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EQUIPMENT MAINTENANCE USING *IR* THERMOGRAPHY

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Introduction

The scope of the infrared thermography survey is confined to the production facility of the selected apparel and rubber sectors in the industrial estate in Sri Lanka. The focus of this assessment is on costs, energy intensive materials and electricity also because of countable wastage of the resources. The main objective of conducting the inspection is to reduce the unnecessary maintenance costs on wastage of material and electricity. Through this study, we investigate the savings and effectiveness of the Infrared thermography technologies. This research gives more impact on the reliability for engineers to keep up with their annual budgets and carry out their plants more efficiently.

The aim of the article is to investigate the cost-efficiency and effectiveness of the Infrared (IR) Thermography in the industrial maintenance sector.

Research objectives:

- Understand the IR Thermography and its value for the Industrial maintenance.
- Examine the highly critical locations or machineries in the production line.
- Analyse the collected IR images with the aid of software and pinpoint the abnormal situations.
- Calculate the various parameters for the perfect output.
- Estimate and compare the output results.
- Pinpoint and repair the defects before their occurrence with the aid of Infrared mechanical and electrical surveys.
- Encourage the facilities' engineers to save vast amounts of money each year with the help of Infrared inspections.

An infrared scan can substantially improve profitability and reduce the operation and maintenance cost by the following ways [1, 2, 4, 7]:

- Instantly pinpointing the defects.
- Testing under the load conditions help to avoid costly shutdowns.
- Reducing the downtime and prevent catastrophic failures.
- Easy to allow for the prior repairing.
- Improve the reliability of maintenance efficiency.

The exact maintenance plan can solve both costs and downtime, so improving efficiency allows the plants to keep running their productions and operations smoothly. Industrial maintenance has many definitions in different approaches such as:

- Corrective / Reactive maintenance.
- Preventive maintenance.
- Predictive maintenance.
- Proactive maintenance [2, 5].

Reactive / corrective maintenance operates on the run to failure strategy.

Preventive maintenance requires more on-going efforts but when executed properly it can reduce the costs in both short and long term. Still there is risk of machine failure occurring, it has a higher chance of identifying and correcting defects before they become a major disaster.

Predictive maintenance involve routinely inspecting machines with various developments including infrared and ultrasound technology. The national aeronautics and space administration (NASA) reported that this technique works to eliminate unexpected breakdowns and scheduled maintenance down time that would otherwise be used to inspect a machine piece by piece. [1, 4, 7]

Proactive maintenance differs from the above three modes because it addresses many more systematic elements of a maintenance program, rather than examine the machine itself. This approach provides much more control to the problems that can lead to machine wear and tear as opposed to the deterioration itself.

Method Study

Initially critical points of the essential or very important machines and electrical circulation unit for the production have to be located. The survey method consists of examining the equipment with an infrared imaging camera, with the cover boards and dead fronts removed. The equipment being inspected should be energized and under normal to full load.

After continuous monitoring collected data is to be inputted to the system. The points where abnormal temperature variations observed are analysed further using other advanced tools like vibration analyser, Laser alignment tool, Oil analyser and Ultrasonic detector. Especially FLIR E60 model camera and FLIR TOOLS software are used for the image capturing and analyzing.

The potential to fail to discovered problems rises from the load being less than thirty percent of the rating of equipment. During the following conditions, measurements are considered a thermal anomaly.

- Temperatures observed exceed acceptable operating ranges.
- Thermal patterns do not conform to the expected signature.
- Temperatures do not correlate with the load readings.

Reports are provided on any significant anomalies found during the inspections. These reports would include an infrared image and a corresponding digital image. Also included are the date and time, the relevant temperature data, and a recap of other pertinent information. The part is then closely scanned, thermal images saved, and other data such as load currents noted. For electrical work, temperatures are given in degrees Celsius and distance between object and equipment in meters unless otherwise noted.

