Małgorzata ŁATKA, Tomasz PIECHOTA

Rzeszow University of Technology, Faculty of Electrical and Computer Engineering, Department of Power Electronics and Power Engineering

doi:10.15199/48.2016.02.39

Electric power quality assessment based on thermographic measurements

Abstract. *Can thermographic images be considered a base of electric power quality assessment in a selected point of the electric power system? It turns out that there they can, beyond any doubt. Thanks to thermographic examination it is possible to observe phenomena which can be the cause of e.g. power stoppages, overvoltages, overloads, and asymmetries in three-phase networks, transformer stations, switching stations, etc. Early response to a damage or approaching failure based on thermographic images — the so-called thermograms — can eliminate or at least mitigate the problems with failure to meet conditions in scope of power supply continuity and reliability, resulting in deterioration of the electric power quality. The paper presents the rules of conducting and selected results of measurements with the use of thermographic camera in the form of thermographic images and their analysis from the point of view of the electric power supply quality in selected points of an electric power system (EPS). Thermograms, obtained readily, contactlessly, and at low cost can be considered an indication to undertake further, more advanced measurements in the scope of the electric power quality.*

Streszczenie. *Czy obrazy termowizyjne mogą być podstawą do dokonania oceny jakości energii elektrycznej w wybranym punkcie systemu elektroenergetycznego? Otóż okazuje się, że jak najbardziej. Dzięki badaniom termowizyjnym można zaobserwować zjawiska, które mogą być przyczyną wystąpienia m.in: przerw w zasilaniu, przepięć, przeciążeń oraz asymetrii zasilania w sieci trójfazowej, w stacjach transformatorowych, rozdzielniach itd. Wcześniejsza reakcja na uszkodzenie czy nadchodzącą niebawem awarię na podstawie obrazów termowizyjnych – tzw. termogramów – może wyeliminować lub przynajmniej ograniczyć na przykład problemy z niedotrzymaniem warunków ciągłości i niezawodności zasilania, czyli zjawiska powodujące pogorszenie jakości energii elektrycznej. W artykule zaprezentowano zasady przeprowadzania pomiarów oraz wybrane wyniki pomiarów kamerą termowizyjną, w postaci obrazów termowizyjnych i ich analizę pod kątem oceny jakości energii elektrycznej w wybranych punktach systemu elektroenergetycznego. Otrzymywane, w bardzo szybki, bezdotykowy i w sumie tani sposób termogramy mogą być wskazaniem do przeprowadzenia dalszych, bardziej zaawansowanych pomiarów w zakresie jakości energii elektryczne (**Ocena jakości energii elektrycznej na podstawie pomiarów termowizyjnych**).*

Keywords: electric power quality, thermographic camera, power quality parameters monitoring.
Słowa kluczowe: jakość energii elektrycznej, kamera termowizyjna, monitoring parametrów jakości energii elektrycznej.

Introduction

The thermographic technology uses infrared radiation to visualize the temperature field on the examined object's surface. Application of the technique in various fields of science, technology, and industry allowed to "see invisible phenomena with the naked eye".

The main advantage of thermal imaging is its non-invasive nature and the speed at which measurements of temperature distribution on surface of the examined object can be taken in the form of thermographic images, the so-called thermograms, for further analysis and troubleshooting.

The infrared radiation used in the thermal imaging is a specific range of the full electromagnetic radiation spectrum, similarly as the microwaves, visible light, radio waves, ultraviolet radiation, gamma radiation, and X-rays. A quantity used to characterize each radiation type is the wavelength range. The infrared radiation includes the following wavelength bands, with the limits determining these bands being purely conventional:

- near-infrared, with wavelengths 0.75–3 µm;
- mid-wavelength infrared, with wavelengths 3–6 µm;
- far infrared, with wavelengths 6–15 µm;
- very-far infrared, known also as extremely far infrared, with wavelengths 15–100 µm [1].

