IEC TR 63534

Edition 1.0 2025-05

TECHNICAL REPORT

Integrating distributed PV into LVDC systems and use cases

ICS 29.020

ISBN 978-2-8327-0373-1

IEC TR 63534:2025-05(en)

THIS PUBLICATION IS COPYRIGHT PROTECTED
Copyright © 2025 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Discover our powerful search engine and read freely all the publications previews, graphical symbols and the glossary. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 500 terminological entries in English and French, with equivalent terms in 25 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

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

CONTENTS

FOREWORD 4
INTRODUCTION 6
1 Scope 7
2 Normative references 7
3 Terms, definitions and abbreviated terms 7
3.1 Terms and definitions 7
3.2 Abbreviated terms 9
4 Selected LVDC use cases and challenges 9
4.1 General 9
4.2 Typical Case I: Nushima Island (Japan) 10
4.3 Typical Case II: LVDC systems enabled hybrid AC/DC systems (Tongli, China) 10
4.4 Typical Case III: DC system in RTWH Aachen University (Germany) 11
4.5 Typical Case IV: Hybrid LVDC systems for hydrogen generation (Singapore) 12
4.6 Typical Case V: LVDC enabled modern green building system (Switzerland) 13
4.7 Typical Case VI: Future Tower in low carbon city of Shenzhen, China 14
4.8 Technical challenges 15
5 DC Interfaces of PV to LVDC systems 15
5.1 DC Interfaces for PV integration 15
5.1.1 Problem statement 15
5.1.2 Critical issues 16
5.2 Controllability of PV systems in LVDC 18
5.2.1 Problem statement 18
5.2.2 Critical issues 19
5.3 Summary 20
6 Fault response of LVDC system integrated with PV overview 20
6.1 Islanding detection of distributed PV systems 20
6.1.1 Problem statement 20
6.1.2 Critical issues 23
6.2 Fault ride-through capability of PV in LVDC system 24
6.2.1 Problem statement 24
6.2.2 Critical issues 24
6.3 Summary 25
7 Stability and oscillation suppression of LVDC with PV 25
7.1 Problem statement 25
7.2 Key issues 26
7.2.1 Modelling of LVDC system with distributed energy sources 26
7.2.2 Effective stability criterion 27
7.2.3 Oscillation suppression and stability enhancement 27
7.3 Summary 29
8 Coordination with standards 29
8.1 Related standards for grid integration of PV generation 29
8.1.1 IEEE 1547™-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces 29
8.1.2 IEC 61727:2004, Photovoltaic (PV) systems – Characteristics of the utility 1245 interface 29

8.1.3 IEC 61215-1:2021, Terrestrial photovoltaic (PV) modules - Design qualification and type approval – Part 1: Test requirements 29
8.2 Related standards for the LVDC distribution system 29
8.2.1 IEC-SEG 4 Systems Evaluation Group – Low Voltage Direct Current Applications, Distribution, and Safety for Use in Developed and Developing Economies 29
8.2.2 IEC TR 63282:2024, LVDC systems – Assessment of standard voltages and power quality requirements 30
8.3 Other related standards 30
8.3.1 IEC 62109-1:2010, Safety of power converters for use in photovoltaic power systems – Part 1: General requirements 30
8.3.2 IEC 62446-1:2016 and IEC 62446-1:2016/AMD1:2018, Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 1: Grid connected systems – Documentation, commissioning tests and inspections 31
8.3.3 IEC TS 62257 series, Recommendations for renewable energy and hybrid systems for rural electrification 31
8.3.4 IEC 60364 series, Low-voltage electrical installations 31
8.3.5 IEC 60364-1:2005, Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions 32
8.3.6 IEC TS 62786-1:2023, Distributed energy resources connection with the grid – Part 1: General requirements 32
9 Summary 32
Annex A (informative) Points of connection in a typical distribution network 34
Bibliography 35