As review any thermo grams provided are noted in the adjacent colour palette temperature span. This temperature span is typically adjusted in order to provide the best image for identification of the problem and not to show relative temperatures between images. Thus, a minor temperature difference can appear very serious in an image with a certain range. Multi-colour pallets are applied to different temperatures to aid in visualization of the thermal patterns. Metals often appear cooler than plastics or coated parts at similar temperatures. For example, an insulated wire may appear hotter in the thermography then a metal terminal even when the lug is actually several degrees warmer. Furthermore, it should be noted that not all materials emit infrared radiation the same way in relation to their temperature. While this difference is emissivity and is taken into account in our calculations and interpretation, it can create confusion for someone not trained in analysing thermography.

Recommendations for follow-up action generally follow temperature standards established by NETA and/or other organizations, with some adjustments for individual situations based on the experience of thermographer. However, remember that these take into account only thermal and load data observed at the specific time. It is important that you review any anomalies reported and make your own assessment of repair or investigation priority. Some other factors also to consider:

- Load might be greater at any time in the future.
- Equipment's history.
- Critical level of the load served.
- Potential cost of an in-service failure.

The load factor is particularly important because the heat generated at a poor connection or defective piece of equipment increases exponentially with the load current. Relatively minor variations in the load could push to catastrophic damages. The following factors determine the priority of the equipment.

Table 1. ***Priority Analysing Chart***

Prioritization Matrix	1	2	3	4	Recommendations
Is the component critical?					
Will a failure injure people?					
Is the measuring reliable?					
Will loads increase or decrease?					
Is the thermal gradient large?					
Will wind decrease?					

Instrumentation for IR Thermography

In order to interpret the thermal images perfectly the thermographer needs to know how different materials and circumstances influence the temperature readings from the thermal imaging camera. Some of the most important factors influencing the temperature readings are emissivity, conductivity, reflection, ambient and temperature [3, 4].

Emissivity: To measure the correct temperatures, one important thing needs to be taken into account – a factor known as emissivity. Emissivity is the efficiency with which an object emits infrared radiation. This is highly dependent on material properties.

Conductivity: Different materials have different thermal properties. Insulation tends to warm up slowly, while metals tend to heat up suddenly. It is called thermal conductivity. Difference in thermal conductivity in two various materials can lead to large temperature differences in some situations.

Reflection: Non-oxidized materials reflect a lot of thermal radiation. Reflections can lead to misinterpretation of the thermal image; the reflection of the operator's own thermal radiation might lead to a false hot spot, for instance. The operator should therefore choose the angle at which the thermal imaging camera is pointed at the object carefully, to avoid such reflections.

Ambient Temperature: Higher ambient temperatures can cover hot spots by heating the entire object, while low ambient temperatures might cool down the hot spots to a temperature below a previously determined threshold.

Six key requirements are important to assess when investigating a suitable combination of thermal imaging camera, software and training: Camera resolution / image quality, Thermal sensitivity, Accuracy, Camera functions, Software handling and Training demands.

In practical measurement application, the radiant energy leaves a target surface, passes through some transmitting medium, usually an atmospheric path, and reaches a measuring instrument. Therefore when making measurements or producing a thermos gram, three sets of characteristics must be considered:

1. Characteristics of the target surface
2. Characteristics of the transmitting medium and
3. Characteristics of the measuring instrument

It is very difficult to determine the spectral sensitivity of an infrared radiometer such as an infrared camera. Consequently, the link between the effective blackbody radiance and the blackbody temperature cannot be established by integration. Furthermore, the sensitivity varies with time and a calibration is necessary – at least once a year or when the detector or an electronic component is replaced. During such a calibration procedure, the correlation between the temperature and the radiances is experimentally established using a laboratory blackbody, situated at the calibration distance of one meter from the camera.

