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Thermovision in Distribution Power Networks

***Abstract**. The paper deals with the use of thermography in distribution power networks. It focuses on the complications of using thermography in normal operation and shows the results of regular measurements of individual parts and units of distribution networks. The paper is concerned with the processing and assessing a large database of thermovision measurements.*

***Streszczenie.** Artykuł traktuje o zastosowaniach termografii w elektroenergetycznych sieciach rozdzielczych. W pracy skupiono się na się na trudnościach użycia termografii w normalnej pracy i przedstawiono wyniki regularnych pomiarów zarówno poszczególnych elementów jak i podzespołów sieci dystrybucyjnych. Omawiane zagadnienia dotyczą przetwarzania i oceny dużej bazy danych pomiarów termowizyjnych. (**Termowizja w elektroenergetycznych sieciach rozdzielczych**).*

Keywords: thermodiagnostics, measurement protocols, distribution network, defect.
Słowa kluczowe: termodiagnostyka, protokoły pomiarów, sieć rozdzielcza, uszkodzenie.

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Introduction

This paper deals with use of thermodiagnostics in distribution networks and subsidiary facilities. For several years thermodiagnostics has been gaining ground as a favourite diagnostic method used for electrical equipment. It is predestined to be used widely in a number of fields because of its low-demand operation. The paper is not concerned with the measurement itself, but processing and assessing the data. The information on the measurements can be found in [1, 2, 5].

When used intensively, thermodiagnostics is a useful information resource which can be used for numerous purposes. The primary use is for maintenance and repair. The secondary uses are as follows. Firstly, statistic processing brings data on defects and failure rate of individual equipment. Secondly, long-term monitoring enables to observe thermal degradation of equipment parts and temperature values can indicate the possibility of the end of a life cycle.

General information on database and its processing

Long-term cooperation has brought about a large database of thermovision measurements where the basic data output is the protocol. The protocol involves all the important data which were measured, conditions (weather, load) of measurement and also other additional information. A simple evaluation of the current condition of the equipment according to warming of the measured parts is included in the protocol, see [3]. The measurements took place from 2002 - 2009 on a large distribution network involving many pieces of equipment. The whole database may be divided into several groups representing individual systems in the energy distribution network. The basic groups are:

- Substations
- DTS - distribution transformer stations
- Lines (overhead)

These groups may further be divided into sub-groups according to the voltage, design, complexity, position, zonation and other. The division depends on required information. There was compared the information with each other and also with other theoretical assumptions.

The database includes approximately 10,000 protocols each containing up to several detected defects, therefore the processing is complex and time-consuming. Lack of unified identification of equipment and its parts is another obstacle and makes classification difficult. The statistic processing can start after overall adjustments, and the outcome can be used in ways presented in the following chapters.

Firstly, MS Excel was used for creating database tables containing assorted and grouped information. Then, contingency tables were used for further adjustments, see [4]. As an example below - Fig. 1 presents individual groups: a damaged anchor clamp of an overhead line and a loose screw on a busbar.

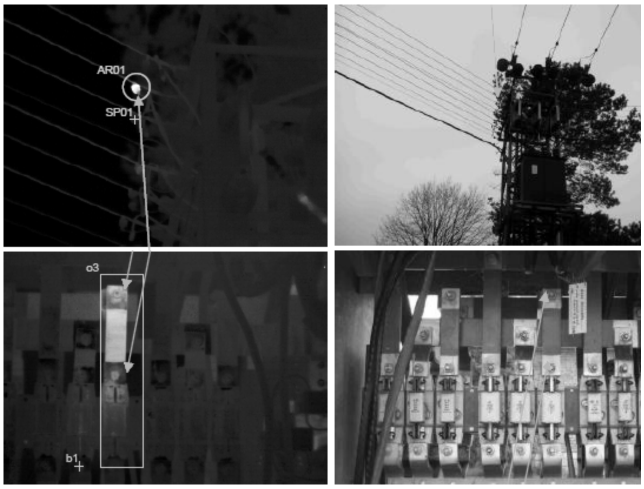

Fig.1. Examples of detected defects

Distribution transformer stations

Distribution transformer stations (further on only DTS) are end transformers which operate as a transformation element between medium voltage (MV) and low voltage (LV). Mostly they are placed in a point of consumption. Their structure may differ, but they always contain a transformer with MV and LV sides and other apparatus. They may be divided according to their design into:

- Pole-mounted
- Tower
- Kiosk
- Compact
- Semiflush
- Flush

All these differ in complexity, power, influence of environment, age and etc. As for the number of elements, MV side is simpler than LV side. The simplest designs have only lightning arresters and fuses on the MV side. The LV side has a great number of connections and contacts for the current line which makes thermovision diagnostics difficult.

