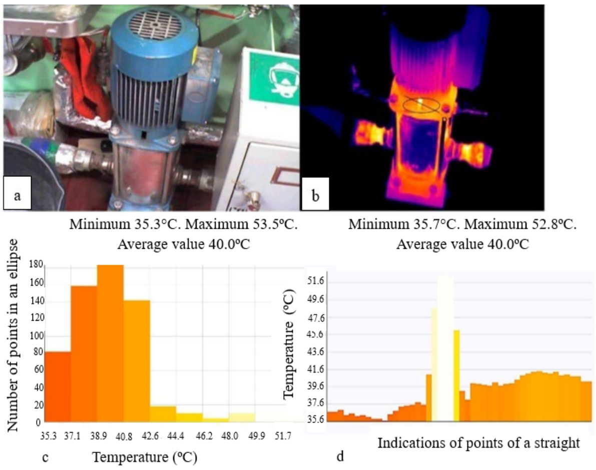

Figure 3. Ship electric fire pump (a), its thermal image (b) and thermograms taken with the TESTO 875 thermal imager (c, d)

Using the TESTO program, the surface under study was converted into thermograms (Figure 3c, 3d), clearly reflecting the distribution of temperature ingredients in the study area.

Thermograms reflect the number (hereinafter: *n*) of points on the surface of an object with a given temperature and the numerical values of the temperature of a certain set of these points. To analyze the elements of an electric pump with a higher temperature, it is necessary to select an area in the region of the bearing assembly (Figure 3b) and also build a thermogram of this area (Figure 3c). The area under study can be characterized not only by area, but also by a set of points located on a straight line, or by separate, arbitrarily chosen points. Figure 3b shows the straight-line P crossing the area under study.

The TESTO program allows you to build a separate linear thermogram for the designated straight-line P, which reflects the temperature distribution along the length n of this straight line (Figure 3d). This thermogram clearly shows the peak temperature in the friction area of the bearing and the distribution of temperature values along the straight line P. In general, the analysis of all considered thermograms allows us to conclude that the bearing temperature is normal, the equipment is operating in normal mode. High-quality construction of thermograms of the studied objects and their primary analysis is provided by an automated software package, which is included in the package of each thermal imager. In addition, the programs are universal and allow you to process thermograms received from thermal imagers from other manufacturers.

Along with thermal imagers, pyrometers and linear scanners are widely used for diagnosing electrical equipment. Pyrometers are infrared devices for remotely measuring temperature at a point. There are two types of pyrometers: manual - for one-time examinations and stationery - for monitoring technological processes. The variety of models (about 500) makes it easy to select the necessary modification for specific applications. Line scanners are permanently mounted scanners designed to provide continuous thermal imaging of moving objects, such as rotary kilns. A complete thermal image is obtained by continuously scanning a narrow beam in a plane perpendicular to the direction of motion or rotation of the object.

When carrying it out, it is essential to identify and eliminate systematic and random errors that affect the measurement results [12].

Systematic errors are contained in the design of the measuring device, and also depend on its choice in accordance with the requirements for measurement perfection (resolution, field of view, etc.).

Random errors that arise during IR testing can be the impact of solar radiation, the choice of emissivity, etc.

Let's consider the IR diagnostic technique using the example of a power transformer.

The procedure for carrying out IR diagnostics, evaluation of measurement results and their reliability are largely determined by taking into account the design features of the controlled electrical equipment and its main elements.

Experience in carrying out IR diagnostics of power transformers has shown that the following faults can be identified with its help:

- the occurrence of magnetic stray fields in the transformer due to disruption of the insulation of individual elements of the magnetic circuit (consoles, studs, etc.);
- disruption of the operation of cooling systems (oil pumps, filters, fans, etc.) and assessment of their effectiveness;
- changes in the internal circulation of oil in the transformer tank (formation of stagnant zones) as a result of sludge formation, design flaws, swelling or displacement of winding insulation (especially for transformers with a long service life);
- heating of internal contact connections of LV windings with transformer terminals;
- turn short circuit in the windings of built-in current transformers;
- deterioration of the contact system of some versions of the on-load tap-changer, etc.

The capabilities of IR diagnostics in relation to transformers have not been sufficiently studied.

The difficulties are that:

- firstly, heat generation when local defects occur in the transformer is “muffled” by natural heat flows from the windings and magnetic circuit;
- secondly, the operation of cooling devices, which promotes accelerated oil circulation, seems to smooth out the temperatures that arise at the site of the defect.

When analyzing the results of IR diagnostics, it is necessary to take into account the design of transformers, the method of cooling the windings and magnetic circuit, operating conditions and duration, manufacturing technology and a number of other factors.

Since the internal state of a transformer is assessed by a thermal imager by measuring the temperature values on the surface of its tank, it is necessary to take into account the nature of heat transfer of magnetic core and windings.

In addition, heat sources are:
- massive metal parts of the transformer, including the tank, pressing rings, screens, pins, etc., in which heat is generated due to additional losses from eddy currents induced by stray fields;
- current-carrying parts of the bushings, where heat is generated due to losses in the current-carrying part and in the transition resistance of the winding tap connector;
- contacts of on-load tap-changer switches.

Hermographic examination of a transformer is in many ways an auxiliary means of assessing its thermal state and serviceability in the operation of associated systems and components. The thermographic examination of the transformer should be preceded by familiarization with the design of the windings, the cooling system, the results of the transformer's operation, the volume and nature of the repair work performed, the duration of operation, the analysis of damage to transformers of identical design (if any), results of operational tests and measurements, etc.

The surfaces of transformer tanks, thermosiphon filters, cooling systems must be inspected and, if possible, dirt, traces of oil must be removed from them, rust must be painted over, i.e. conditions have been created to ensure the same emissivity of transformer surfaces.