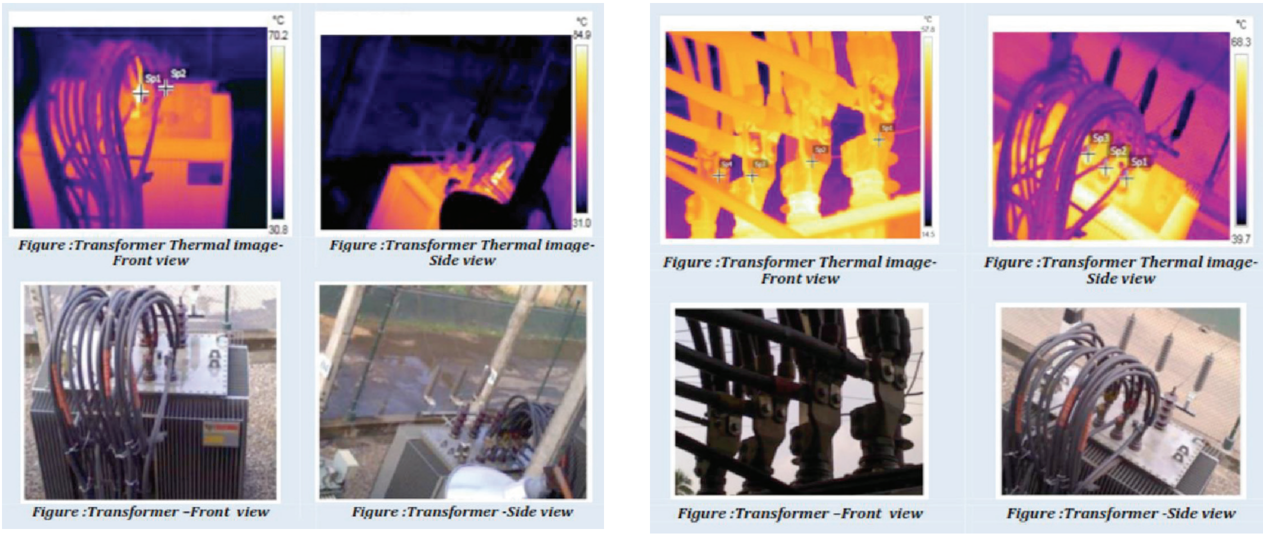
An infrared camera measures the flux of the incoming radiation. Thus, a radiometer in front of an object detects not only the emitted radiance but also a part of exigent radiance due to the reflection of the ambient fluxes by the object surface. It is called noise of thermography. Noise is generally undesired signal and in IR it can be Electronic (shot noise, thermal noise, flicker), optical (random fluctuation of the incident radiation like Heating or Illuminating) and Environment (EMI caused by the Heavy Machinery, whirring, radio broad casting and of course heavy power lines) However, the quantitative error of the measurement has been difficult to evaluate precisely and systematically – not only in high temperature conditions but also in conditions near ambient. Errors impair the minimum detectable size and the noise equivalent temperature difference of the mechanical scanning of the IR system.

Cost Analysis

There are various benefit analysis for loose terminal connections. In this case study we test the connection failure on transformer terminals.

The monthly Infrared thermography survey confirmed that the transformer connection bolt is loose. Further investigation revealed that the transformer was increasing the heat in the terminal point. Hot connection indicates a loose connection. Current transformer is having bar primary with air core, and secondary, the coil with large number of turns, hence very high voltage will be induced if secondary is open or the connection on secondary side with load (meter/relay) are not tightened properly or loose. The high "independent" primary apertures will induce high secondary voltage, and will damage the load or the secondary winding. In order to avoid that the secondary of current transformer must be shortened when not in use Normally, at low currents as a transformer has good insulation and air has a very high breakdown this will do no damage to the CT itself but if for some reason breakdown occurs it can create damage and arcing. However, at very high amps this can create significant damage and even prove fatal.

