PD IEC/TS 62446-3:2017

BSI Standards Publication

Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance

Part 3: Photovoltaic modules and plants – Outdoor infrared thermography

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National foreword

This Published Document is the UK implementation of IEC/TS 62446-3:2017.

The UK participation in its preparation was entrusted to Technical Committee GEL/82, Photovoltaic Energy Systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance –
Part 3: Photovoltaic modules and plants – Outdoor infrared thermography

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC (PV) SYSTEMS – REQUIREMENTS FOR TESTING, DOCUMENTATION AND MAINTENANCE –

Part 3: Photovoltaic modules and plants – Outdoor infrared thermography

FOREWORD

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- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62446-3, which is a technical specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

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The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
82/1188/DTS	82/1242A/RVDTS

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62446 series, published under the general title *Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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PHOTOVOLTAIC (PV) SYSTEMS – REQUIREMENTS FOR TESTING, DOCUMENTATION AND MAINTENANCE –

Part 3: Photovoltaic modules and plants – Outdoor infrared thermography

1 Scope

This part of IEC 62446 defines outdoor thermographic (infrared) inspection of PV modules and plants in operation. The inspection can include cables, contacts, fuses, switches, inverters, and batteries. This inspection supports the preventive maintenance for fire protection, the availability of the system for power production, and the inspection of the quality of the PV modules. Included in this document are the requirements for the measurement equipment, ambient conditions, inspection procedure, inspection report, personnel qualification and a matrix for thermal abnormalities as a guideline for the inspection.

This document defines outdoor thermography on photovoltaic (PV) modules and Balance-of-system (BOS) components of PV power plants in operation, using passive techniques (standard system operating conditions under natural sunlight, without any external power or irradiation sources). IEC 60904-12-1 covers general methods for laboratory or production-line PV module thermographic imaging but not the specific details that are most relevant to outdoor imaging of operational power plants including BOS components.

Two different levels of inspections are currently used:

a) A simplified thermographic inspection. This is a limited inspection to verify that the PV modules and BOS components are functioning, with reduced requirements for the qualification of personnel. For example, during a basic commissioning of a PV plant. Authoritative conclusions regarding module quality are not possible with this inspection, and examples of abnormalities are provided to aid the inspector.

b) A detailed thermographic inspection and analysis. This may include thermal signatures which differ from the examples provided, and therefore requires a deeper understanding of the thermal abnormalities. For example, it may be used for periodic inspections according to the IEC 62446 series and for trouble-shooting the cause of underperforming systems. Absolute temperature measurements may be made. An authorized expert in PV plants, together with thermography experts can perform the inspection.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-131, *International Electrotechnical Vocabulary – Part 131: Circuit theory*

IEC 60216-2, *Electrical insulating materials – Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria*

IEC 60216-5, *Electrical insulating materials – Thermal endurance properties – Part 5: Determination of relative thermal endurance index (RTE) of an insulating material*

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IEC 60269-1, *Low-voltage fuses – Part 1: General requirements*

IEC 61095, *Electromechanical contactors for household and similar purposes*

IEC 61215-1, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1: Test requirements*

IEC 61439-1, *Low-voltage switchgear and controlgear assemblies – Part 1: General rules*

IEC 61724-1, *Photovoltaic system performance – Part 1: Monitoring*

IEC 61730-1, *Photovoltaic (PV) module safety qualification –Part 1: Requirements for construction*

IEC 61730-2, *Photovoltaic (PV) module safety qualification –Part 1: Requirements for testing*

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC 62109-1, *Safety of power converters for use in photovoltaic power systems – Part 1: General requirements*

IEC 62446-1, *Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 1: Grid connected systems – Documentation, commissioning tests and inspection*

IEC 62446-2:–, *Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 2: Grid connected photovoltaic (PV) systems – Maintenance of PV systems*[1]

IEC 62930:–, *Electric cables for photovoltaic systems with a voltage rating of 1,5 kV d.c.*[1]

ISO 9488, *Solar energy – Vocabulary*

ISO 9712, *Non-destructive testing — Qualification and certification of NDT Personnel*

VATh- Directive, *Electrical Infrared Inspections – Low Voltage. Planning, execution and documentation of infrared surveys on electrical systems and components ≤1kV* (http://www.vath.de/docs/richtlinien/VATh-Richtlinie_Elektro_NS+PV_engl_web.pdf)

EN 16714-3, *Non-destructive testing – Thermographic testing of electric installations*

EN 50110-1, *Operation of electrical installations – Part 1: General requirements*

DGUV BGV/GUV-V A3 E, *Accident prevention regulations, Electrical installations and equipment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836, ISO 9488, IEC 60050-131 and the following apply.

[1] To be published.

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ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
abnormal thermal behavior
thermal signature of an element that cannot be explained by its operating condition or its technical design, e.g. position of load resistors

[SOURCE:IEC 60050-903:2013, Amendment 1:2014, 903-01-22; modified: adapted to thermal behavior]

3.2
reflected temperature
T_{refl}
mean apparent temperature of the ambient that is reflected by the object towards the IR-camera

Note 1 to entry: Measured in Celsius (°C).