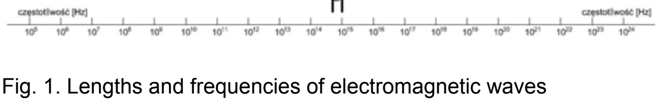

Fig. 1. Lengths and frequencies of electromagnetic waves

The thermal imaging is a technology allowing to observe and register infrared radiation emitted by physical bodies. Values of the emitted infrared radiation intensity registered by thermographic devices (cameras) allow to create an image constituting a representation of the temperature distribution pattern on the examined object's surface. The infrared imaging technology is a convenient diagnostic tool in industrial applications. It turns out that the thermal imaging can be applied with success also in the electric power engineering.

The thermographic camera is a unique tool to identify those locations in an electric power system where measurements or repairs should be undertaken, because occurrence of a failure in EPS is usually preceded by an increase of temperature at given point. Detection of "hot spots" allows to undertake preventive measures before a costly failure occurs. The thermographic method allows to detect a number of potential problems, damages, or faults in various components and devices of electric power stations, switching stations, and power distribution systems in a noninvasive and time-saving way on the whole surface of the examined object and with accuracy unavailable until now [2].

Thermographic measurements in the electric power engineering are used for, among other things: detecting overheating spots in electric devices and systems, which can include e.g. fuses, switches, contact, overhead and cable lines, substations, transformers, thyristors, motors, insulators, electric circuits; monitoring operation of and detecting overheating spots in rotating machines and devices; and testing electronic circuits for heat distribution paths, effectiveness of cooling, and possible short-circuit points.

Early response to a damage or expected failure based on the obtained thermograms will eliminate, for instance, issues related with failure to meet the power supply continuity and reliability conditions, i.e. the problems with deterioration of the electric power quality. Analysis of thermograms can be also an indication of necessity to continue examination of a given point of the electric power system, as it can turn out that there are further problems in meeting another electric power quality parameters such as asymmetry of currents and voltages or asymmetry of the load.

The thermographic camera registers intensity of electromagnetic radiation in the infrared portion of its spectrum and converts its distribution patterns into visible images. The source of the infrared radiation is the heat, so this specific radiation type is called also the heat radiation or thermal radiation. Each body characterized with temperature value of which exceeds the absolute zero (–273°C or 0°K) emits radiation in the infrared range.

Application of thermographic cameras in the electrical power engineering seems therefore to be very obvious. Wherever the current flows and resistance occurs, heat is generated and temperature increases. Therefore the issue of obtaining information about condition of the electric power network based on thermal properties of the observed system elements can be reduced to taking measurement with a thermographic camera in a skilled and correct way, followed by correct interpretation of thermograms. This includes measurements and inspections of power generators, electric power lines, transformers, and switchgears together with capacitor banks. In fact, all these elements of the system have an effect on the electric power quality [3].

Principles of thermographic measurements

The thermographic camera is used for contactless imaging of the temperature distribution pattern on an observed surface based on the measurement of intensity of the electromagnetic radiation emitted by individual surface elements. After pointing the camera at an element of the electric power system, subsystem, sub-unit, or electric power transmission line, a color image representing radiation of the object in infrared range called the thermogram is shown on the liquid crystal display [4].

The recorded images are analyzed by means of dedicated computer programs which allow to determine precisely the temperature in a selected location, whereas analysis of thermograms on the computer screen offers the possibility to identify all irregularities. By comparing thermograms taken at different points in time or those of different elements it is easy to find common trends or differences which can be considered first warning signs about incoming troubles and an indication to take further, more detailed measurements.

The rule of two-stage measurements in electric power networks should be adopted. The first stage includes identification of points with increased temperature; in the second step, measurement of the temperature of the suspicious element are taken from a close but still safe distance. To use thermographic cameras for finding those EPS points which are responsible for deterioration of the electric power quality, it is necessary, once any suspicions are grown (increased temperature), to connect an electric power quality analyzer to the examined point in order to determine whether the temperature increase is accompanied by deterioration of the electric power quality through e.g. asymmetry of currents, short or long power stoppages, overvoltages, etc.