4. CONCLUSIONS

The widespread use of thermal imaging control methods makes it possible to qualitatively solve the problem of diagnosing and assessing the technical condition of various industrial facilities.

1. The thermal imaging method has a number of undeniable advantages (remoteness, clarity, objectivity, high performance, efficiency, etc.) compared to traditional methods for diagnosing electrical equipment, which makes it indispensable when examining a large group of dissimilar objects of electrical equipment within one enterprise.
2. Thermal imaging inspections of electrical equipment are carried out during its operation without disconnecting the load, therefore, during periodic inspections, defects can be quickly detected at an early stage of their development. An analysis of the results of the thermal imaging method with the above similar methods shows its advantages and specific verification for detecting problems related to temperature and thermal radiation. Thermal imaging method of detecting hypersensitivity to small temperature changes allows you to identify problems and prevent emergencies.

REFERENCES

[1] Y. Lina, C. Lia, Y. Yanga, J.F. Qina, X. Sub, H. Zhanga, W. Zhangao, "Automatic Display Temperature Range Adjustment for Electrical Equipment Infrared Thermal Images", The 4th International Conference on Power and Energy Systems Engineering (CPESE 2017), pp. 454-459, Berlin, Germany, 25-29 September 2017.
[2] A.C. Teich, "Thermography for Power Generation and Distribution", Materials Evaluation, Columbus, American Society for Nondestructive Testing, Vol. 50, No. 6. pp. 658-662, 1992.
[3] R.R. Rayl, "Transmission Line Infrared Procedures", ASNTs Infrared Thermography Topical Conference Cleveland, American Society for Nondestructive Testing, Columbus, p. 117-127, 1997.
[4] A.V. Afonin, R.K. Newport, V.S. Polyakov, et al., "Fundamentals of Infrared Thermography", Mining Science and Technology, p. 240, Moscow, Russia, 2004.
[5] S.A. Bazhanov, "Infrared Diagnostics of Electrical Equipment of Switchgears", Mining Science and Technology, p. 76, Moscow, Russia, 2000.
[6] S.V. Rzayeva, N.A. Ganiyeva, "Application of Emission Spectra to Study Characteristics of a Barrier Discharge", The 18th International Conference on Technical and Physical Problems of Engineering (ICTPE), pp. 119-123, 30 October 2022.
[7] S.V. Rzayeva, N.A. Ganiyeva, N.M. Piriyeva, "Investigation of Characteristics of a Barrier Discharge in a Water-Air Environment", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 55, Vol. 15, No. 2, pp. 44-49, June 2023.
[8] S.V. Rzayeva, N.S. Mammadov, N.A. Ganiyeva, "Over voltages", Journal of Energy Research and Reviews, Vol. 13, No. 1, pp. 7-13, India, 2023.
[9] S.V. Rzayeva, N.S. Mammadov, N.A. Ganiyeva, "Neutral Grounding Mode in the 6-35 KV Network through an Arcing Reactor and Organization of Relay Protection Against Single-Phase Ground Faults" German International Journal for Contemporary Science, Issue 42, pp. 31-34, Germany, October 2022.
[10] www.infiray.com.
[11] https://baltech.ru/baltech-tr-0170/.
[12] V.P. Vavilov, A.N. Aleksandrov, "Infrared Thermographic Diagnostics in Construction and Energy", M.: Energoprogress, p. 186, 2014.

BIOGRAPHIES

Name: **Sona**
Middle Name: **Vaqif**
Surname: **Rzayeva**
Birthday: 14.10.1976
Birthplace: Baku, Azerbaijan
Bachelor: Electrical Engineering, Department of Electrothermal Installations and High Voltage Technology, Energy

Faculty, Azerbaijan State Oil Academy, Baku, Azerbaijan, 1998
Master: Electrical Engineering, Department of Electrothermal Installations and High Voltage Technology, Energy Faculty, Azerbaijan State Oil Academy, Baku, Azerbaijan, 2006
The Last Scientific Position: Chief Laborant, Department of Electromechanics, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, Since 2003
Research Interests: High Voltage Technologies, Electrochemistry
Scientific Publications: 43 Papers, 2 Books, 2 Patents, 11 Theses

Name: **Nigar**
Middle Name: **Akif**
Surname: **Ganiyeva**
Birthday: 19.11.1975
Birthplace: Baku, Azerbaijan
Bachelor: Electrical Engineering, Department of Electrothermal Installations and High Voltage Technology, Energy Faculty, Azerbaijan State Oil Academy, Baku, Azerbaijan, 1999
Master: Information, Department of Informatics, Odessa Law Academy, Kiev, Ukraine, 2015
The Last Scientific Position: Chief Laborant, Department of Electromechanics, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, Since 2000
Research Interests: High Voltage Technologies, Electrotechnical Materials
Scientific Publications: 20 Papers

Name: **Najiba**
Middle Name: **Melik**
Surname: **Piriyeva**
Birthday: 13.12.1973
Birthplace: Kurdamir, Azerbaijan
Bachelor: Electrical Engineering, Department of Electrothermal Installations and High Voltage Technology, Energy Faculty, Azerbaijan State Oil Academy, Baku, Azerbaijan, 1997
Master: Electrical Engineering, Department of Electrothermal Installations and High Voltage Technology, Energy Faculty, Azerbaijan State Oil Academy, Baku, Azerbaijan, 1999
Doctorate: Electrotechnical Systems and Complexes, Department of Electromechanics, Azerbaijan State University of Oil and Industry, Baku, Azerbaijan, 2017
The Last Scientific Position: Assist. Prof., Department of Electromechanics, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, Since 2001
Research Interests: High Voltage Technologies, Electrotechnical Materials
Scientific Publications: 53 Papers, 7 Books, 5 Theses