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To cite this article: F Nicolescu and D N Robescu 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **664** 012045

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Fault analysis for wastewater treatment plant equipment using thermography

F Nicolescu¹, D N Robescu²

¹Maritime University , Constanta, Romania

²University POLITEHNICA , Bucharest , Romania

Corresponding author: florinnicolescu61@gmail.com

Abstract. Infrared thermography is a very effective non-destructive control method for detecting and locating defects. It is a technique that allows to obtain, with the help of an equipment called thermal imaging camera, the image or thermal imprint of a targeted area in the field of infrared radiation. Infrared thermography deals with the acquisition and analysis of thermal information obtained using non-contact infrared scanning equipment

1. General Consideration

Infrared thermography (TIR) is a modern technique that deals with the acquisition and analysis of thermal information obtained remotely using non-contact infrared scanning equipment. Infrared thermography is a very effective non-destructive and non-invasive control method for detecting and locating electrical and mechanical defects. Thermography is a technique that allows obtaining, with the help of equipment called thermal imaging cameras, the image or thermal footprint of an area monitored in the field of infrared radiation. In recent years, thermography has acquired a special importance in the maintenance activity, especially in the following fields: periodic preventive control of electrical installations to identify "hot" points generated by high resistance connections, improper grounding, and electrical circuits in which abnormal power flows occur due to imbalances or overloads, control of mechanical and electrical equipment, in association with vibration analysis, control of thermal insulation, etc.[1]

Infrared thermography allows the measurement of temperatures at a distance (a few centimeters to tens of meters) and without direct contact, which is indispensable, as for example, in the case of live electrical equipment or in the case of parts or materials at high temperature, or inaccessible. By this, thermography is a non-destructive investigation method, because it does not intervene and does not influence in any way the investigated material, object or process.[2]

Thermography has long been used in industry to monitor the thermal regimes of technological installations and processes. All bodies have a thermal footprint, the infrared radiation emitted by them being different for areas with different temperatures. This radiation can be captured with specialized transducers that convert infrared radiation (invisible to the eye) into visible images. However, it is known that any object with a temperature higher than absolute zero (0 Kelvin = -273.15 °C) emits infrared radiation (energy). In the electromagnetic spectrum, the range of infrared radiation is between 0.7 and 100 µm but the wavelengths used by thermographic cameras is currently in the range of 2 - 15 µm. Using infrared thermography, we can now monitor the performance of thermal phenomena that



occur in electrical and mechanical equipment in wastewater treatment plants. In the most common situations, defects or problems of non-compliant operation are accompanied by an increase in temperature in the area of the defect, which is translated by an increase in the emission of infrared radiation.

However, there are also situations in which the unjustified decrease in temperature in certain component parts of the equipment is translated as a signal that can lead to a non-conformity in their operation. Following the thermographic scanning of the devices or the component parts of the systems, we will obtain infrared images, (this thermal images represent a "thermal map") that analyzed by color variation will suggest the different operating temperature levels of the inspected equipment. After generation, the thermogram is digitally processed in order to locate the exact points of thermal stress and defects. It should also be noted that evaluating a thermogram obtained by scanning a device, system or installation during proper operation can provide extremely valuable information about the normal thermal map that will be a reference in evaluating future scans and timely remediation of potential failures.

2. Wastewater treatment plant equipment

Within a wastewater treatment plant there are a multitude of electrical equipment and devices whose role is to ensure the development in good condition and without interruption of the treatment process. The continuous process character of WWTP is also reflected in the electrical equipment. When choosing electrical equipment and appliances, it will be considered that their number is equal to the number of necessary equipment plus a spare one.

2.1. Transformation stations, transformers

The transformation substations that ensure the power supply of the WWTP are of the type Mt 20 kV/ Lt 0.4 kV and are equipped with electrical transformers whose powers vary between 400 and 630 kVA depending on the value of the active power of the consumers served by each substation. transformation in part.