Results of measurements taken with the use of camera can be affected by e.g. the atmosphere, clouds, precipitation, and heat waves, as such features also emit infrared radiation and thus distort the results. What is important here is the quality and type of the camera, its proper calibration, and possible restriction of factors affecting measurement results, because it is very difficult to estimate the combined effect on various types of interference.

When taking measurements by means of thermographic camera, an important parameter is the emissivity of the examined object. The quantity has been defined in order to refer radiation emitted by a real body to this generated by the standard which is the black body. The emissivity determines the ability of a given body to emit its internal energy with the reflected and transmitted energy being neglected.

In order to determine temperature of an object, it is necessary to know its emissivity. The actual emissivity value depends on the body material type, body temperature, and the radiation wavelength [3].

Results of thermographic measurements

Thermographic diagnostic methods are used not only to detect failures in electric devices occurring in individual points of an electric power system, but can be also used to search for and identify such locations in the EPS where power quality issues can appear in future.

This paper presents selected results of measurements for various EPS elements [5]. The presented thermographic measurements were taken in an industrial plant on a number of elements of its power system by means of a thermographic camera by FLIR Systems, Inc. [6].

An element extending operating capability and quality of a thermographic device is the software supplied by the measuring instrument's manufacturer. Options offered by such software include comprehensive analysis of the registered thermographic images. With the use of the software, it is possible to process the pictures (thermograms). The temperature distribution over surface of the examined object can be visualized in various color palettes, e.g. blue-red (Fig. 2a), grey scale (Fig. 2b), high contrast (Fig. 2c), hot metal (Fig. 2d), iron (Fig. 2e), and amber (Fig. 2f). Information on availability of such options in given device can be important, as improper interpretation of colors can result in fallacious analysis of thermograms.

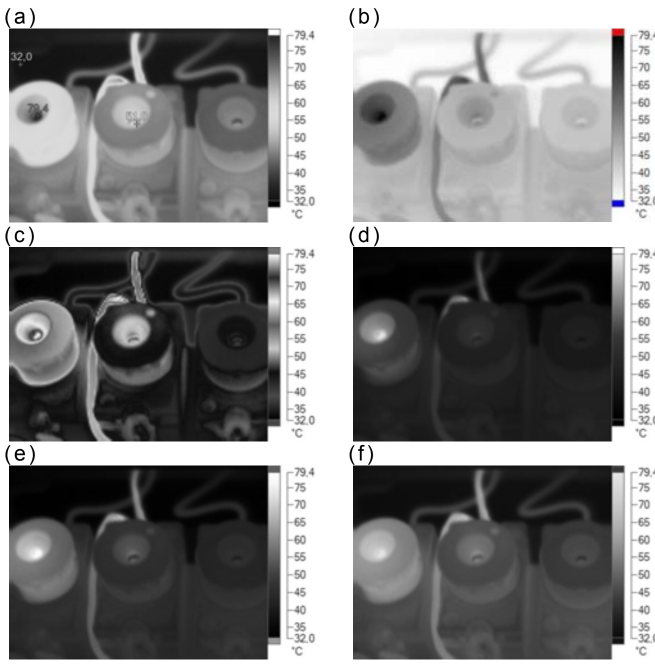

Fig. 2. Example images showing temperature distribution over surface of the examined object presented with the use of different color palettes: (a) blue-red; (b) grey scale; (c) high contrast; (d) hot metal; (e) iron, (f) amber

The most comfortable and “intuitive” palette as far as the visual readout is concerned is the thermogram represented in blue and red shades, completed with markers denoting the minimum, the maximum, and the central point temperature, as is shown in Fig. 2a.