Note 2 to entry: Some manufactures of IR cameras use the term: ambient temperature.

3.3
atmospheric air temperature
defined in Celsius (°C) for the geographic installation location as measured and documented by meteorological services for this geographic location

3.4
Beaufort (scale)
Bft
quantifies wind speed by phenomenological criteria, e.g. movement of branches and trees

SEE: Annex E.

3.5
cloud coverage
for the inspection two types of clouds are to differ: Cumulus and Cirrus. The cloud coverage should be given in okta (part of eight of cloud coverage)

SEE: ISO 15469:2004[18][2].

3.6
emissivity of the object
ε
ratio of the thermal radiation that is emitted by the surface of an object compared to a black body radiator both at the same temperature

3.7
Instantaneous Field of View
IFOV
field of view of one pixel of an IR-camera-lens combination

Note 1 to entry: Measured in milliradian (mrad).

[2] Numbers in square brackets refer to the Bibliography.

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3.8
Noise Equivalent Temperature Difference
NETD
smallest temperature difference detectable by an IR-camera

Note 1 to entry: Measured in millikelvin (mK).

3.9
thermal steady state conditions
usable measurement conditions, which show stable temperatures and temperature differences

4 Requirements of inspection equipment

4.1 General

This clause states the minimum requirements for equipment used for thermographic (infrared) inspection within the scope of this document. It includes requirements for the infrared (IR) camera, the photo camera and equipment to record ambient conditions.

All equipment shall be date and time synchronized prior to use, to easily match images to system conditions, for example the in plane irradiation, and DC-load of the plant.

4.2 Minimum requirements for IR-cameras used for inspecting PV plants

The specifications of the infrared camera shall fulfil the minimum requirements according to Table 1.

Table 1 – Minimum requirements for IR-cameras

	Features	Minimum requirements
a	Spectral response	2 µm to 5 µm (mid wavelength) or 8 µm to 14 µm (long wavelength) [1]
b	Temperature-sensitivity and calibration range (object temperature range)	–20 °C to +120 °C
c	Operating ambient air temperature range	–10 °C to +40 °C
d	Thermal sensitivity	NETD ≤ 0,1 K at 30 °C
e	Geometric resolution	1) PV module: max. 3 cm of the module edge per pixel[2] 2) Electrical connections: The geometrical resolution (Real measurement spot[3]) has to match the smallest object area to be verified. Futher details can be found in Clauses A.1 and A.2.
f	Absolute error of measurement	< ± 2 K
g	Adjustable parameters	Emissivity (ε), reflected temperature (T_{refl})
h	Adjustable functions	Focus, temperature level and span
i	Measurement functions	Measuring spot, measuring area with average and maximum temperature

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	Features	Minimum requirements
j	Calibration	The measuring system (camera, lens, aperture and filter): The thermographic camera shall be traceably calibrated at least every two years. The calibration has to be documented. If the camera is not compliant (absolute temperature and/or temperature differences), it may be readjusted by the manufacturer.
k	Documentation	Storing of the infrared picture with all radiometric information to be able to determine absolute temperatures. Non-radiometric pictures can only provide pattern and eventually temperature differences.

1 Cameras operating in wavelength range of 2 µm to 5 µm shall only be used for thermography of electrical BOS components, e.g. fuses. Due to the transparency of glass in the range of 3 µm the use of that range on PV modules can lead to measurement errors.

2 3 cm length of edge per pixel equals 5 x 5 pixel on a 6“ PV cell.

3 The real measuring spot mostly is defined as 3 x 3 pixel, for high-quality optics.

Use of an IR camera with resolution ≥ 320 x 240 pixels and a separate photo camera are recommended, with monitor and remote control or a swivelling display.

4.3 Requirements for photo cameras for documentation of the findings

Visual photos documenting the state of the module/plant are recommended, however visual photos of any thermal abnormality are required. One photo of every safety relevant abnormality (see Table 4) shall be taken.

The resolution of the visual photo shall be significantly higher than the IR image and shall have a similar field of view to sufficiently capture all details of the object (e.g., busbars, ribbons of a solar cell, broken front glass, fuse and fuse holder). It shall be ensured that IR and visual photo capture the same area of interest while fulfilling the resolution requirement. A separate photo camera and IR camera are recommended, in order to ensure sufficient resolution of visual photo (typically at least 30 times higher).

NOTE In many cases, the basic photo camera which is integrated into the infrared camera is not able to provide the requested resolution. For an IR camera of 640 x 480 pixel a separate photo camera with at least 9 Mpix is suitable.

4.4 Requirements for equipment to record the ambient conditions

To detect thermographic abnormalities correctly, certain ambient conditions have to be met. Equipment to measure these conditions should be compliant to the minimum requirements in Table 2.

