THE ANALYSIS OF THERMOGRAPHIC REPORTS WITH EMPHASIS ON EMISSIVITY COEFFICIENT DETERMINATION OF BARE CONDUCTORS AND JOINTS

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ABSTRACT

This paper presents experiences with infrared aerial inspections of middle voltage overhead lines from helicopter performed by the distribution company Elektro Ljubljana. It describes the most frequent problems at detecting overheated points with an infrared camera. Particular emphasis is on determination of emissivity coefficients of some types of bare conductors and joints by means of the experiments performed in the field.

INTRODUCTION

In the recent years, Slovenian distribution companies and the transmission company have started using non-contact methods for diagnostics and fault detection on high voltage (HV) and middle voltage (MV) overhead lines. These methods enable uninterrupted operation during inspections and have the advantage of determining faults before they develop into malfunctions that could interrupt transmission of electrical energy. Non-contact inspections are performed with cameras from the ground or from a helicopter. Manual inspections enable flexible movement and measurement even in closed systems. Aerial inspections are performed more quickly and can uncover faults that cannot be detected from the ground.

The most frequently performed inspections of overhead lines for the purposes of maintenance and planning of electrical power networks in Slovenia are video recording, infrared thermography and corona inspections. Most of the aforementioned aerial inspections in the past five years have been performed by Flycom.

FAULT ANALYSIS WITH AERIAL IR SURVEYS

IR surveys enable early detection of electrical and mechanical problems on heat-emitting devices and structures. Aerial IR and video recording consists of several phases described in detail in reference [1]. The following conditions have to be met for successful aerial recording:

- Before the inspection, the appropriate load on the lines has to be arranged with the client.
  - During the recording, the load on the line should be at least 40% of the nominal load.
  - The optimal load is approximately 75%.
  - If the load is higher than 90%, the lines are very hot, which makes accurate detection of overheated locations difficult.
- During the inspection, the client should record the load on the line frequently (every 15 minutes).
- Appropriate weather conditions (moderate sunlight, no rain, no snow on the ground and in the immediate area).

The faults detected with aerial IR recording of MV networks mostly included the following components: current clamps, connections, line disconnectors, compression joints, bare conductors, insulators and cable heads. Table 1 presents the faults detected by the distribution company Elektro Ljubljana. The values are presented in percentages with respect to the type and the location of the fault on the MV overhead line. The percentages relate to the overall amount of faults detected with aerial IR recording of the overhead MV network of Elektro Ljubljana. The faults in Table I are sorted according to the level of importance, i.e. excess of heat at the overheated spot. Excessive temperature (ΔT) is the difference between the temperatures of the overheated spot and the undamaged spot, as recorded by the IR camera. According to ΔT, the faults are classified in three categories described in the report [2]:

- Critical, $\Delta T > 30^\circ C$,
- Typical, $30^\circ C \geq \Delta T > 5^\circ C$,
- Initial, $\Delta T \leq 5^\circ C$.

Table I: Faults detected with aerial IR inspections of the Elektro Ljubljana MV network

Location of the fault	Critical %	Typical %	Initial %	**Total %**
Current clamps	10.45	17.91	1.49	**29.85**
Connections	20.90	19.40	1.49	**41.79**
Line disconnectors	7.46	4.48	0.00	**11.94**
Compression joints	1.49	5.97	1.49	**8.96**
Bare conductors	0	0	2.99	**2.99**
Insulators	0	0	2.99	**2.99**
Cable heads	0	0	1.49	**1.49**
Total	**40.30**	**47.76**	**11.94**	**100**

Table I shows that 40% of the detected faults were critical, meaning that they demanded immediate intervention. 48% of the detected faults were typical, meaning that they needed to be serviced during the next planned maintenance. The initial faults (approx. 12%) demanded monitoring.

TEMPERATURE MEASUREMENTS WITH AN IR CAMERA

In addition to fault detection, IR recording enables non-contact temperature measurement. The temperature of electrical lines in relation to electrical current is calculated using standard equations [3], taking into account most of the relevant parameters. The calculations can be problematic if these parameters are unknown, or if the material characteristics listed in tables are distorted due to wear, damage, corrosion, etc. This makes temperature measurement with an IR camera a sound procedure, as it shows both, the location and the intensity of the fault.

IR recordings not only detect the emissions for the object of measurement (object), but also the emissions of the surroundings, therefore the emissivity coefficient of the object and the temperature of the environment have to be known values. Due to emissivity, a portion of the ambient emissions is reflected from the object and captured by the IR camera and has to be taken into account in calculating the actual temperature. The accuracy of temperature measurement is also influenced by the atmosphere, which absorbs a portion of the emissions on their way from the object to the IR camera.

Modern IR cameras are connected to computers equipped with software for capturing, saving and analysis of IR recordings. The values of the parameters the IR camera takes into account in calculations have to be set before the measurements. The most important parameters are:

- Surface emissivity of the object,
- Reflected ambient temperature,
- Distance between the object and the IR camera,
- Relative air humidity and temperature.