Figure 1 – LVDC system on Nushima Island 10
Figure 2 – Hybrid AC/DC distribution system demonstration project in Tongli, Suzhou, with the integration of LVDC system 11
Figure 3 – DC system in Campus Melaten of RTWH Aachen University 12
Figure 4 – A testbed for clean energy innovations with PV and H_2 generation 13
Figure 5 – Green building with multi-energy supply system 14
Figure 6 – System architecture of Future Tower 14
Figure 7 – Classification of the RE DC interface from different aspects 16
Figure 8 – Two types of PV integration interface to LVDC in literature 16
Figure 9 – Two-stage power converter integrating a PV module to a DC network 16
Figure 10 – Expression of the operation range on the specific front-end input port 17
Figure 11 – PV and its interfacing converter linked to an upstream grid 19
Figure 12 – Classification of islanding detection methods 21
Figure 13 – Schematic diagram of cascaded system in Middlebrook criterion 26
Figure 14 – Unified form of the LVDC systems 26
Figure 15 – Division of two subsystems 27
Figure 16 – Position selection of the virtual impedance 28
Figure A.1 – One-line diagram of a typical distribution network 34

Table 1 – Features of islanding detection methods 21

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

INTEGRATING DISTRIBUTED PV INTO LVDC SYSTEMS AND USE CASES

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) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at https://patents.iec.ch. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TR 63534 has been prepared by subcommittee SC 8A: Grid integration of renewable energy generation, of IEC technical committee TC 8: Systems aspects of electrical energy supply. It is a Technical Report.

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

Draft	Report on voting
8A/187/DTR	8A/191/RVDTR

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 Report 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/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, or
- revised.

INTRODUCTION

During the 2019 IEC SC 8A plenary meeting in Shanghai, China, DECISION 2019/5, based on a proposition by the China National Committee, was approved and written into List of Decisions (see document 8A/61/DL): It consisted in a new Preliminary Work Item (PWI) called “Integrating distributed PV into LVDC systems and use cases”. It was approved to create a new WG led by SC 8A, with participation from SC 8B called “Integrating distributed PV into DC systems and use cases”. It was approved to nominate Prof. ZHU Miao from CN NC as the convenor.

The task is to develop a series of projects regarding integrating distributed PV into DC systems and use cases with emphasis on large-scale and high penetration of renewable energy (RE) via low voltage direct current (LVDC) system within the following scopes of operational behaviour and coordinated control between RE and DC system, for example including DC interface for RE integration, fault response and stability issues of LVDC integrated RE, etc.

It is increasingly important to optimize the performance and efficiency of renewable-enabled power systems by integrating DC power into various low voltage applications, such as buildings, vehicles, and electronic devices. DC power generated by PV systems is more compatible with the DC-based electronic devices used in these applications, making it more efficient and cost-effective.

Nonetheless, there lacks a standard or reference framework that would orient original equipment manufacturers (OEMs), engineering, procurement, and construction (EPC) as well as other RE system operators to provide continuous high-quality generation services to grids.

In this context, the intention of this document is to present necessary technical screening and then to offer profound insights to the formulation of relevant standards. It helps to deal with both the converter-level and grid-level requirements on PV integration via DC integration, to pave a way to further develop a series of standards/technical reports with emphasis on high penetration of PV via LVDC system.

INTEGRATING DISTRIBUTED PV INTO LVDC SYSTEMS AND USE CASES

1 Scope

This document reviews existing theoretical attempts and engineering applications in the area of solar PV systems coupled to LVDC systems. There are three aspects that are identified to be highly relevant to standard compilations:

- power converters and possible control mechanisms that are eligible for facilitating the interlinking between PV and LVDC networks;
- local PV system islanding detection algorithms and fault ride through in case of main grid faults;
- stability analysis of PV interacting with LVDC systems and corresponding stabilization methods;

An inventory of existing (mostly IEC and national) standards is also presented, based on which different sorts of PV integration scenarios are elaborated. Gaps between actual standards and future needs are analyzed and guidelines for evolution are presented.

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 62934, *Grid integration of renewable energy generation – Terms and definitions*