

TECHNICAL SPECIFICATION IEC TS 62257-7-1

First edition
2006-12

**Recommendations for small renewable energy
and hybrid systems for rural electrification –**

**Part 7-1:
Generators – Photovoltaic arrays**

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Reference number
IEC/TS 62257-7-1:2006(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

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IEC

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Part 7-1: Generators – Photovoltaic arrays

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Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE **XC**

For price, see current catalogue

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**RECOMMENDATIONS FOR SMALL RENEWABLE ENERGY AND
HYBRID SYSTEMS FOR RURAL ELECTRIFICATION –****Part 7-1: Generators – Photovoltaic arrays**

FOREWORD

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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 62257-7-1, which is a technical specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This first edition of IEC 62257-7-1 is based on IEC/PAS 62111 (1999); it cancels and replaces the relevant parts of IEC/PAS 62111.

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

Enquiry draft	Report on voting
82/406A/DTS	82/446/RVC

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

A list of all parts of the IEC 62257 series, published under the general title, *Recommendations for small renewable energy and hybrid systems for rural electrification* can be found on the IEC website.

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

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- withdrawn,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

A bilingual edition of this document may be issued at a later date.

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Withdrawn

INTRODUCTION

The IEC 62257 series of publications intends to provide to different players involved in rural electrification projects (such as project implementers, project contractors, project supervisors, installers, etc.) documents for the setting-up of renewable energy and hybrid systems with a.c. voltage below 500 V, d.c. voltage below 750 V and power below 100 kVA.

These publications provide recommendations for

- choosing the right system for the right place;
- designing the system;
- operating and maintaining the system.

These publications are focused only on rural electrification concentrated in, but not specific to, developing countries. They must not be considered as all-inclusive of rural electrification. The publications try to promote the use of renewable energies in rural electrification. They do not deal with clean mechanism developments at this time (CO₂ emission, carbon credit, etc.). Further developments in this field could be introduced in future steps.

This consistent set of publications is best considered as a whole, with different parts corresponding to items for the safety and sustainability of systems at the lowest possible life-cycle cost. One of the main objectives of the series is to provide the minimum sufficient requirements relevant to the field of application, i.e. for small renewable energy and hybrid off-grid systems.

The purpose of this part of IEC 62257 is to propose a framework for project development and management and it includes recommended information that must be taken into consideration during all the steps of the electrification project.

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RECOMMENDATIONS FOR SMALL RENEWABLE ENERGY AND HYBRID SYSTEMS FOR RURAL ELECTRIFICATION –

Part 7-1: Generators – Photovoltaic arrays

1 Scope

This part of IEC 62257 specifies the general requirements for erection and operation of PV arrays in decentralized rural electrification systems.

This technical specification contains requirements for ELV and LV PV arrays (see Table 1). Particular attention must be paid to voltage level, as this is important for safety reasons and has an influence on protective measures and on the skill and ability level of people operating the systems.

Table 1 – Voltage domains for PV arrays

Voltage domain	Voltage (volts)	
	Alternating current	Smoothed direct current
ELV	$U_n \leq 50 \text{ V}$	$U_{oc} \leq 120 \text{ V}$
LV	$50 \text{ V} < U_n \leq 1\,000 \text{ V}$	$120 \text{ V} < U_{oc} \leq 1\,500 \text{ V}$

Note ELV limits are provided by IEC 61201.

For the sake of completeness, this technical specification gives requirements for d.c. voltages below and above 120 V. However for rural electrification projects it is strongly recommended to choose a voltage in the range of extra low voltage, taking into account the assumed skills of the operators, installers and users. Nevertheless, designers must be aware that decreasing the voltage means increasing the current and thus transferring voltage hazards to current risks (risk of fire, etc.).

The following PV array configurations are considered (see Figure 5 to Figure 7):

- single string of modules;
- multi-string PV array;
- PV array divided into several sub-arrays.

Direct current systems, and photovoltaic systems in particular, pose various hazards in addition to those derived from conventional a.c. power systems, for example the ability to produce and sustain electrical arcs with currents that are not much greater than normal operating currents. This technical specification addresses those safety requirements arising from the particular characteristics of photovoltaic systems.

The aim is to provide safety and fire protection requirements for:

- uninformed persons, including owner(s)/occupier(s) and users of the premises where photovoltaic arrays are installed;
- informed workers (e.g. electricians) working on these systems; and
- emergency workers (for example fire fighters).

For installation of PV arrays see IEC 60364-7-712.

2 Normative references

The following referenced documents are indispensable for the application 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 60050-811:1991, *International Electrotechnical Vocabulary – Chapter 811: Electric traction*

IEC 60287 (all parts), *Electric cables – Calculation of the current rating*

IEC 60364 (all parts), *Low-voltage electrical installations*

IEC 60364-4-41, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock*

IEC 60364-5-54, *Electrical installations of buildings – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements, protective conductors and protective bonding conductors*

IEC 60449, *Voltage bands for electrical installations of buildings*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 61140, *Protection against electric shock – Common aspects for installation and equipment*

IEC 61173, *Over-voltage protection for photovoltaic (PV) power generating systems – Guide*

IEC 61201, *Extra-low voltage (ELV) – Limit values*

IEC 61215, *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 61643-12, *Low voltage surge protective devices – Part 12: Surge protective devices connected to low voltage power distribution systems – Selection and application principles*

IEC 61646, *Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 62257-5, *Recommendations for small renewable energy and hybrid systems for rural electrification – Part 5: Protection against electrical hazards*

IEC 62257-6, *Recommendations for small renewable energy and hybrid systems for rural electrification – Part 6: Acceptance, operation, maintenance and replacement*

IEC 62305-2, *Protection against lightning – Part 2: Risk management*

IEC 62305-3, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

3 Terms and definitions

3.1

available, readily

capable of being reached for inspection, maintenance or repairs without necessitating the dismantling of structural parts, cupboards, benches or the like

3.2

blocking diode

diode connected in series to module(s), panel(s), sub-arrays and array(s) to block reverse current into such module(s), panel(s), sub-array(s) and array(s)

3.3

bypass diode

diode connected across one or more cells in the forward current direction to allow the module current to bypass shaded or broken cells to prevent hot spot or hot cell damage resulting from the reverse voltage biasing from the other cells in that module

3.4

cable

assembly of one or more conductors and/or optical fibres, with a protective covering and possibly filling, insulating and protective material

[IEV 151-12-38]

3.5

cable core

the conductor with its insulation but not including any mechanical protective covering

3.6

shield (of a cable)

a surrounding earthed metallic layer to confine the electric field within the cable and/or to protect the cable from external electrical influence

Note Metallic sheaths, armour and earthed concentric conductors may also serve as shields.