Emissivity coefficient

The emissivity coefficient (ε) is the most important parameter in IR camera measurements, therefore it is described in detail below. The consequence of an incorrect setting of the ε value is that the temperature values shown by the IR camera are not the actual values and can significantly differ from them, especially with objects with a low ε value. Usually, the software for IR recording analysis allows subsequent adjustments of ε, enabling correction of results for simultaneously captured objects with different ε values.

The emissivity coefficients ε are listed in tables of IR camera user manuals [e.g. 4, 5], in literature [e.g. 13], on various web sites [e.g 14], and in scientific articles [e.g. 9] and reports [e.g. 6, 7, 8]. Of the sources mentioned above, we have followed the findings of the reference [8], where the authors describe research in which, among other things, the ε values of bare conductors of a transmission network were measured. The value measured for new conductors [8] was ε≈0.19, while the values for conductors in operation depended on their age and atmospheric pollution. They are listed in the range from 0.29 to 0.94. For practical calculations in less polluted areas the value used was ε=0.5, elsewhere they used ε=0.7. One of the first elementary research of measurements of ε for overhead bare conductors is described in [9]. The values in [9] are similar to values in [8]. The proposed value for new conductors is ε=0.23, while the value for the oldest and the most polluted is ε=0.95, but the authors even report measuring ε=0.99 for some of the objects.

The dimensions of the objects (e.g. lines, joints), their wear and unavailability of instruments for precise measuring of ε are the reasons we cannot determine their actual values. Additionally, the available sources [e.g. present ε for various materials in wide value ranges, e.g. for Aluminium 0.2 to 0.8 [5], which is not useful in practice. Therefore, users of IR cameras are often faced with having only one option left, determining ε by themselves. The references [4 and 5] describe the most common methods of determining ε using simple tools and an IR camera:

- Using a thermocouple,
- Using reference emissivity,
- Carving a hole in the object,
- Heating or cooling of the object to a known temperature.

All of the above methods are based on indirect determination of the object's ε using a known temperature of the object or covering the object with a (band of) material with known ε. In our research, we used the thermocouple method. Figure 1 presents the results of changing ε of a Al/Fe 70/12 mm^2 conductor and a joint, Type 2 of the same conductor.

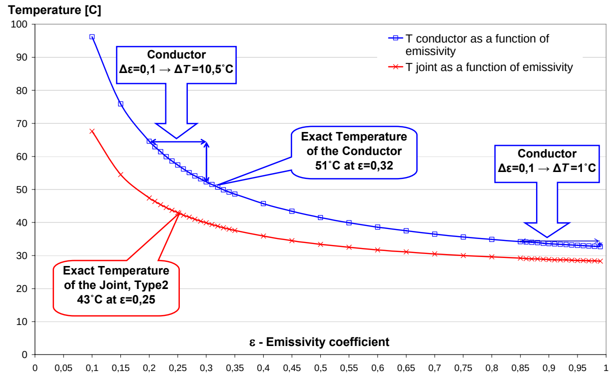

Fig. 1: The influence of ε on IR temperature measurement

Figure 1 shows the temperature of the Al/Fe 70/12 mm^2 conductor (blue curve with squares) and the temperature of the joint (red curve with crosses) in relation to ε. Figure 1 clearly shows that temperature changes are bigger with lower ε values. This means that if an object's ε value is low, it has to be determined precisely, otherwise IR camera measurements will be very inaccurate. Similar to the authors of the article [9], we have determined that values in the range between 0.9 and 0.99 do not influence the calculations significantly.

Reflected ambient temperature

The reflected ambient temperature parameter is significant to compensation of the ambient emissions that influence the object and are reflected from it to the IR camera, as well as to the compensation of ambient emissions between the object and the IR camera. When performing outdoor IR recording this parameter has to be set to the so-called sky temperature, which is difficult to determine. To ensure the quality of IR recordings, recording in cloudy weather is recommended (absence of sun and snow) as we can assume that the reflected ambient temperature is equal to the air temperature.

Distance between the object and the IR camera

The distance between the object and the IR camera is used for compensation for atmospheric absorption of the object's emissions that increases with distance.

Relative air humidity

The IR camera enables the compensation for lowered atmospheric permeability due to increased humidity. Water vapour in the atmosphere acts as an absorber of thermal emissions. When recording distant objects (more than 20m away [4]), relative humidity must be specified.

THE RESULTS OF EMISSIVITY MEASUREMENTS USING AN IR CAMERA AND THERMOCOUPLES

In searching for and determining of the levels of faults shown on IR images as overheated spots an appropriate accuracy of temperature measurements is very significant. As described above, the object's ε value is also very significant. Simultaneously with IR recording from a helicopter, a video image is also captured, while the overheated spots are additionally photographed, offering a high-resolution image of the fault in addition to the IR image. The combined images enable precise detection of overheated spots. If emissivity coefficients of the objects are known, we can also determine their temperatures. To determine emissivity coefficients as accurately as possible, heating tests and indirect measurements of ε values for various conductors and joints used in the Slovenian electrical power networks were performed.