In order to save the transformer that should be immediately tightened at the terminal points with proper torque. Otherwise overload would lead to premature failure. The failures would result in approximately EUR 2,500 repair cost, and EUR 4,800 loss of production including the labour cost. If it would fail before taking the predictive actions failures would amount to a loss of EUR 7,000. However, the failure was discovered using thermal camera and immediate actions were taken with the cost of just EUR 20 for the maintenance. Vast amount of unnecessary maintenance budget was saved due to this small detection and immediate clever action.



a *b*

Fig. 1. Transformer a – before repairing, b – after repairing

Table 2. ***Maintenance cost analysis with actual cost***

Material cost		**No of units**	**Cost per unit (EUR)**	**Total (EUR)**
Galvanize bolt (16x75 mm)		6	0.25	1.50
Nut (16 mm) – (Mild steel)		6	0.09	0.54
Spring washer (Stainless Steel)		6	0.08	0.48
Plat washer (Stainless Steel)		12	0.08	0.96
Cu plate for flag (240x180x6mm) with drill hole		1	4.10	4.10
Sub Total				7.58
Man Hour Calculation	No of Persons	No of Hours	Cost per Hour (EUR)	Total (EUR)
	3	2.5	1.36	10.2
Total Cost for the repair (EUR)				**17.78**

Table 3. ***Opportunity cost analysis (Production Lost)***

Material Cost		**No of units**	**Cost per unit (EUR)**	**Total (EUR)**
LV Transformer bushing and seal kit		1	980.73	980.73
500 mm cabel (meter)		30	48.59	1457.7
Lug (500 mm)		2	11.56	23.12
Sub Total				2461.55
Man Hour Calculation	No of Persons	No of Hours	Cost per Hour (EUR)	Total (EUR)
	4	6	1.36	10.2
Total Cost for the repair (EUR)				**2471.75**
Production lost	**No of Hours**	**Production for one hour (kg)**	**Outsource compound cost per one kg**	**Total (EUR)**
Line 01	6	2430	0.06	931.63
Line 02	6	2910	0.06	1047.6
Line 03	6	4850	0.06	1746.0
Line 05	6	2490	0.06	896.4
Sub Total				4621.63

Table 4. ***Opportunity cost analysis (saving)***

Man Hour Calculation	No of Persons	No of Hours	Cost per Hour (EUR)	Total (EUR)
Line 01	7	6	1.29	54.18
Line 02	7	6	1.29	54.18
Line 03	7	6	1.29	54.18
Line 05	7	6	1.29	54.18
Sub Total				216.72
Total Cost for the repair (EUR)				**4838.35**

Table 5. ***Total cost analysis***

Total Cost for the repair (EUR)	**7310.10**
Total Saving (EUR)	**7292.32**

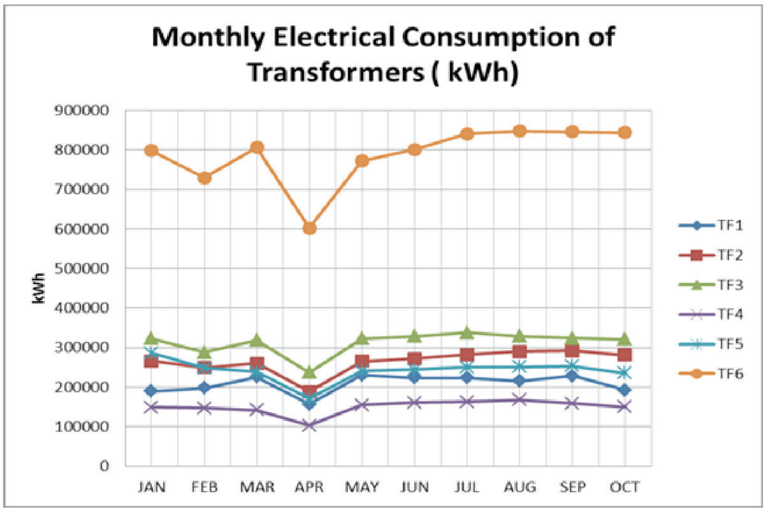


Fig. 2. Electrical consumption

The only source of Energy is Electricity. Energy Consumption has increased by about 40000 kWh for Transformer No. 6 only. Other transformers are supplying approximately the same amount of energy. The decrease in Energy consumption in the month of April is due to plant shutdown during the New Year Festival in Sri Lanka.