Figure.1 Transformation Station 20/0,4 kV

These transformers are three-phase oil-cooled transformers, their adjustment being done under load, the circulation of the cooling oil being natural and the cooling of the oil being natural. All the parameters of the electrical network are permanently monitored in the SCADA system, so that any non-compliance in the WWTP power supply system can be corrected in real time. The medium voltage cells supplied from the national energy system through the 20kV Mt network, supply the transformers that supply voltage on the 0.4 kV LT electrical distribution panels.



Figure. 2 Medium Tension Cell

2.2. Backup generators

Although such equipment are considered particularly important objectives and, theoretically, the national energy system through local energy distributors must ensure a continuous supply scheme of theirs, there may be situations in which the power supply is interrupted for various periods of time, which would produce major effects at the level of the WWTP. Therefore, when designing the internal power supply system of such an objective, backup power supplies are provided to ensure continuity in the power supply. These backup power supplies are electric generators or generators that are thermal machines coupled to shafts with electric generators.



Figure. 3 Backup generators

Considering that the WWTP must not go into failure, the power of the generators for the backup supply is chosen as to ensure the entire necessary power for the operation of the entire WWTP. The generators that ensure the continuity for the WWTP power supply have powers between 400 and 630 kVA. The automatic transition from the basic power supply, from the electrical network, to the backup power supply is done by means of an automation equipment called A.A.R., the automatic activation of the reserve.

2.3 Electrical switchboards, electrical appliances

Electrical switchboards are complex electrical equipment that have the role of distributing electricity from transformers to consumers powered by its bars. Depending on the complexity of the electrical panels and the functionality they must fulfill, they are divided into:

- general low voltage switchboards - these are usually found in the transformer station and ensure the distribution of electricity through the cables of the main and secondary switchboards;
- the main and secondary panels - are fed from the general panels and in turn supply distinct technological sections or equipment within the technological process;
- dedicated panels of various equipment (pumps, ventilation panels, compressors, etc.) - ensures the supply of separate equipment in the process.

The electrical panels include several types of electrical appliances, each of them having a well-defined role in the electrical scheme of energy distribution. Automatic circuit breakers devices that ensure the connection and disconnection of the supply circuits of the consumers connected to the electrical panel. Fuses in their constructive, fusible or automatic forms have the role of protecting the circuits against short circuit and overload.

The contactors have the role of execution element, coupling or disconnecting supply circuits depending on the received order. The relays have various constructive forms depending on the role they must play in the electrical diagrams. Thus, we can find thermal protection relays (especially on the supply circuits of electric motors, thus protecting them from overload), time relays, execution relays, differential relays, etc. Reactive energy compensation is also done at the level of general electrical panels by installing automatic reactive energy compensation batteries. The compensation of the reactive energy can be done both at the level of the general panels in the stations, and locally, at the level of the large consumers that produce the reactive energy.



Figure. 4 Automatic battery for local reactive energy compensation

3. Infrared thermography as a defectoscopy method

Using infrared thermography, we can now monitor the performance of electrical and mechanical equipment on WWTP by analyzing thermal phenomena that occur in normal exploitation. In the most common situations, defects or problems of non-compliant operation are accompanied by an increase in temperature in the area of the defect, therefore an increase in the emission of infrared radiation. However, there are also situations in which the unjustified drop in temperature in certain areas or component parts of the equipment appear, which is a signal for a non-conformity in their operation. The use of infrared thermal imaging equipment for the rapid detection of hot spots in electrical installations is the best known application of thermal imaging, being also one of the easiest.

A quick identification of the fault points does not raise big problems, the scanning being done relatively quickly but the correct measurement of the temperature and the determination of the severity of the defect according to an established criterion requires an adequate preparation. The analysis of the causes of the defects of the hydromechanical equipment and installations from the treatment plants is based on the on-site observations and the intervention sheets on the equipment from the moment of finding the defect. The better this analysis is performed, the better the causes underlying the defects can be understood. Depending on the complexity of the methods, this analysis can be categorized as follows (Table 1):

Table 1.