The tests were performed by connecting the measured objects (conductor, joint) to an AC current transformer (50Hz), using it to increase the current in 10% increments to the object's nominal value (e.g. for Al/Fe 70/12 mm^2, 290A). The intervals between current changes were 25 minutes. During heating and recording with the IR camera we were measuring the parameters, necessary for the settings: temperature, relative humidity, wind speed, distance between the object and the camera, and ambient temperature. Measuring the temperature of the object is essential for determining ε. At lower voltages (up to 5 V), the temperature was measured with contact measurement. The emissivity parameter on the IR was adjusted until the temperature value on the camera was equal to the one attained by contact measurement. Below are photographs of the objects and their IR images.

Fig. 2: Photograph of a Al/Fe 70/12 conductor

Fig. 3: IR image of a Al/Fe 70/12 conductor, ε=0.32

Fig. 4: Photograph of a joint for Al/Fe 70/12, Type 1

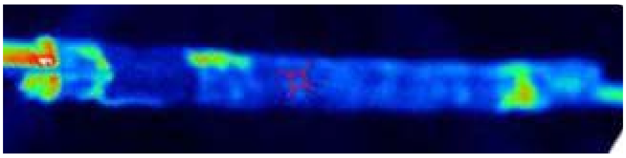

Fig. 5: IR image of a joint, ε=0,4 (clean part) , Type 1

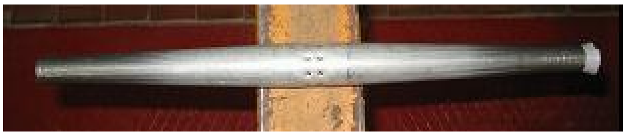

Fig. 6: Photograph of a joint for Al/Fe 70/12, Type 2

Fig. 7: IR image of a joint, Type 2, ε=0.25

Fig. 8: Photograph, joint, Type 3

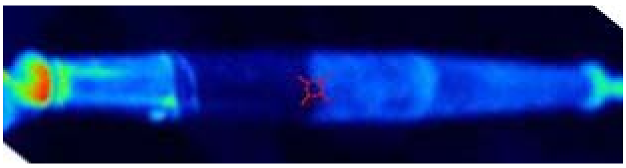

Fig. 9: IR image of a joint, Type 3, ε=0.28

Each of the objects was at a certain spot covered with a band with reference emissivity ε=0.92. The IR images 3, 7, 11 show the bands with a constant ε=0.92 as a bright rectangle. Contact measurements of temperature were performed in their proximity. Thus, we were able to check the results with a contact thermometer, the IR camera and the known ε. The values for the described objects of measurement are presented in Table II.

Table II: Emissivity coefficients for observed samples

Sample	Condition	ε
Bare conductor Al/Fe 70/12 mm^2	New	0.32
Joint for bare conductor Al/Fe 70/12, Type 1	New	0.4
Joint for bare conductor Al/Fe 70/12, Type 2	New	0.25
Joint for bare conductor Al/Fe 70/12, Type 3	New	0.28
Joint for bare conductor Al/Fe 490/65, Type 4	Old	0.37
Bare conductor Al/Fe 490/65	Old	0.65
Bare conductor Al/Fe 490/65	Overheated, greasy-black	0.97

In addition to the ε value of undamaged objects, ε values of overheated spots are also important for determining the levels of faults. Overheated spots have been exposed to higher temperatures, therefore they age more quickly and acquire a different ε value than undamaged spots. An example of a bad joint, Type 4, images 10 and 11.

Fig. 10: Photograph of an overheated joint, Type 4

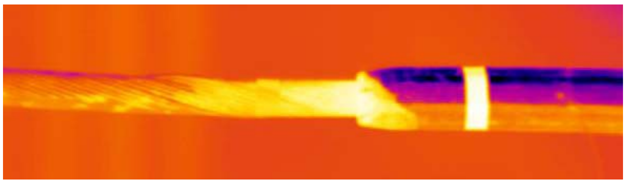

Fig. 11: IR image of an overheated joint, Type 4

As can be seen in picture 10, the conductor is coloured greasy black at the beginning of the joint due to efflux of protective grease, protecting the steel core of the conductor. As unpleasant as picture 10 is to operators and maintenance workers of electrical power networks, it is delightful to IR image diagnosticians. All our tests show that such greasy black spots have a high and nearly constant value of ε=0.97, serving as a good reference point for exact determination of overheated spots.

CONCLUSION

Knowing the emissivity coefficients of the elements of electrical power networks is key to non-contact temperature measurements. Precise temperature measurements enable fault diagnostics and efficient servicing. A part of the research presented in this paper has determined the following emissivity coefficients:

- New joints, from 0.25 to 0.3,
- New Al/Fe conductors, from 0.3 to 0.35, and
- Greasy black overheated parts of conductors and joints, 0.97.

Further activities will enable supplementation of the emissivity coefficient catalogue with appropriate high-resolution and IR images of the elements that can be recorded from air.

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