Thermographic pictures differ from the image seen “with the naked eye”. Thermograms can include blurred contours and sometimes the pictures lack sharpness. Nevertheless, regardless of the selected color scheme, all thermograms of Fig. 2 show an asymmetry of load in individual phases. The real cause can be found only by means of more detailed measurements of the current rms value or waveform (harmonic content) performed e.g. by an electric power quality analyzer.

Measurements taken in power switching boards

The following part of this paper presents selected results of measurements in the form of photographs in visible light collated with thermograms for various cases [5].

Fig. 3 shows a fragment of an electric cabinet from each a high-power electric device is supplied. It can be seen that one of the conductors connected to the screwed clamp terminal of BM-type fuse (marked with digit 1) has a darker color. This is an evidence of insulation overheating. In the case discussed here, the fuse cartridge installed on this phase had has gone particularly frequently, which resulted in power failures and the related loss of continuity of the power supply.

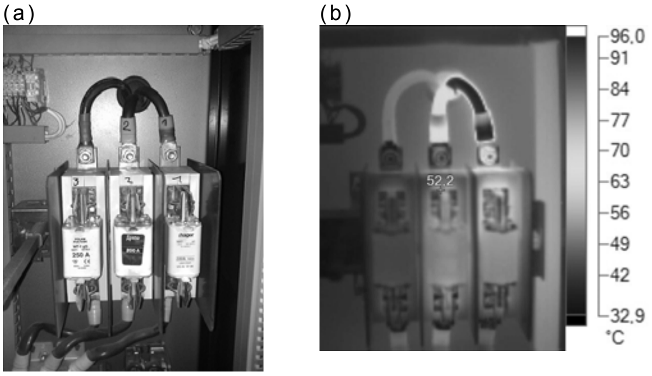

Fig. 3. A photograph (a) and thermogram (b) of the interior of an electric cabinet

Fig. 4 shows a picture of a power switchboard containing a three-phase residual current device and four single-phase circuit breakers. The inspection carried out “with the naked eye” corresponding to the photographic part of Fig. 4 did not arouse any suspicions, however in the course of periodical inspections of switchboards carried out with the use of thermographic camera it has been noticed

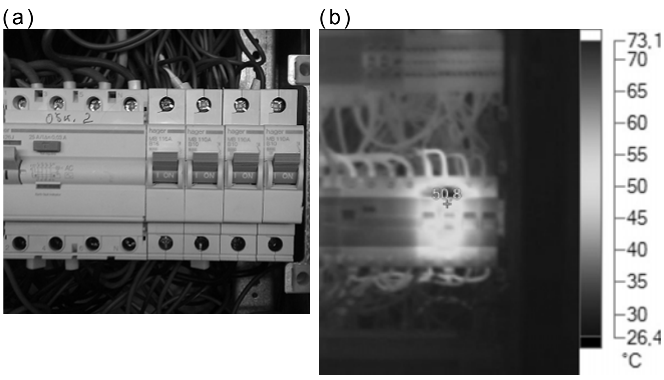

Fig. 4. A picture (a) and thermogram (b) of a switchboard

that temperature at certain point on one of the circuit breakers exceeded 70°C, as shown in Fig. 4b. As a result of analysis of the cause behind obtaining such thermographic image it has been found that the cause could be a faulty contact. Lack of good contact results in increased current intensity in one of the phases (asymmetry of currents), and as a consequence, increased temperature. Such wrong connection can be the cause of permanent damage of the switch and power supply stoppage, as well as unnecessary costs relating to purchase of spare parts.

Example of Fig. 5 shows a photo of another switchboard and two thermograms — before and after connecting a group of single-phase receivers in to a three-phase supply system with total rated power of several dozen kW. This is not a intermediate state or a transient, but such situation persist for e longer period of time in the system because the receivers are connected to the network simultaneously and the operate continuously for some time.