Table 1. Defects on DTS detected in 2002

Devices	Degree of warming 2	3	4	All
Fuse	19	380	1025	1424
Transformer	5	82	251	338
Circuit breaker	4	54	232	290
Measuring transformer	3	27	132	162
Disconnect switch	0	11	131	142
Connection	0	12	43	55
Other	3	61	102	166

From the database the most problematic parts were assessed according to the number of defects detected. These parts were assessed according to the results from 2002 when about 450 DTS were checked. From the number of 2500 detected defects, only 100 (approx. 4%) of them were on the MV sides and the others were on LV sides. The classification of defects according to the type of equipment is in Table 1. The voltage value is neglected here.

Table 2 shows numbers of defects for different DTS designs in the years 2002 - 2009 within the limited area including over 3400 DTS. Blank spaces mean that there was no measurement that year. The results show that the kiosk type DTS has the most defects. When complexity of a DTS connection is neglected, up to 48 defects were found during one measurement. This value is, however, unique and the calculated average values (Table 2) give bigger picture of the results. It may be stated that the results correspond with the age of the DTS. The latest building has the minimum number of defects; however their thermovision check is difficult because their bodies are compact units where individual contact elements cannot be seen.

Table 2. Found defects sorted according to the DTS type, blank space – no measurement

Type	Data	2002	2003	2004	2005	2006	2007	2008	2009	All
Kiosk	Average LV	3.78	1.64	4.03	3.46	3.63	2.54	2.00	1.95	3.02
	Maximum LV	30.00	22.00	48.00	27.00	23.00	21.00	18.00	15.00	48.00
	Average MV	0.10	0.06	0.05	0.10	0.07	0.03	0.01	0.04	0.07
	Maximum MV	5.00	4.00	2.00	6.00	4.00	2.00	1.00	1.00	6.00
Compact	Average LV							0.23	0.18	0.21
	Maximum LV							3.00	2.00	3.00
	Average MV							0.00	0.00	0.00
	Maximum MV							0.00	0.00	0.00
Pole-mounted	Average LV			0.92	1.13	1.27	0.90	1.03	0.87	1.01
	Maximum LV			9.00	17.00	10.00	12.00	14.00	14.00	17.00
	Average MV			0.04	0.12	0.01	0.02	0.01	0.00	0.03
	Maximum MV			3.00	9.00	1.00	3.00	2.00	1.00	9.00
Total Average LV		3.78	1.64	1.69	2.03	2.05	1.38	1.10	0.95	1.74
Total Maximum LV		30.00	22.00	48.00	27.00	23.00	21.00	18.00	15.00	48.00
Total Average MV		0.10	0.06	0.04	0.12	0.03	0.02	0.01	0.01	0.04
Total Maximum MV		5.00	4.00	3.00	9.00	4.00	3.00	2.00	1.00	9.00

As the tables show, the results correspond with the assumption of complexity of different voltage sides. Also, they differ according to the design. Table 3 gives numbers of measurements and numbers of detected defects on different levels, which gives a ratio of total number of defects to number of measurements. The calculated ratio shows that the problems on the LV parts are far bigger than those on the MV side.

Table 3. Number of measurements and total defects

LV	Number of measurements	Total defects	DE/ME Ratio
Kiosk	1576	4760	3.020
Compact	96	20	0.208
Pole-mounted	2597	2629	1.012
Total	4269	7409	1.736
MV	Number of measurements	Total defects	DE/ME Ratio
Kiosk	1576	107	0.068
Compact	96	0	0.000
Pole-mounted	2597	84	0.032
Total	4269	191	0.045

Substations

Substations are backbone parts of an electricity network. They are more complex compared to DTS including more movable parts and a more complicated system of connection. They are outside and interior. Within their structure they may contain two or more voltage levels depending on their position within the whole network. Those providing interconnection of the transmission and distribution network are the most complicated ones.