Internal		External	
Mechanical	Electric	Mechanical	Electric
Coil displacement	Electric punctures	Pulsating load	Transient voltages
Ballbaring defect	Rotor bar interruptions	Overloads	Unbalanced loads
Eccentricity	Magnetic circuit faults	Defective assembly	Voltage variations

4. Infrared condition monitoring

Universally, the electric industry understands that temperature is an excellent indicator to the operating condition and hence the reliability and longevity of an electrical component. Associations like IEEE, ANSI, IEC and manufacturers all publish standards and temperature ratings for electrical components. It is well understood that the life of electrical components and materials is drastically reduced as temperatures are increased. Infrared condition monitoring is the technique capable of revealing the presence of an anomaly by virtue of the thermal distribution profile which the defect produces on the surface of the component. The defect will normally alter the thermal signature of the surface due to the change in the amount of heat generated and the heat transfer properties of the component. To determine an adverse operating temperature of a component it is necessary to first determine a baseline. For electrical systems the baseline is established when the system is operating under normal load and operating conditions [1]. Once a clear understanding is obtained on what the normal thermal signature is for the many electrical apparatuses and components, the thermography technician will be able to quickly identify a thermal anomaly. On larger more critical components such as transformers, circuit breakers, capacitors etc., the baseline images and data will be stored and compared to new data collected from each inspection interval [2].

For the classification of thermal abnormalities, three critical levels and their corresponding recommended maintenance actions were defined:

- I - Overheating $\geq 130^{\circ}\text{C}$ (Serious): immediate outage of the equipment affected for the repairing of the anomaly.
- II - Overheating between 75°C and 130°C (Priority): repairing of the anomaly as soon as possible.
- III - Overheating between 45°C and 75°C (Programmed): repairing of the anomaly when possible

Correction factors considering the effects of variables such as emissivity, environment temperature and relative humidity, wind influence and distance to the object were established to be considered in the measuring.

Therefore, the overheating measured at any level of load could be referred to such maximum admitted loading level, so as to consider the most unfavorable conditions that could be present during their operation [3].

Thermographic Reports, provide information that identify with certainty the item on which a thermal abnormality has been detected, together with a picture and a thermographic image of the abnormality detected, to facilitate the repairing tasks for the maintenance personnel. Besides, they add additional information, such as over-temperature registered and temperatures of reference, load level at the time of the scan and maximum admitted load, overheating above the environment temperature referred to the maximum admitted load and thermal classification of the abnormality. Next figures present infrared Thermography of thermal anomaly detected:



Figure. 5 Infrared thermography for electrical panel

Figure 5 shows a thermal scan of an electrical panel in which the faulty connection to terminal number 2 of the contactor can be observed. It can be seen that the temperature of the subassembly is on average about 30 °C, while that of conductor 2 is about 50 °C. This indicates a faulty connection to the contactor terminal.