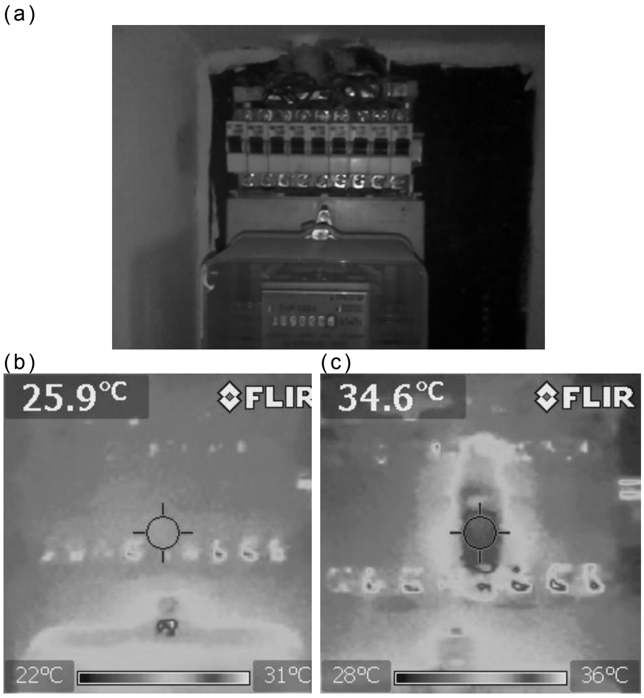

Fig. 5. A picture of a switchboard (a) and thermograms taken: before (b) and after (c) connecting a group of power receivers

The thermograms reveal clearly some irregularity in the electric power supply system. One of the phases, and more precisely, one of separate circuits of the phase, is much more heavily loaded with respect to others. Single-phase receivers, which are typically connected to the supply network in this plant, have been incorrectly distributed between individual supply voltage phases, which can be very easily found by taking a thermogram by means of a thermographic camera.

Measurements taken in a transformer station

The thermographic picture shown in Fig. 6 was taken in the transformer station of a low-voltage switching station. Fig. 6a presents a thermogram of busbars where uneven loading of phases is clearly visible, while Fig. 6b shows a correct phase load distribution. In the second case, the temperature difference between power supply buses is negligible and amounts to few degrees only. This is an evidence of correct operation of the connected devices. In case of individual phases being loaded unevenly, temperature differences can be significant meaning that considerable asymmetries can occur in phase voltages and currents which in turn can affect operation of various power receivers (e.g. electric motors) or even make their normal operation impossible. This can be the cause of significant electric power quality deterioration in this very point of the electric power system.

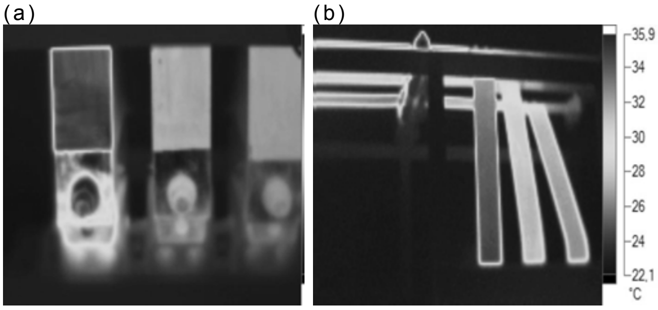

Fig. 6. A thermogram of busbars in a transformer station with individual buses loaded: (a) unevenly and (b) evenly

In such circumstances it may prove to be necessary to carry out a detailed analysis of the root cause of the observed condition, resulting in recommendation to connect an electric power quality analyzer to this very point of the electric power system.