[IEV 461-03-04]

3.7

class I equipment

equipment in which protection against electric shock does not rely on basic insulation only, but which includes an additional safety precaution in that accessible conductive parts are connected to the protective earthing conductor in the fixed wiring of the electrical installation in such a way that accessible parts cannot become live in the event of a failure of the basic insulation

NOTE 1 Class I equipment may have parts with double insulation or parts operating at SELV.

NOTE 2 For equipment intended for use with a flexible cord or cable, this provision includes a protective earthing conductor as part of the flexible cord or cable.

3.8

class II equipment

equipment in which protection against electric shock does not rely on basic insulation only, but in which additional safety precautions such as double insulation or reinforced insulation are provided, there being no provision for protective earthing or reliance upon installation conditions. Such equipment may be one of the following types:

- equipment having durable and substantially continuous enclosures of insulating material which envelops all metal parts, with the exception of small parts, such as nameplates, screws and rivets, which are isolated from live parts by insulation at least equivalent to reinforced insulation. Such equipment is called insulation-encased Class II equipment;

- equipment having a substantially continuous metal enclosure, in which double insulation is used throughout, except for those parts where reinforced insulation is used, because the application of double insulation is manifestly impracticable. Such equipment is called metal-encased Class II equipment;
- equipment that is a combination of the types described in Items (a) and (b)

NOTE 1 The enclosure of insulation-encased Class II equipment may form part of the whole of the supplementary insulation or of the reinforced insulation.

NOTE 2 If the equipment with double insulation or reinforced insulation throughout has an earthing terminal or earthing contact, it is considered to be of Class I construction.

NOTE 3 Class II equipment may be provided with means for maintaining the continuity of protective circuits, insulated from accessible conductive parts by double insulation or reinforced insulation.

NOTE 4 Class II equipment may have parts operating at SELV.

3.9 class III equipment

equipment in which protection against electric shock relies on supply at SELV and in which voltages higher than those of SELV are not generated

NOTE Equipment intended to be operated at SELV and which have internal circuits that operate at a voltage other than SELV are not included in the classification and are subject to additional requirements.

3.10 double insulation

insulation comprising both basic insulation and supplementary insulation

[IEV 195-06-08]

3.11 earthing

a protection against electric shocks

3.12 extra-low voltage ELV

voltage not exceeding the relevant voltage limit of band I specified in IEC 60449

[IEV 826-12-30]

NOTE 1 See also IEC 61201.

NOTE 2 Voltage not exceeding 50 V a.c. and 120 V d.c. ripple free are considered to be ELV.

3.13 $I_{MOD_REVERSE}$

the current a module can withstand in the reverse direction to normal without damage to the module. This rating is obtained from the manufacturer at expected operating conditions

NOTE 1 This current rating does not relate to bypass diode rating. The module reverse current is the current flowing through the PV cells in the reverse direction to normal current.

NOTE 2 A typical figure for crystalline silicon modules is between 2 and 2,6 times the normal short circuit current rating $I_{SC\ MOD}$.

3.14 $I_{SC\ MOD}$

the short circuit current of a PV module or PV string at Standard Test Conditions (STC), as specified by the manufacturer in the product specification plate

NOTE As PV strings are a group of PV modules connected in series, the short circuit current of a string is equal to $I_{SC\ MOD}$.

3.15 **$I_{SC\ S-ARRAY}$**

the short circuit current of a PV sub-array at Standard Test Conditions (STC), and equal to:

$$I_{SC\ S-ARRAY} = I_{SC\ STC\ MOD} \times S_{SA}$$

where S_{SA} is the number of parallel-connected PV strings in the PV sub-array

3.16 **$I_{SC\ ARRAY}$**

the short circuit current of the PV array at Standard Test Conditions, and is equal to:

$$I_{SC\ ARRAY} = I_{SC\ STC\ MOD} \times S_A$$

where S_A is the total number of parallel-connected PV strings in the PV array

3.17**junction box**

closed or protected connecting device allowing making of one or several junctions

[IEV 442-08-03]

3.18**live part**

conductor or conductive part intended to be energized in normal operation, including a neutral conductor, but by convention not a PEN conductor or PEM conductor or PEL conductor

NOTE This concept does not necessarily imply a risk of electric shock.

[IEV 195-02-19]

3.19**PEL conductor**

conductor combining the functions of both a protective earthing conductor and a line conductor

[IEV 195-02-14]

3.20**protected extra-low voltage****PELV**

an extra-low voltage system which is not electrically separated from earth, but which otherwise satisfies all the requirements for SELV

3.21**PEM conductor**

conductor combining the functions of both a protective earthing conductor and a midpoint conductor

[IEV 195-02-13]

3.22**PEN conductor**

conductor combining the functions of both a protective earthing conductor and a neutral conductor

[IEV 195-02-12]

3.23**power conditioning unit
PCU**

a system that converts the electrical power delivered by the PV array into the appropriate frequency and/or voltage values to be delivered to the load, or stored in a battery or injected into the electricity grid (see Figure 5 to Figure 7)

3.24**power conditioning unit, isolated**

a power conditioning unit where there is electrical separation between the input and output circuits (e.g. by means of an isolation transformer)

3.25**power conditioning unit, non-isolated**

a power conditioning unit where there is no electrical separation between the input and output circuits

3.26**PV array**

a) a mechanically integrated assembly of modules or panels and support structure that forms a d.c. electricity-producing unit. An array does not include foundation, tracking apparatus, thermal control, and other such components

[IEC 61836, Ed.2¹⁾, definition 3.3.45 a)]

b) a mechanically and electrically integrated assembly of PV modules, and other necessary components, to form a DC power supply unit

[IEC 60364-7-712, definition 712.3.4]

NOTE A PV array may consist of a single PV module, a single PV string, or several parallel-connected strings, or several parallel-connected PV sub-arrays and their associated electrical components (see Figure 5 to Figure 7). For the purposes of this standard the boundary of a PV array is the output side of the PV array disconnecting device. Two or more PV arrays, which are not interconnected in parallel on the generation side of the power conditioning unit, shall be considered as independent PV arrays.