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Table 2 – Requirements for equipment to record the ambient conditions

	Parameter	Equipment	Accuracy
a	Irradiance	Irradiance sensor (crystalline silicon cell or pyranometer)	Calibration: ± 5 %
b	Ambient (air) temperature	Temperature sensor (shielded from direct light and wind)	Calibration: ±2 K
c	Wind speed	Bft scale (visual) or anemometer	Estimation
d	Cloud coverage	Photo camera	Estimation
e	Degree of soiling	Photo camera	Estimation Estimation can be done using procedure according to IEC 61724-1
f	Module or string current	DC (clamp) ampere meter (or inverter reading[1]	Calibration: ± 2 %
[1] Note that the inverter reading may not give accurate results or be calibrated. Though it may be useful for some BOS components, it may also not have resolution for PV string-level current measurement.			

5 Inspection procedure

5.1 General

An inspection of the PV plant should be done during the commissioning and operation of the power plant, in accordance with applicable health and safety regulations. The recommended interval for periodic thermography inspections is four years but the applied intervals for a specific installation shall be agreed upon with the owner / operator, or they might be defined by national electric codes and safety regulations for electrical installations.

The owner, operator or an authorized person shall give the inspector(s) an introduction into the safety specific regulations of the PV plant to be inspected, including details of the plant and electrical layout. A second person should be present during inspection, and may be required by local safety regulations. At least one of the persons performing the inspection shall have technical knowledge of the specific system, and of PV plants in general. Inspections shall be done following applicable safety regulations, for example in accordance to EN 50110-1 or DGUV BGV/GUV-V A3 E.

The detailed inspection scope shall be defined prior to the inspection and agreed in writing between the involved parties.

The plant shall be under operating conditions. The part of the system under evaluation shall be in thermal steady state condition and free of partial shading (if possible). Soiling should be low (less than 10 % operating current Impp loss) and homogeneous, without causing partial shading (e.g., by bird droppings, leaves, vegetation) to avoid thermal effects. If strong soiling or partial shading due to, for example bird droppings, is observed on the PV modules, it is recommended to clean the entire system prior to inspection. Note that the performance of the system may change as a result of the cleaning. Ensure modules are at thermal steady state after cleaning prior to performing infrared imaging inspection.

For quantification of soiling, it is recommended to conduct measurements according to IEC 61724-1. This might be helpful to compare measurements from periodic inspections.

Collecting IR images can be done in different ways, e.g., using tripods, by hand or drones. Care shall be taken that the method selected still meets the resolution requirements, and to ensure understanding of the method used (e.g., reflections). Any known deviations or limitations shall be noted in the inspection report.

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National regulations and laws may apply to using IR cameras and other equipment like drones.

The inspection results verify the status at the time of inspection. Issues of intermittent or changing nature may or may not be captured at the time of inspection.

5.2 Visual inspection

Prior to the thermographic inspection of the PV plant, it is recommend to do a visual inspection to determine whether the requirements of 5.1 are met. Observations such as bird droppings, strong soiling, burn spots on modules or other Balance of System (BOS) components shall be documented by photos and location prior to the thermographic inspection. If possible, those findings should be resolved (e.g. by cleaning) prior to the thermographic inspection especially during comissioning. Photos post-cleaning (pre-imaging) should be documented. However, it may be desireable to conduct the thermography inspection without cleaning, e.g. for a root-cause analysis for a poor performing PV power plant.

Upon observation of thermal anomalies, it is desireable to visually inspect the component and visually observe any abnormal conditions in the area. The PV module visual inspection procedures in IEC 61215-1 and IEC 61730-2 may be useful references. A visual photo shall be captured for every thermal abnormality type.

5.3 Environmental conditions

The inspection should be performed under the conditions specified in Table 3.

Table 3 – Required inspection conditions

	Parameter	Limits
a	Irradiance	• Minimum 600 W/m^2 in the plane of the PV module for PV module inspection • Measured operating current shall be a minimum of 30 % of rated system current within the inspected current path (typically > 30 % of PV module name plate Isc at STC (equals typically > 300W/m^2 in the plane of the PV modules) for inspection of other electrical components (e.g. cables, connectors, connections). Recommended for inspection are > 600 W/m^2. NOTE Example for single string with no parallel connection: 30 % of STC Isc current. Isc to be taken from PV module name plate and not to be measured on PV plants.
b	Wind speed	Maximum 4 Bft or 28 km/h (see Annex E)
c	Cloud coverage	Maximum 2 okta of sky covered by cumulus clouds
d	Soiling	No or low. Cleaning recommend, e.g. if bird droppings exist.

NOTE For cloud coverage, find further information in ISO 15469:2004.

After change in operating conditions, for example load or irradiance (due to e.g. cirrus clouds) of >10 % per minute, a waiting time of 15 min is recommended to regain the steady state measurement conditions.

The cloud coverage should not consist of more than 2 okta of cumulus clouds, because of misleading reflections on the modules.

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