Conclusions

The diagnostic capabilities of maintenance technologies have increased in recent years with advances made in sensor technologies. These advances, breakthroughs in component sensitivities, size reductions, and most importantly costs, have opened up an entirely new area of diagnostics to the O&M practitioners. Infrared thermography technology is applied at the major power consuming machines and critical machines for the production in the plant. The report clearly shows the essential of the maintenance methodology. This research might be helpful to the Sri Lankan engineers who are struggling in handling the maintenance costs with the top-level management. The following facts noted at the end of this process.

1. Improving the equipment effectiveness, In other words, looking for the big losses, finding out what
2. Prove the energy savings through the proper maintenance techniques and making improvements.
3. Minimize the unexpected machine shutdowns and reduce the downtime period for maintenance.
4. Introduce effective maintenance plans in Sri Lankan plants.
5. Solution providing and suggesting procuring more effective equipment by evaluating the costs of operating and maintaining the new equipment throughout its life cycle, long-term costs will be minimized.

The expected savings are possible if the recommended measures are implemented. Some of the measures are qualitative and would mitigate wastage of energy whilst others give direct benefits to the bottom line. If an energy management and reporting system would be implemented it could continually improve the energy consumption practices but also ensure a commitment from the staff which is vital for managing energy cost which would result to profitability of the company. Apart from initial purchasing expenses, warranty, speed, size and memory were also some factors, which have been taken into account. In addition, various instruments and training features are available in the world market. Thus, engineers have to take responsibility and should be able to discuss with top-level management in order to move to another step beyond the predictive maintenance. Most industry experts would agree (as well as most reputable equipment vendors) that this equipment should not be purchased for in-house use if there is not a serious commitment to proper implementation, operator training, and equipment monitoring and repair.

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Summary

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This work attempts to show some case studies through Infrared thermography involvements in the industrial maintenance. Initially critical points of the essential or very important machines and electrical circulation units for the production have to investigated. The points where we observed abnormal temperature variations were further analysed using other advanced tools like: vibration analyzer, Laser alignment tool, Oil analyser and Ultrasonic detector. The main objective is to prove that by implementing a good scheduled thermography survey one can decrease major expenses and save time. In addition, it has the capacity to contribute to the reliability of maintenance and minimize unexpected plant shutdowns dramatically in small and large-scale industries.

Keywords: *Infrared (IR) Thermography, reliability, emissivity, conductivity, reflection, ambient temperature.*

Santrauka

ĮRENGINIŲ PRIEŽIŪRA NAUDOJANT *IR* TERMOGRAFIJĄ

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Šiame darbe pateikti keli tyrimai atliekant pramoninių įrenginių priežiūrą naudojant infraraudonuosius spindulius. Pirmiausia išsiaiškinami esminiai ar labai svarbūs mašinų ir elektros cirkuliacijos įrenginių taškai. Taškai, kuriuose buvo pastebėti nenormalūs temperatūros pokyčiai, toliau analizuojami naudojant pažangius įrankius, tokius kaip vibracijos analizatorius, lazerinio išlyginimo įrankis, tepalų analizatorius ir ultragarsinis jutiklis. Pagrindinis tyrimo tikslas – įrodyti, kad priežiūrai taikant termografinius metodus galima sumažinti pagrindines laiko ir pinigų sąnaudas. Taip pat tokia priežiūra padeda išlaikyti įrangos patikimumą ir smarkiai sumažina tikimybę, kad gamybos veikla gali sutrikti mažose ir didelės apimties pramonės įmonėse.

Prasminiai žodžiai: *infraraudonųjų spindulių (IR) termografija, patikimumas, spinduliavimas, laidumas, atspindys, aplinkos temperatūra.*

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