Summary

The thermographic camera is an excellent tool streamlining diagnostics of the condition of electric power networks, systems, and line components, transformer stations, and power distribution systems inside buildings. Thanks to thermographic examination it is possible to detect asymmetries of power supply in three-phase systems, examine condition of transformers and high/low-voltage power lines, check correctness of operation of the switches, find possible irregularities in cooling electronic circuits, monitor operation of electric motors, locate overload conditions in mechanical devices, and perform many other control operations not listed above. The instrument allows to locate swiftly any overheating spots. In electric switchboards, the most common faults or failures are relating to contact problems occurring at terminals of electric components and increased temperature of overheated conductors. The condition of cables and conductors, as well local cracks and leakage conductances in insulation surfaces, have a significant effect on electric power supply safety and consistency.

Early detection of irregularities contributes to avoidance of unexpected failures or damages in the electric power network, allowing thus to save time and money related to repair of failures.

An important merit of the thermographic camera consists in possibility to detect a pre-failure condition in the operating system or machine, under the load, without the necessity to de-energize it.

Thermography is a comparative method, therefore to assess the status of an electric power network of its elements correctly it is also necessary to take into account the status of neighboring similar elements or thermograms obtained from observations consistently carried out earlier. In three-phase circuits it is obvious that thermal images of elements are to be compared to their counterparts in other phases. Once any difference between the phases is found, it is necessary to identify the cause and to this end, additional tests and measurements focused on the electric power quality parameters with the use of the dedicated analyzer can prove very helpful.

Consistency of periodical thermographic inspection of EPSs is also recommended in view of the system elements being subject to tear and wear in time, which can result in failures. Such situations can end up with unscheduled power stoppages, challenging thus the overall power supply reliability. Therefore, thermograms can provide first signals of an approaching shorter or longer power failures, whereas allowing such a situation to arise will result in deterioration of the electric power quality. Systematic inspections with the use of a thermographic camera allows to avoid such situations, and what is more, it can be performed swiftly, safely, and without stopping the inspected devices.

The range of application of thermographic test methods in various fields of technology is very wide. The few selected examples presented in this article show that they include cases where lack of prevention can lead to a large number of failures, including those involving the risk of fire. Lack of failure prevention can affect the whole electric power system and is ultimately equivalent to exposing the consumers to risk of electric power supply shortages and quality deterioration.

To sum up, from the point of view of problems related to the electric power quality, thermographic cameras can be used for early elimination of some causes of power stoppages (failures to ensure power supply continuity), overvoltages, and voltage/current asymmetries. In case of such phenomena, thermographic measurements and analysis of the obtained thermograms can be helpful in eliminating or at least reducing the related risks.

Worth considering is also the conception to use the thermal imaging for monitoring other phenomena and events occurring in EPS stations as a number of them can be "seen earlier and better in the infrared than with the naked eye".

***Authors**: Małgorzata Łatka, DSc, Eng., Rzeszow University of Technology, Faculty of Electrical and Computer Engineering, ul. W. Pola 2, 35-959 Rzeszów, Poland, E-mail: mlatka@prz.edu.pl Tomasz Piechota, MSc, Eng., a graduate of the Rzeszow University of Technology, Faculty of Electrical and Computer Engineering*

REFERENCES

[1] Madura H., Sosnowski T., Bieszczad G., Termowizyjne kamery obserwacyjne - budowa, zastosowania i krajowe możliwości realizacji, *Przegląd Elektrotechniczny*, 9/2014

[2] Zastosowanie termowizji w przemyśle — wskazówki, http://www.kameratermowizyjna.com

[3] Minkina W., Pomiary termowizyjne — przyrządy i metody. Wydawnictwo Politechniki Częstochowskiej, Częstochowa 2004

[4] Kupras K., Rutkowski P., Nowoczesne techniki kontroli instalacji i urządzeń z zastosowaniem kamer termowizyjnych, http://www.elektro.info.pl — 11/2005

[5] Piechota T., Zastosowanie kamery termowizyjnej do kontroli stanu instalacji elektrycznej, Politechnika Rzeszowska, Rzeszów 2015

[6] Flir System: Operating Manual — flir i5, Publ. No T559590 Rev a506, 2011