Concerning thermodiagnostics, it is important to check every attachment – firm or movable. Most of attachments are screw-in, but there are also parts with open contact system – such as disconnectors. In addition, there are also encased parts. Lately the whole encased distributors have been used, which makes the thermodiagnostics check difficult. When monitoring the parts with encased contact system, it is important to check their circuit connection.

When analysing the part of the database including the measurements at substations it is necessary to discuss the most problematic parts at substations. The database includes approximately 1100 entries that were measured at about 80 substations in the years 2002 and 2003. Table 4 shows their most problematic parts. The lines give numbers of defects and the columns give importance degree. This table is not divided according to voltage levels and does not compare substations with each other because every substation is unique as such, and therefore groups would be difficult to make. It can be seen in the table that the most problematic parts are disconnectors with 50% share of defects, which is due to their frequent use. Disconnectors are parts with mechanical movement and open contact system which must withstand changeable weather conditions. The disconnectors are followed by measurement transformers, circuit breakers, bushings and etc.

Table 4. Problems detected on substation equipment

			Degree				
Equipment			1	2	3	4	Total
Bushing				9	18	47	74
Circuit breaker				8	30	62	100
Transformers			1	2	5	23	31
MTP,PTP,PTN				3	37	94	134
Disconnectors				38	150	310	498
Inductor/choke					3	9	12
Cables				5	6	39	50
Main breaker						3	3
Busbars, lines, connecting blocks, jumper, connections				5	47	53	105
Total			1	70	296	640	1007

In Table 5 have been classified detected defects according to voltage levels in the monitored electricity network. It must be emphasized that 10 kV level is not much used, while 22 kV voltage level is the most frequently used and the number of detected defects complies with this fact. The structure of most substations is – the inlet includes HV parts and the outlet (towards consumer) contains several MV fields. Concerning the design – the HV part is usually outside and MV parts are outside or interior. As for the equipment itself, it is necessary to differentiate between the connections according to the voltage level.

Table 5. Defects according to voltage level

Voltage		Total
0.4		36
6.3		195
10		7
22		559
110		278
(Blank)		2
Total		1077

If groups should be made to compare the substations, the substations of the same voltage values and similar connection would have to be selected. Furthermore, ratios of fields on different voltage levels would have to be evaluated, as well as ages of substations (resulting structure), and outside or interior designs.

Finally, Figure 2 is an example of a thermovision check of an interior 22 kV substation where a defect was detected because of warming of the clamp of the measurement transformer.

Overhead lines

The last chapter of the analysis deals with the overhead lines on voltage levels of 22 and 110 kV which are used within the area of the given distribution network. Cables are omitted. These lines are constructed from AlFe wires of various cross-sections and arrangements. The MV lines use mostly three-lead suspension and the HV lines have seven conductors (6 phase and 1 earth wire).

In terms of complexity, HV lines are higher and have more complicated tower design with the corresponding number of structural connections of conductors. On the contrary, the design of MV lines is much simpler, yet including elements which HV lines miss, e.g. sector disconnectors, reclosers, measuring points and etc. Furthermore, proximity of transformer stations is bigger and covering of the area is denser which means bigger total length. These elements make the lines more complex. However, HV lines are more important for distribution.

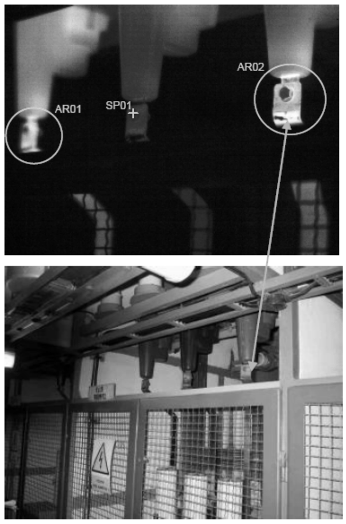

Fig.2. Warmed connector of a measurement transformer in the interior 22 kV substation

In Figure 3 there is an example of an MV line on the left and an HV line on the right, both with warmed clamps.

Concerning lines, about 1,050 records were entered into the database within the years 2002 and 2003. Unfortunately, the lengths of the monitored sections were not recorded, only the data of detected defects. Of total records, about 380 are on MV level and the rest is on the HV level.

