IEC TS 63109

Edition 1.0 2022-03

TECHNICAL SPECIFICATION

Photovoltaic (PV) modules and cells – Measurement of diode ideality factor by quantitative analysis of electroluminescence images

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160

ISBN 978-2-8322-1090-3

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

® Registered trademark of the International Electrotechnical Commission

CONTENTS

FOREWORD 4
INTRODUCTION 6
1 Scope 7
2 Normative references 7
3 Terms and definitions 7
4 Procedures for quantitative analysis of EL intensity 8
4.1 General 8
4.2 Samples 9
4.3 Apparatus 9
4.4 EL image capturing and camera calibration 9
4.5 Procedures of analysing data to derive n values (refer to Annex A) 9
5 Measurement report 9
Annex A (normative) EL intensity dependence on the injection current 11
A.1 General 11
A.2 Derivation of diode ideality factor 11
Annex B (informative) Examples of measurements of diode ideality factor n 13
B.1 General 13
B.2 Examples of n value of cells 13
B.2.1 Example 1 – Module without defect 13
B.2.2 Module with defect 15
Annex C (informative) Diode ideality factor n as an indicator of the output performance of PV modules – Measurement using proposed single diode model – 19
C.1 General 19
C.2 Practical single diode model 20
C.3 Concise derivation method of n using photo response parameters 26
Bibliography 28

Figure 1 – Scheme for labeling position of cells in a module viewed from the light-facing side according to coordinates (i,j) 10
Figure A.1 – Electroluminescence intensity dependence on injection current 12
Figure B.1 – EL image (module without defect) 13
Figure B.2 – EL intensity dependence on injection current (module without defect) 14
Figure B.3 – EL image (aged module) 15
Figure B.4 – EL intensity dependence on injection current (aged module) 15
Figure B.5 – Diode ideality factor n of 3,F 16
Figure B.6 – EL image (defective module) 17
Figure B.7 – EL intensity dependence on injection current (defective module) 17
Figure B.8 – Diode ideality factor n of 4,E 18
Figure C.1 – Equivalent circuit model in dark considering series resistance R_S and shunt resistance R_{sh} 20
Figure C.2 – Equivalent circuit model in dark for the practical single diode model 20
Figure C.3 – Schematic I-V characteristic in dark using linear coordinates 21
Figure C.4 – Schematic I-V characteristic in dark using semi-logarithmic scales 21

Figure C.5 – Equivalent circuit model under photo irradiation considering series resistance R_S 23
Figure C.6 – Equivalent circuit model under photo irradiation for practical single diode model 23
Figure C.7 – Photo response showing I_{ph} – V_{ph} characteristic flowing through the load 24
Figure C.8 – Diode current as a function of the diode voltage 25
Figure C.9 – Semi-logarithmic plot of diode current versus diode voltage 25
Figure C.10 – Schematic consideration of photo-response change with increasing the diode ideality factor n 26

Table B.1 – Performance of module without defect (module A) (at STC) 14
Table B.2 – Performance of aged module (module B) (at STC) 16
Table B.3 – Performance of PID module (at STC) 18

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

PHOTOVOLTAIC (PV) MODULES AND CELLS – MEASUREMENT OF DIODE IDEALITY FACTOR BY QUANTITATIVE ANALYSIS OF ELECTROLUMINESCENCE IMAGES

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.

IEC TS 63109 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
82/1955/DTS	82/1992/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under 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.

INTRODUCTION

EL (Electroluminescence) diagnosis technique has been widely used for the evaluation of photovoltaic cells and modules photographically. EL images can identify various kinds of deficiencies, such as cracks and pin-holes in substrates, breakdown and detachment of electrodes, etc. In addition to these qualitative inspections, the quantitative analysis of EL intensity can reveal the electronic performance of photovoltaic cells [1] to [7][1]. The EL intensity is proportional to the total number of minority carriers in photovoltaic cell bodies. The injection of minority carriers is governed by the I-V characteristics of pn junctions following the diode rectification formula, which yields that the EL intensity dependence upon the injection current will derive the diode ideality factor [8].

The proposed analysis method is not intended to give the criteria for the diagnosis of cells and modules, but the measured values of n are informative for stakeholders to share a common view about degradation phenomena among themselves. This standard measurement technique may be useful for the following stakeholders:

a) Manufacturers – checking validity of samples for both development and quality control (refer to Annex C).

b) Power producers – checking suspicious modules for potential failures (refer to Annex B).

c) Reuse – evaluation of value of second-hand modules (refer to Annex B).

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

PHOTOVOLTAIC (PV) MODULES AND CELLS – MEASUREMENT OF DIODE IDEALITY FACTOR BY QUANTITATIVE ANALYSIS OF ELECTROLUMINESCENCE IMAGES

1 Scope

This document specifies a method to measure the diode ideality factor of photovoltaic cells and modules by quantitative analysis of electroluminescence (EL) images.

This document provides a definition of the term diode ideality factor n, as the inverse of increment ratio of natural logarithm of current as a function of applied voltage, which is related to the fill factor FF, and is useful as an effective indicator to represent the output efficiency of photovoltaic cells and modules with the other key parameters open circuit voltage V_{oc} and short circuit current I_{sc}.

This document is only applicable to crystalline silicon photovoltaic cells and modules.

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 60904-13:2018, *Photovoltaic devices – Part 13: Electroluminescence of photovoltaic modules*

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