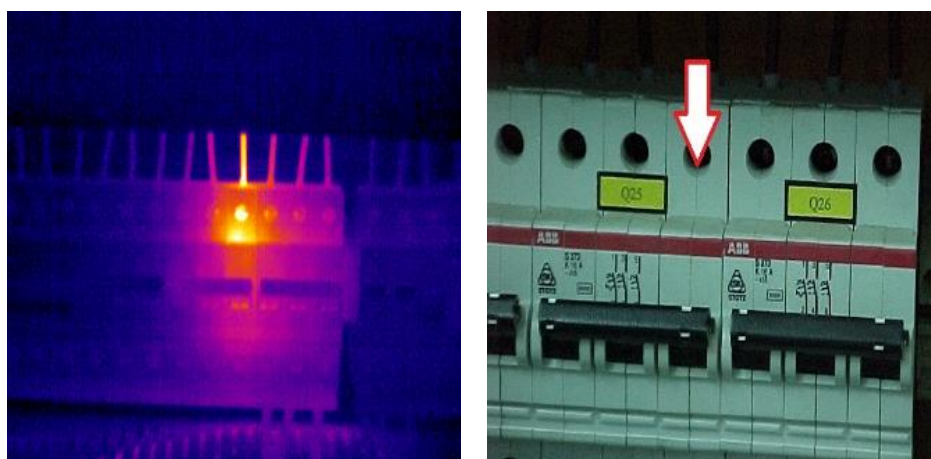


Figure. 6 Infrared thermography for electrical panel



Figure. 7 Infrared thermography for electrical panel

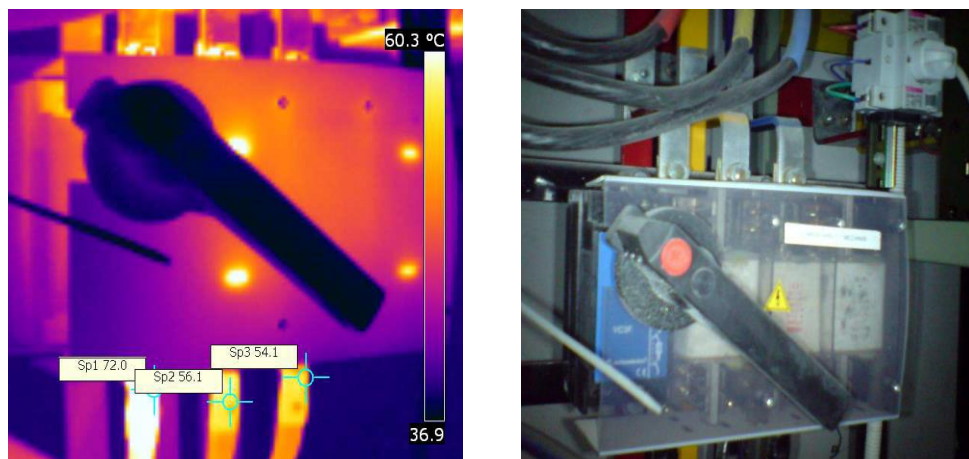


Figure. 8 Imbalance between phases

In the figure above (Figure 8) it is shown an imbalance between phases at the time of inspection. It is recommended to check its load over time cable and restore balance so as not to exceed 10% between phases.

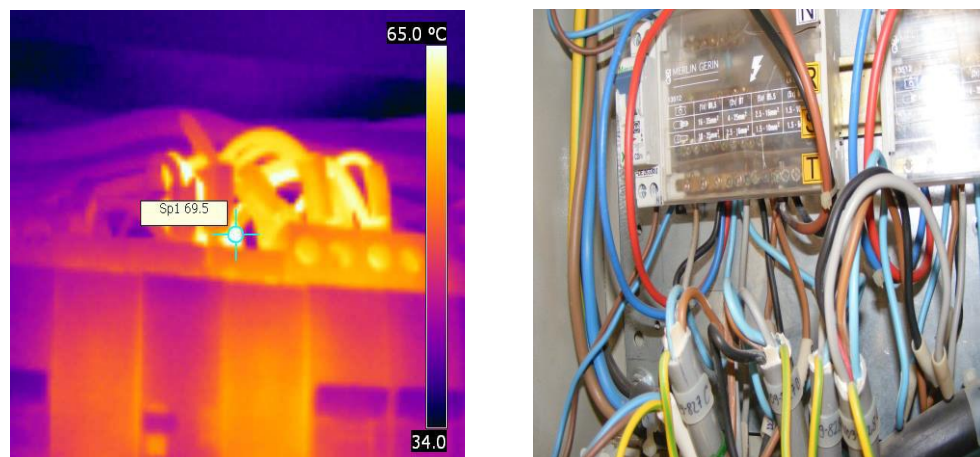


Figure. 9 Overheating due to the difference in load per phase at the time of measurement

From the results of IR scans performed during the survey (Fig.10), highlights that most of problems were found in conductor connection accessories and bolted connections (48%), mainly derived from deficiency of adjustment and/or materials (anomalies in bimetallic surfaces joints, rust, non-adequate use of inhibitory grease).