The evaluation of data has revealed the most problematic parts of lines. As for 22 kV lines these were connectors of any kind with 80% share, yet other defects were detected on e.g. lightning arresters, insulators, fuses and etc. So much for the 22 kV lines, as during the thermovision checks the focus was on 110 kV lines.

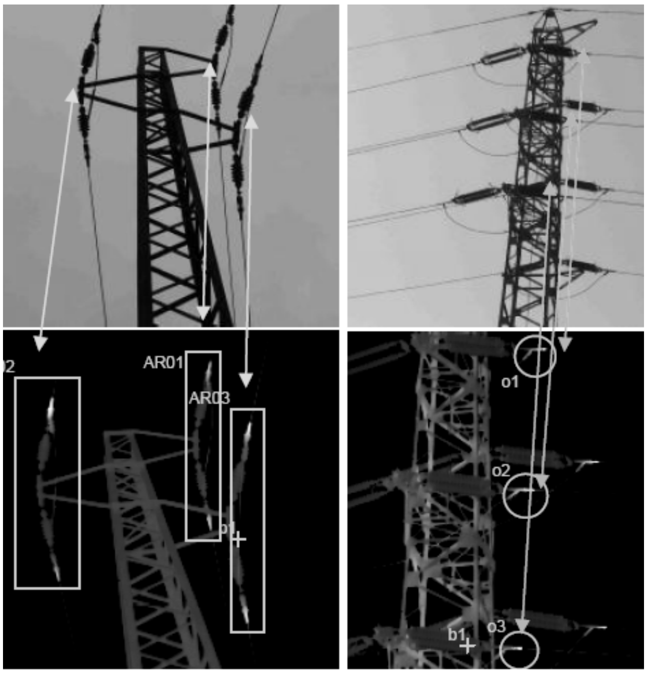

Fig.3. MV and HV transmission tower designs with warmed gun type clamps

The total evaluation for 110 kV lines is given in Table 6, which shows the most problematic parts on the HV lines with gun type clamp at the top (see Figure 3). It is a clamp used for lines interconnection between the poles and between the suspensions of insulators. There were also problems with the bushings and finally, with the conductor itself.

Table 6. Problems detected on HV line equipment

		Degree of warming			
Device	Part of dev.	2	3	4	All
Falling line	Gun type clamp	6	0	0	6
	Clamp	0	1	0	1
	Screw clamp	0	0	1	1
Dead-end clamp	Clamp	0	5	9	14
Bushing	Coat	0	1	0	1
Waist	Gun type clamp	127	63	3	193
	Clamp	0	62	82	144
	Screw clamp	4	13	13	30
	Wire	1	1	0	2
Clamp	Clamp	3	33	15	51
Line	Wire	0	0	1	1
	Gun type clamp	9	78	131	218
	Connection	0	1	12	13
	All	150	258	267	675

Analysis of Results

The results presented in this paper have been acquired by the processing of the above mentioned database. Other adjustments or new methods of processing can bring even more information. However, the methods used for measuring temperatures must be as accurate as possible to ensure successful continuity of the research [6].

In previous chapters there have been discussed possible outputs of thermodiagnostics with the purpose of drawing attention to the problem equipment and its parts. In the following work it is necessary to deal with the reasons of the defects and how information obtained by thermodiagnostics may be used. The main focus will be on the issue of warming of the gun type clamps. In addition to the results of the database analysis, there have been managed to obtain other information from practice and there are clamps available for running experiments in order to find the cause of the defects. According to the information from the maintenance, these defects may often result in failure and consequent outages. If the problem of defective clamps could be removed or restrained, the reliability of HV distribution networks would increase.

But first, the proportional models of the clamps must be made. Then thermal processes affecting the clamp during normal operation will be simulated by the finite element method. If this method shows the possible cause of the problem, practical tests in laboratories will be run to verify theoretical assumptions.

Conclusion

This paper has discussed the processing and evaluation of results of long-term measurements using the thermal camera. The output is statistic processing of items from the databases, which shows the problem parts elaborated in individual chapters.

The focus was on statistic processing of defect databases. Further research shall deal with the causes of defects as such. If the database could be enlarged, it would be a valid source of information for e.g. comparison of problematic nature of the same equipment from different producers and evaluating of the influence of age of equipment on the distribution of its thermal field.

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