3.27**PV array cable**

the output cable of a PV array that connects the PV array junction box to the PV array disconnecting device

3.28**PV array, earthed**

a PV array where one of the poles of the d.c. output circuit is electrically bonded to earth

3.29**PV array, floating**

a PV array where none of the poles of the d.c. output circuit is electrically bonded to earth

3.30**PV array, isolated**

a PV array where there is at least a simple electrical separation between the PV array output circuit (d.c. side) and the a.c. system

NOTE A simple electrical separation of power circuits is usually achieved by means of a power transformer.

3.31**PV array junction box**

a junction box where all strings of any array are connected

1) In preparation.

[IEC 60364-7-712, definition 712.3.5, modified]

3.32

PV array voltage

the PV array voltage is considered to be equal to $V_{OC\ ARRAY}$ under worst case conditions

NOTE The open circuit voltage is dependent on the cell temperature and technology.

3.33

PV cell

a) the basic unit of photovoltaic conversion, a semiconductor device that can convert light directly into electrical energy;

b) the basic photovoltaic device [see IEC 60904-3]

NOTE The preferred term is "solar photovoltaic cell" or "photovoltaic cell", colloquially referred to as a "solar cell".

3.34

PV module

the smallest complete environmentally protected assembly of interconnected cells

[see IEC 60904-3, IEC 61277]

NOTE Colloquially referred to as a "solar module".

3.35

PV module junction box

an enclosure affixed to a PV module, where the electrical connections to the PV module are made

3.36

PV string

a circuit of series-connected modules

3.37

PV string cable

a cable connecting the modules in a PV string, or connecting the string to a junction box or to the d.c. terminals of the power conditioning unit (see Figure 5 to Figure 7)

3.38

PV sub-array

the portion of an array that can be considered as a unit

[IEC 61277, definition B.12, modified]

3.39

PV sub-array cable

the output cable of a PV sub-array that carries only the output current of its associated sub-array in normal operation, and that connects the PV sub-array with the other PV sub-arrays that constitute the PV array

NOTE PV sub-array cables are only relevant for PV arrays that are divided into sub-arrays (see Figure 7 for clarification).

3.40

PV sub-array junction box

an enclosure where all the PV strings of a PV sub-array are electrically connected in parallel and where protection devices may be located if necessary (see Figure 7)

NOTE PV sub-array junction boxes are only relevant for PV arrays that are divided into sub-arrays

3.41

reinforced insulation

insulation of hazardous-live-parts which provides a degree of protection against electric shock equivalent to double insulation

NOTE Reinforced insulation may comprise several layers which cannot be tested singly as basic insulation or supplementary insulation.

[IEV 195-06-09]

3.42

supplementary insulation

independent insulation applied in addition to basic insulation, for fault protection

[IEV 195-06-07]

3.43

simple separation

separation between electric circuits or between an electric on a local earth by means of basic insulation

[IEV 826-12-28]

3.44

ripple-free d.c.

for sinusoidal ripple voltage, a ripple content not exceeding 10% r.m.s.

NOTE Therefore the maximum peak value does not exceed 120 V for a nominal 108 V ripple-free d.c. system.

3.45

SELV

safety extra-low voltage

an extra-low voltage system which is electrically separated from earth and from other systems in such a way that a single fault cannot give rise to the risk of electric shock

3.46

STC

Standard Test Conditions

a standard set of reference conditions used for the testing and rating of photovoltaic cells and modules. The Standard test conditions are:

- a) PV cell temperature of 25 °C;
- b) irradiance in the plane of the PV cell or module of 1000 W/m²;
- c) light spectrum corresponding to an atmospheric air mass of 1,5

3.47

V_{OC MOD}

the open circuit voltage of a PV module at Standard Test Conditions, as specified by the manufacturer in the product specification

3.48

V_{OC ARRAY}

the open circuit voltage at Standard Test Conditions of a PV array, and is equal to:

$$V_{OC ARRAY} = V_{OC MOD} \times M$$

where M is the number of series-connected PV modules in any PV string of the PV array.

NOTE This standard assumes that all strings within a PV array are connected in parallel; hence the open circuit voltage of PV sub-arrays and PV strings is equal to V_{OC ARRAY}.

3.49 voltage

differences of potential normally existing between conductors and between conductors and earth as follows:

- extra-low voltage: not exceeding 50 V a.c. or 120 V ripple-free d.c.;
- low voltage: exceeding extra-low voltage, but not exceeding 1 000 V a.c. or 1 500 V d.c.
- high voltage: exceeding low voltage.

NOTE In consideration of ELV status, $V_{OC\ ARRAY}$ must be used.

4 Design

4.1 Electrical design

4.1.1 Functional configuration of PV powered systems

Figure 1 illustrates the general functional configuration of a PV powered system.

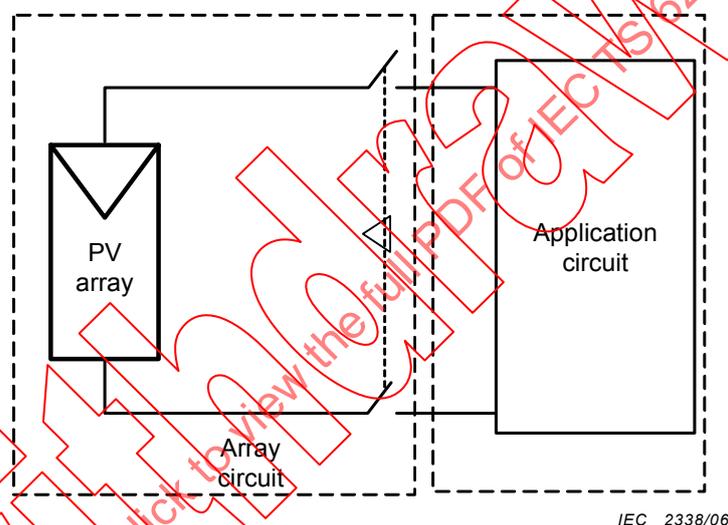


Figure 1 – General functional configuration of a PV powered system

Three kinds of application circuit are considered:

- PV array is connected to DC loads;
- PV array is connected to AC loads via conversion equipment;
- PV array is connected to AC grid forming elements via conversion equipment.

Except where the array is less than 200 W and the array voltage is ELV, all current-carrying conductors from the array shall be capable of being interrupted using a load-breaking switch.