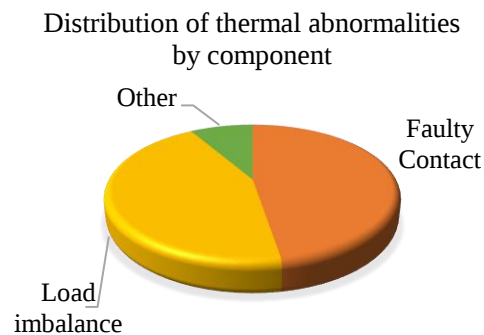


Figure. 10 Distribution of thermal abnormalities by component

Besides, an important number of thermal anomalies appears in disconnectors contacts (45%), from mainly of defected contacts by deformations, deficient pressure of contact, incorrect alignment of arms and dirtiness (Fig. 6). Anyway, a significant number (7%) grouped in Others validates the efforts of scanning all the equipment identified.

These determinations allowed to focus the tasks developed during the scheduled PM, introducing improvements in the maintenance practices carried out. Besides that, an increased awareness by the maintenance working teams in the actions executed to solve the abnormalities detected was achieved, resulting this in an important contribution for the decrease of the critical “hot spots” found.

By analyzing the evolution of the abnormalities detected during the survey period, we see that in the period as a whole, a growing tendency to the reduction of thermal abnormalities related with the total number of item scanned for all critical levels is presented (Fig. 11). The decrease of thermal abnormalities with higher critical level is attributed to its early detection and their addressing by means of programmed outages, taking corrective actions to prevent the abnormality could evolve to a worse critical level. On the other hand, the decrease of thermal abnormalities with a lower critical level can be attributed to an improvement in the practices of the maintenance working teams since the experience acquired

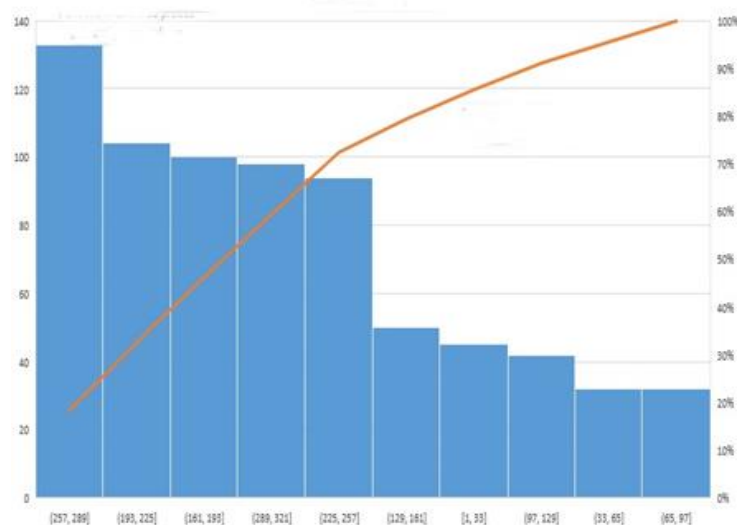


Figure. 11 Failure probability for electrical WWTP equipment based on IR scan

The purpose of determining the statistical parameters of reliability is to obtain indices on the type of distribution law that best adjusts the experimental data. Preliminarily the n experimental data, denoted by x_i are ordered in ascending order. The indicators of location, variation and shape of the distribution are determined.

Arithmetic mean:

$$Ma = \bar{x} = \frac{1}{n} \cdot \sum_{i=1}^n x_i$$

Geometric average:

$$Mg = \sqrt[n]{\prod_{i=1}^n x_i}$$

Harmonic average:

$$Mh = \frac{n}{\sum_{i=1}^n \frac{1}{x_i}}$$

Square mean :

$$Mp = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^n (x_i)^2}$$

Median:

$$me = \frac{x_{\frac{n}{2}} + x_{\frac{n}{2}+1}}{2}$$

Variation Indicator:

Dispersion :

$$D = \frac{1}{n} \cdot \sum_{i=1}^n (x_i - \bar{x})$$

Mean square deviation :

$$\sigma = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^n (x_i - \bar{x})^2}$$

