



BSI Standards Publication

Photovoltaic devices

Part 13: Electroluminescence of photovoltaic modules

National foreword

This Published Document is the UK implementation of IEC TS 60904-13:2018.

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.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2018
Published by BSI Standards Limited 2018

ISBN 978 0 580 93228 1

ICS 27.160

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 September 2018.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------



IEC TS 60904-13

Edition 1.0 2018-08

TECHNICAL SPECIFICATION



**Photovoltaic devices –
Part 13: Electroluminescence of photovoltaic modules**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160

ISBN 978-2-8322-5991-7

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	4
1 Scope.....	6
2 Normative references	6
3 Terms and definitions	6
4 Imaging	7
4.1 Apparatus	7
4.1.1 Electroluminescence imaging camera	7
4.1.2 Dark room imaging studio or environment.....	9
4.1.3 Power supply.....	7
4.1.4 Computer interface with camera and power supply for image capture	11
4.1.5 Image processing and displaying software.....	11
4.1.6 Safety and handling	12
4.2 Procedure	12
4.2.1 Camera settings and positioning.....	12
4.2.2 Camera settings	13
4.2.3 Sharpness determination and classification	14
4.2.4 Imaging	16
4.2.5 Image correction.....	17
4.3 Image signal-to-noise ratio.....	18
4.3.1 General	18
4.3.2 Imaging procedure.....	18
4.3.3 Analysis.....	18
4.3.4 SNR criteria.....	19
5 Evaluation of EL images	20
5.1 Principles of electroluminescence	20
5.2 Image interpretation.....	21
5.2.1 Series resistance	21
5.2.2 Minority carrier lifetime and diffusion length.....	21
5.2.3 Shunt resistance.....	21
5.2.4 Assignment of root cause	21
5.3 Histogram based analysis of the electroluminescence signal	21
5.3.1 General	21
5.3.2 Image information	22
5.3.3 Bias current effects.....	22
5.3.4 Analysis of intensity distributions	22
5.3.5 Variance	22
5.3.6 Kurtosis	22
5.3.7 Skewness	22
5.3.8 Pixel (or area)-weighted electroluminescence relative to an ideal module	22
6 Reporting.....	22
Annex A (normative) Procedures for image correction.....	24
A.1 Dark current and stray light removal.....	24
A.2 Vignetting	24
A.2.1 Vignetting correction.....	24
A.2.2 Vignetting as a function of angle from the optical axis.....	24
A.2.3 Correction for vignetting	24

Annex B (informative) Focus	26
B.1 General.....	26
B.2 Application of the Tenengrad function and Sobel operator	26
Annex C (normative) Quantifying solar cell cracks in photovoltaic modules	27
C.1 General.....	27
C.2 Cell crack modes	27
C.3 Basis of cell damage quantification	28
C.4 Procedure	30
Annex D (informative)	32
D.1 Qualitative interpretation of electroluminescence images crystalline Si PV modules	32
D.2 Qualitative interpretation of electroluminescence images in thin-film PV modules	36
Bibliography.....	39
Figure 1 – Various semiconductor detector materials and their absolute spectral response [1].....	8
Figure 2 – Electroluminescence emission spectra for (a) Si, (b) ZnO/CdS/Cu(In,Ga)Se ₂ (CIGS) [2], and (c) CdS/CdTe [3].....	8
Figure 3 – Example of frame subtraction given in Figure 3a) to Figure 3c), with images taken in ideal dark room conditions given in Figure 3d).....	12
Figure 4 – EL image with introduced two edges using aluminum tape	15
Figure 5 – Edge gradient image GEdge from the Figure 4 EL image's first derivative in orthogonal direction G_{x,y}	15
Figure 6 – Excerpt of the EL image of Figure 4 and plot of image intensity values along line L₂	15
Figure 7 – Images of regions of multicrystalline silicon solar cells with three SNR₅₀ values as labeled.....	20
Figure 8 – Emission of light (hν) associated with the electroluminescence process in solar cells of PV modules.....	20
Figure 9 – Scheme for labeling position of cells in a module viewed from the light-facing side according to coordinates (i,j) in portrait orientation (a) or rotated into landscape orientation (b), which shall be indicated if applicable.....	23
Figure B.1 – EL image of a solar cell (left) and a silicon module (right)	26
Figure C.1 – Single cell region of a module with $0,1 \times I_{SC}$ applied showing crack types, as labeled.....	27
Figure C.2 – Example of normalized EL intensity histograms calculated from the EL images of modules with various levels of cell cracking and resulting power degradation, indicated by I_{max}	29
Figure C.3 – Example of quantifying solar cell cracks in photovoltaic modules: (a) EL image produced with $0,1 \cdot I_{SC}$ forward bias current, and (b) image of regions considered damaged.....	31
Table 1 – Detectors and their applicable wavelengths.....	7
Table 2 – Sharpness classes, examples of images meeting the criteria of the classes, and examples of distinguishable features.....	16
Table D.1 – Descriptions of observables, features, and known causes, along with electroluminescence images for crystalline Si modules	32
Table D.2 – Descriptions of observables, features, and known causes, along with electroluminescence images for thin-film modules	36

INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC DEVICES –

Part 13: Electroluminescence of photovoltaic modules

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when:

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the possibility in the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 60904-13, which is a technical specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

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

Enquiry draft	Report on voting
82/1292/DTS	82/1424/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 60904 series, published under the general title *Photovoltaic devices*, can be found on the IEC website.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

PHOTOVOLTAIC DEVICES –

Part 13: Electroluminescence of photovoltaic modules

1 Scope

This part of IEC 60904 specifies methods to:

- a) capture electroluminescence images of photovoltaic modules,
- b) process images to obtain metrics about the images taken in quantitative terms, and
- c) provide guidance to qualitatively interpret the images for features in the image that are observed.

This document is applicable to PV modules measured with a power supply that places the cells in the modules in forward bias.

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 TS 61836:2016, *Solar photovoltaic energy systems – Terms, definitions and symbols*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 as well as the following apply.

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 electroluminescence EL

emission of optical radiation resulting from the application of electrical energy

3.2 open circuit

electrical circuit that has a break, or “open”, somewhere in the conductive path

Note 1 to entry: A module or laminate exhibits an “open circuit” if defective or damaged so that no current can flow through it when attached to an external circuit at the module electrical connection points.

Note 2 to entry: A PV module itself is in open circuit condition if one or both of the module electrical connection points are not connected to anything or current is not flowing as defined in IEC TS 61836:2016, 3.4.57.