NOTE In unearthed systems this is a general requirement of IEC 60364.

In earthed systems (where the application circuit is earthed), the switch is required to interrupt current caused by an earth fault within the array.

Because the array is current limited, overcurrent protection cannot provide interruption of this fault situation.

4.1.2 PV array earthing

4.1.2.1 General

To consider the PV array earthing it is necessary to consider the complete PV system earthing configuration. Two separate issues are addressed:

- earthing of the main current carrying conductors of the array (system earthing);
- earthing of exposed conductive parts for lightning protection and/or equipotential bonding.

NOTE To realize earthing on the field, see IEC 62305-3.

4.1.2.2 PV array system earthing

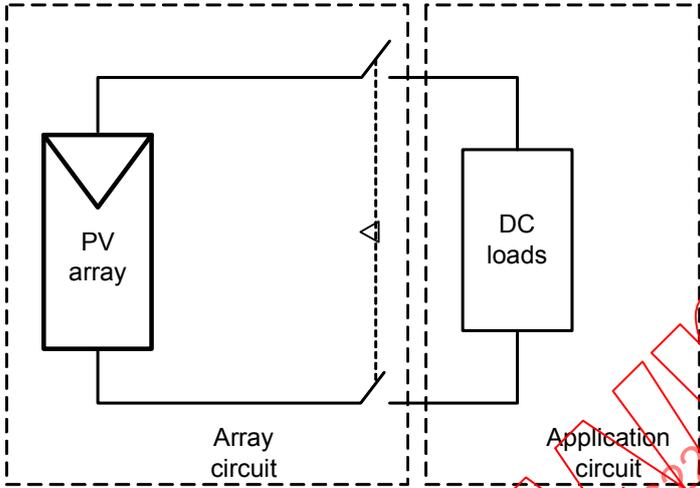
In the following Table 2, several configurations are considered. No consideration is given to earthing of exposed conductive parts, which is covered in the following clause.

Table 2 – PV system earthing configurations

Photovoltaic array earthing equipment	Figures	Application circuit	Consequence on the status of the PV array
Unearthed	Figure 2a	Unearthed DC loads	Floating
	Figure 2b	Earthed DC loads	Fixed to earth
	Figure 2c	AC loads connected via isolated PCU	Floating
	Figure 2d	AC loads connected via a non-isolated power conditioning unit	Fixed by the status of the neutral of the application circuit
Earthed ^{a b}	Figure 2e	Unearthed DC loads	Fixed to earth
	Figure 2f	Earthed DC loads	
	Figure 2g,2h	AC loads connected via isolated PCU	Not permitted according to IEC 60364
	Figure 2i	AC loads connected via a non-isolated power conditioning unit PCU	
<p>^a In non-centre-tapped, earthed PV arrays, either the positive or negative pole could be connected to the earth, but the preferred configuration is to earth the negative, because connecting the positive to earth could result in corrosion of the earthing electrode.</p> <p>^b In a centre-tapped earthed PV array where the PV array is equally divided into two segments connected in series and the midpoint connected to earth. The "consequences on the status of the PV array" column is not changed whether the array is centre-tapped earthed or earthed on only one pole.</p>			

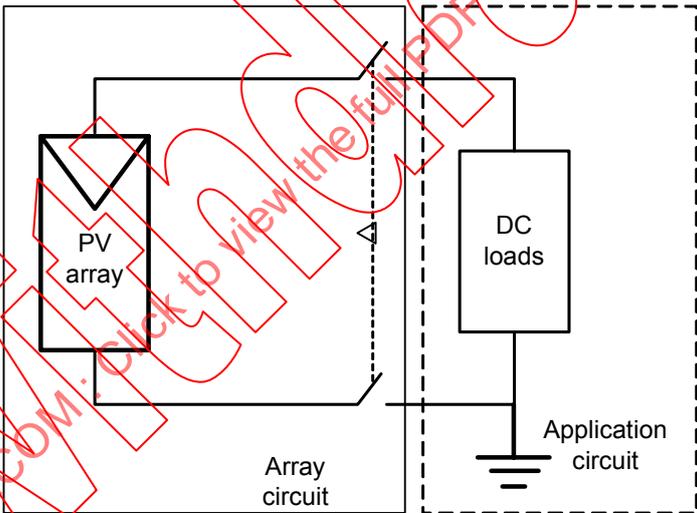
The requirements of manufacturers of power conditioning equipment to which the PV array is connected shall be taken into account in determining the most appropriate system earthing arrangement.

The following subfigures of Figure 2 illustrate the system earthing arrangements listed in Table 2:



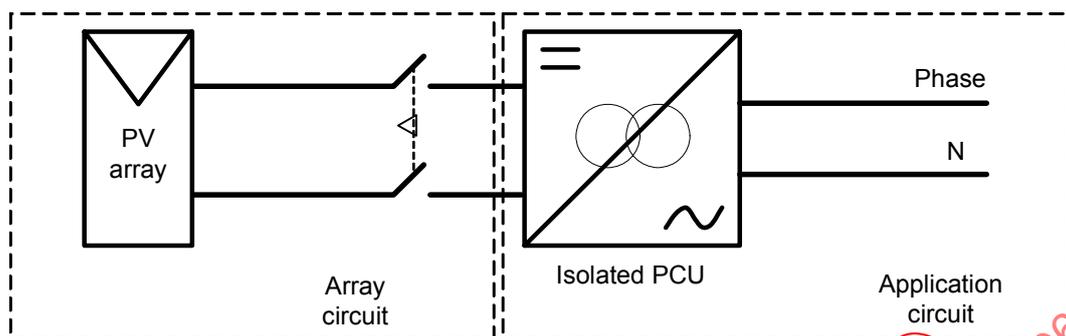
IEC 2339/06

Figure 2a – Unearthed PV array and unearthed d.c. load application circuit



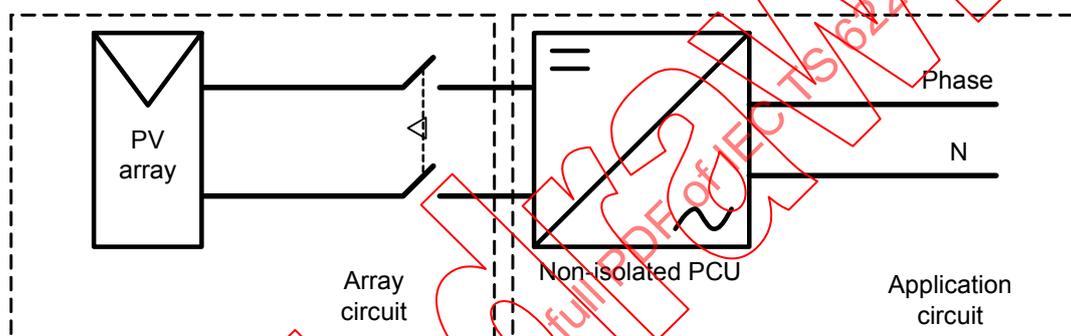
IEC 2340/06

Figure 2b – Unearthed PV array and earthed d.c. load application circuit



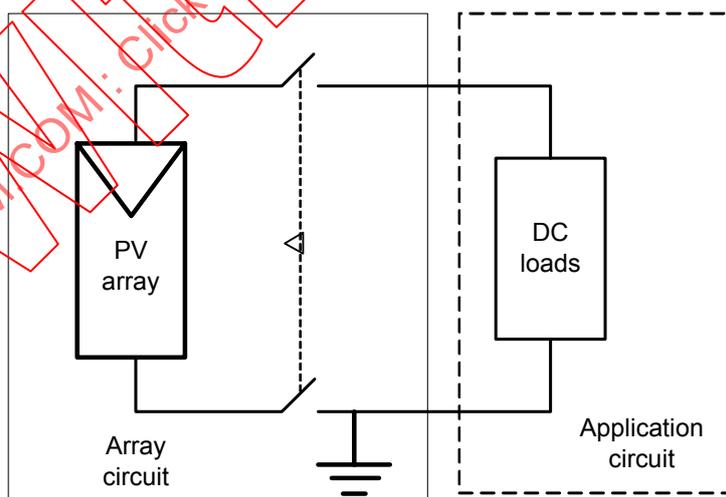
IEC 2341/06

Figure 2c – Unearthed PV array connected to a.c. loads via an isolated PCU application circuit



IEC 2342/06

Figure 2d – Unearthed PV array connected to a.c. loads via a non-isolated PCU application circuit



IEC 2343/06

Figure 2e – Earthed PV array and unearthed d.c. load application circuit

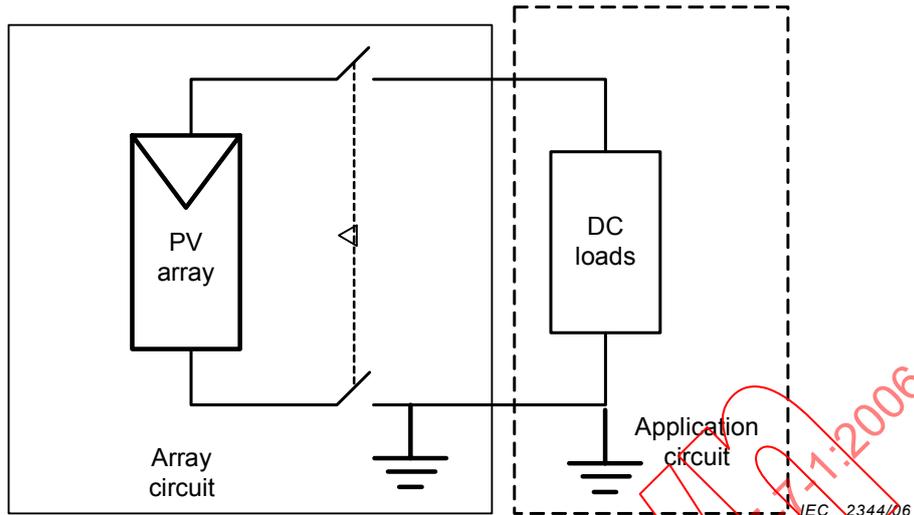


Figure 2f – Earthed PV array and earthed d.c. load application circuit

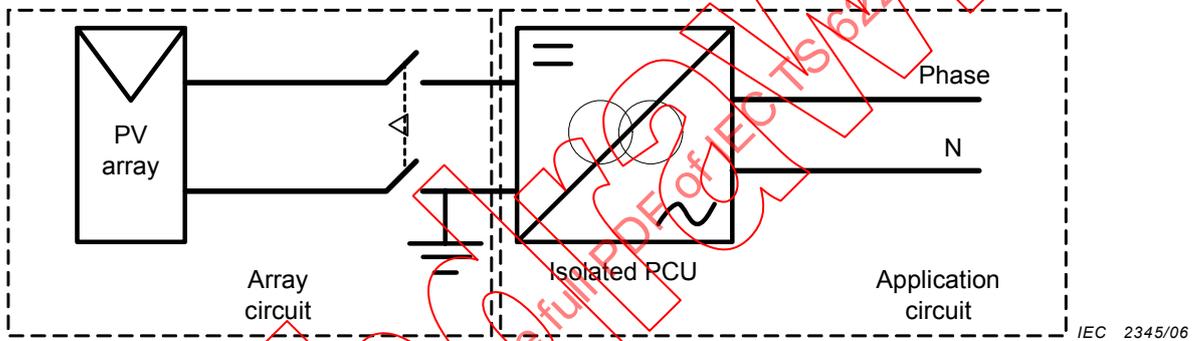


Figure 2g – Earthed PV array connected to a.c. loads via an isolated PCU application circuit