Variation coefficient:

$$c_v = \frac{\sigma}{\bar{x}}$$

In the case of reliability studies, the Distribution Function also known as the Product Reliability Function (equipment or system), and by definition it represents - the probability of a product malfunctioning over a period of time (0, t). Where T is a random variable that represents the malfunction time of a product and R (t) Reliability function - representing the probability of malfunction of the product in the time interval (0, t) in which case:

The electrical installations in the WWTP have their operation being directly influenced by the working conditions. In view of these findings, the Weibull distribution law is used to model such survival processes. Among the known forms of the Weibull Law of Distribution (bi and triparametric,) is considered for modeling reliability, the form with two parameters, which has the following mathematical expression:

$$RN(t) = K \cdot \beta \cdot \left(\frac{F_P \cdot F \cdot F_U}{t} \right)^{(\beta-1)} \cdot \exp \left[-\lambda \cdot \left(a + b \cdot \frac{t}{T_N} \right) \right]$$

5. Benefits of infrared electrical inspections

Since most problems on an electrical system are proceeded by a change in its thermal characteristics and temperature, whether hotter or cooler, a properly trained and experienced thermographer is able to identify and analyze these problems prior to costly failure occurring. Infrared electrical inspections provide many benefits to the recipient. The two key advantages from which the others stem, are:

1. The reduction in disassembling, rebuilding or repairing components which are in good operating condition. This type of repair is meaningless and costly and may lead to a 30 percent reduction of production. Furthermore, it is not guaranteed that the component will be in better condition after the repair, since the location of the problem or cause was not established. With infrared thermography you identify and hence repair only what needs repairing.[9]
2. Problems that truly exist will be identified quickly, giving time to repair the problem before failure. In most cases, the problem is identified well before the problem becomes critical. Depending on the temperature and criticality of the component, the decision can be made to repair immediately, repair at the first opportune time, or monitor on a continual basis until the critical temperature is reached or until the repair can be scheduled. Identifying a true anomaly, scheduling the repair, and eliminating the actual cause of the problem within a proper time frame is the most efficient and cost-effective way to maintain the system.

The other advantages of an infrared inspection program are based on the above overall advantages, yet are no less important.

They are:

- Safety - failure of electrical components could be catastrophic, injuring or even killing employees, maintenance personnel or the public.

- Greater system security - locating the problems prior to failure greatly reduces unscheduled outages, associated equipment damage and downtime.
- Increased revenue - with more uptime, revenue is maximized. With less maintenance on good components and faster repairs of faulty components, maintenance costs are reduced leading, to a better bottom line.
- Reduced outage costs - the cost of an emergency outage is ten times greater than planned maintenance. More efficient inspections - since all common electrical problems announce themselves as an increase in temperature, they are easily detected in a minimum amount of time. No service interruption is required for infrared inspections.

Improved and less expensive maintenance:

- a. precise pinpointing of problems minimizes time required for predictive and preventive maintenance,
- b. maintenance efforts are directed to corrective measures rather than looking for the problem,
- c. repair only what requires repairing, reducing repair time and unnecessary replacement of good components. Reduce spare parts inventory - with improved inspection techniques giving advanced warning of failure,

6. Conclusion

The infrared thermography method is a modern method of inspecting electrical installations and can lead to early action to limit outages due to unforeseen events. Inspection with the thermography chamber is absolutely necessary to avoid falls in the power supply of installations and equipment as well as to avoid a fire that may occur due to their overheating. Infrared thermography has been used as a condition monitoring tool to predictively maintain electrical systems, even before the terms "condition monitoring" and "predictive maintenance" were used. In nearest future, virtually every electric generation and distribution company, as well as every major manufacturing and process facility, will be using infrared thermography as a condition monitoring technique to increase reliability and decrease electric losses, or downtime.

Knowing in advance the probability of damage to electrical or mechanical equipment or apparatus is an undeniable advantage and contributes to reducing maintenance and repair costs, while being an important factor in increasing the safety of passenger and freight traffic.

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