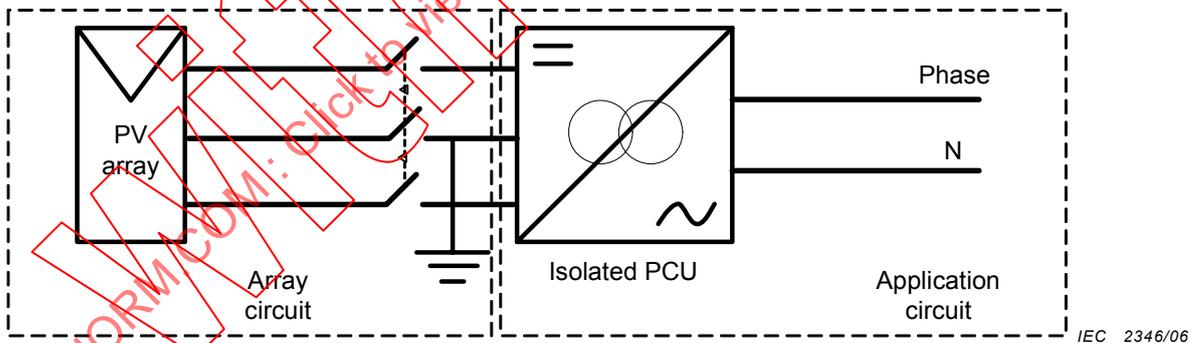
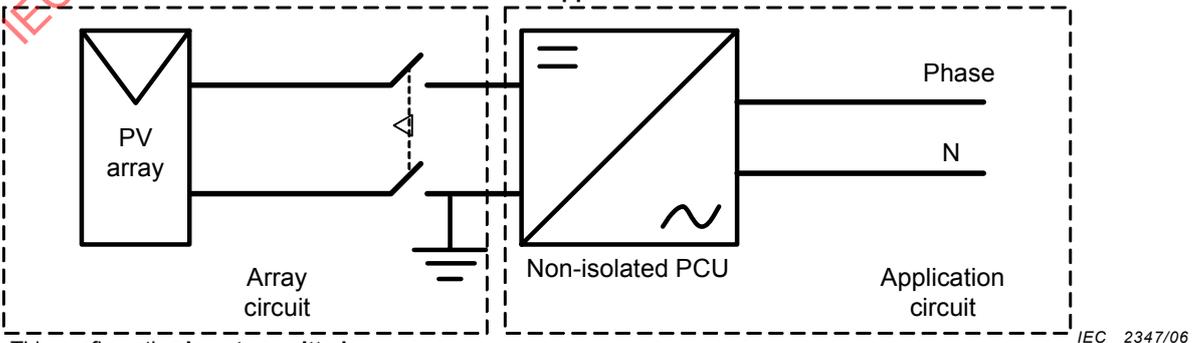


Figure 2h – Centre-tapped earthed PV array connected to a.c. loads via an isolated PCU application circuit



NOTE This configuration **is not permitted**.

Figure 2i – Earthed PV array connected to a.c. loads via a non-isolated PCU application circuit

Figure 2 – PV system earthing configurations

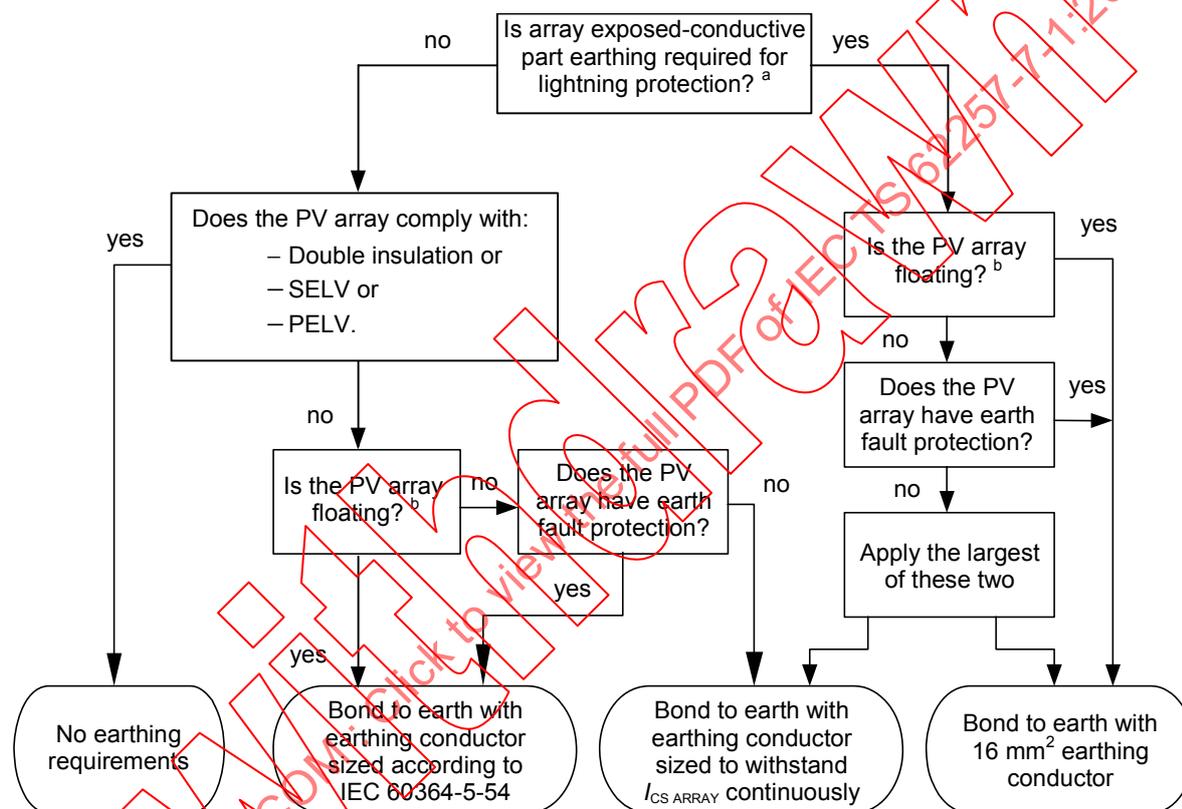
4.1.2.3 Earthing of exposed conductive parts and equipotential bonding

There are three possible reasons for earthing exposed conductive parts of a PV array:

- a) protective earthing to provide a path for fault currents to flow;
- b) lightning protection;
- c) equipotential bonding to avoid uneven potentials across an installation.

An earth conductor may perform one or more of these functions in an installation. The dimensions and location of the conductor are very dependent on its function.

Figure 3 is a flow chart for sizing the conductor required for bonding of the exposed-conductive parts to earth according to the earthing status of the PV array (see Table 1). Figure 4 shows an unearthed PV array and d.c. loads configuration.

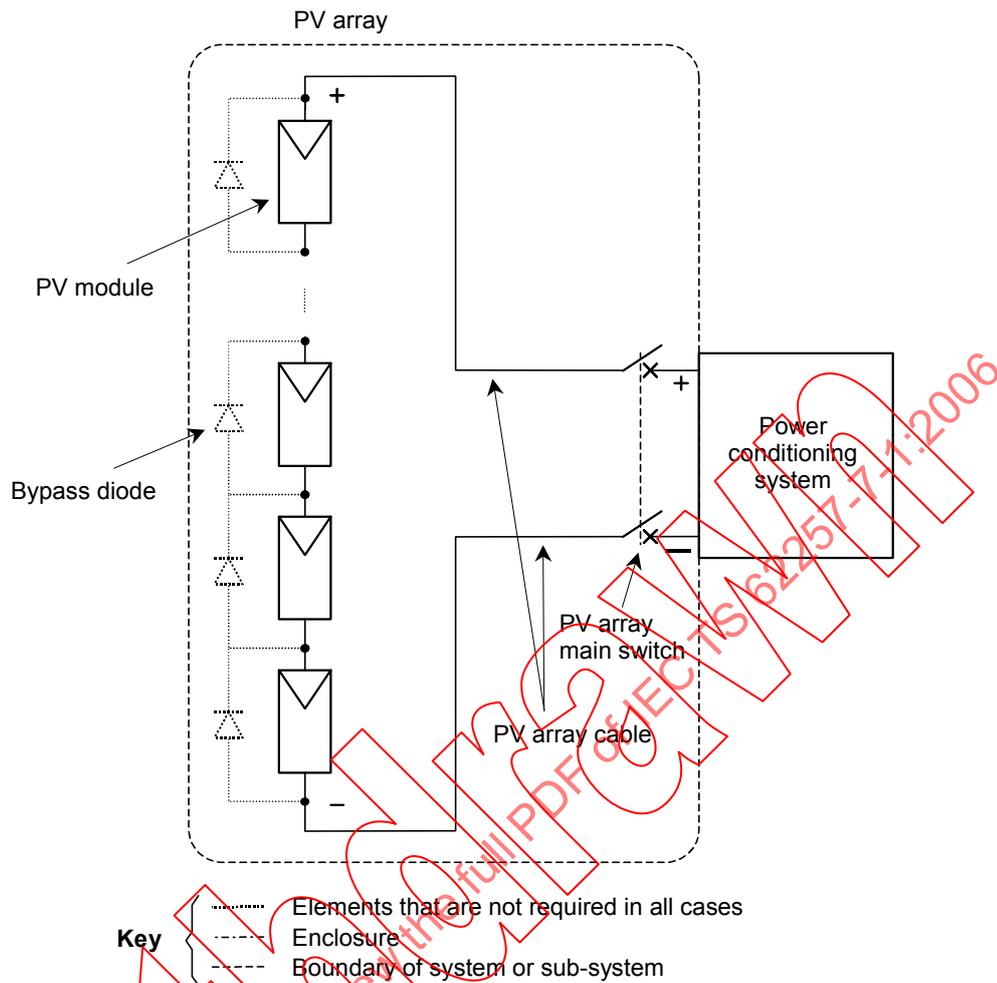


IEC 2348/06

^a To answer this question, you can follow the recommendations of IEC 62305-2 and IEC 662305-3 or refer to local information such as number of thunder days per year or other lightning characteristics. Assessment should include relative position on the PV array to other buildings, structures, environmental stuff able to protect the PV array from lightning strokes.

^b Floating PV array means an array which is not directly connected to earth but is connected to an application circuit which is either unearthed or isolated.

Figure 3 – PV array exposed-conductive parts earthing decision tree



IEC 2350/06

NOTE Unless a battery is present a load-breaking isolator is sufficient as the PV array main switch. If a battery is present, overcurrent protection is required.

Figure 5 – PV array diagram – single string case

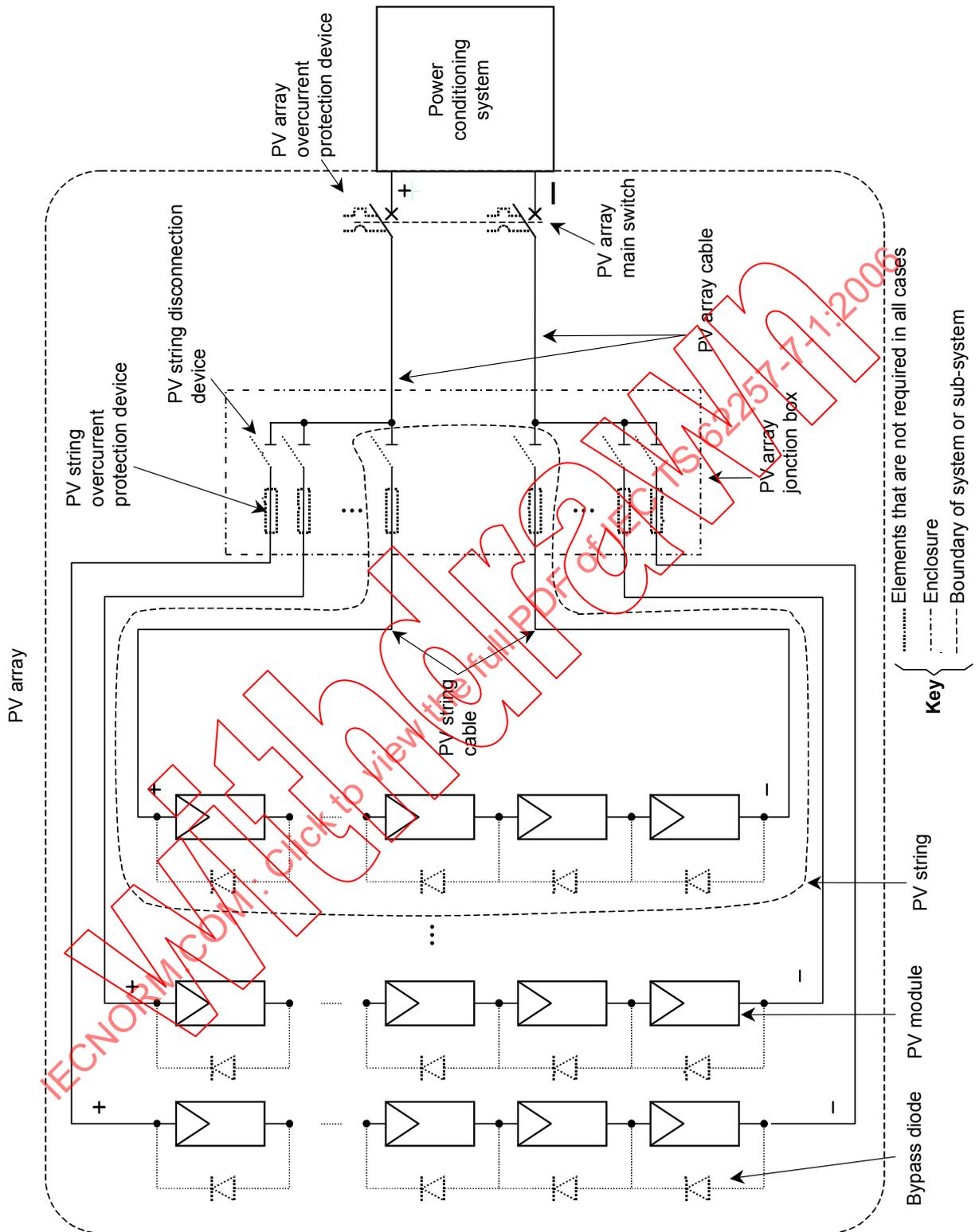
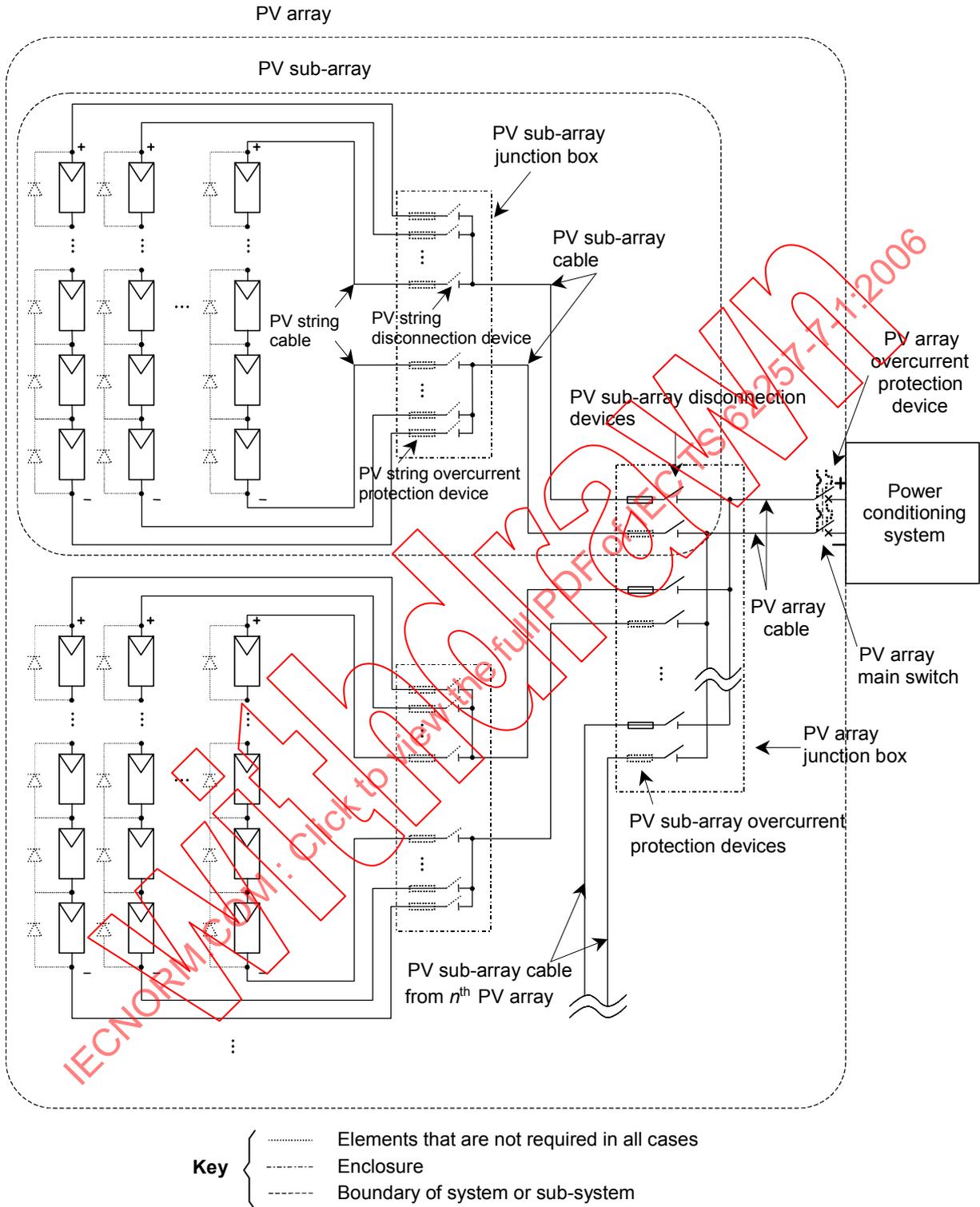


Figure 6 – PV array diagram – multi-string case



IEC 2352/06

Figure 7 – PV array diagram – multi-string case with array divided into sub-arrays

NOTE In Figures 5, 6 and 7, components drawn in dotted format are not required in all cases. The figures indicate the location in the circuit when they are required. See text for requirements (Tables 5, 6 and 7, and subclauses 6.1.7 and 6.1.8 are examples).

4.1.4 Series-parallel configuration

To reduce mismatch and improve PV array yield, all PV strings within a PV array should be of the same technology, have the same number of series connected PV modules (see Figure 5 to Figure 7). In addition, all PV modules within the PV array should have similar rated electrical characteristics including short circuit current, open circuit voltage, maximum power current, maximum power voltage and rated power (all at STC).

NOTE This is a design issue which needs to be considered by the project implementer, particularly when replacing modules or modifying an existing system.

4.1.5 Batteries in systems

Batteries in PV systems can be a source of high prospective fault currents. The location of fault current protection related to battery systems is generally between the battery and charge controller (see for example case study A4 in Annex E) and as close as practical to the battery. This protection can be used to provide overcurrent protection for PV array cables (see 5.3.4.3) provided the PV array cable is rated to withstand the same current as the battery overcurrent protection device.

NOTE The current rating of string cables must be much higher in battery systems if no individual o/c protection is provided (see 6.1.4.1.2/Table 5). In this case, the nearest downstream o/c protection may be the battery fuse.

4.1.6 Considerations due to prospective fault conditions within a PV array

In any installation, the source of prospective fault currents needs to be identified.

Systems containing batteries may have high prospective fault currents due to the battery characteristic (see 4.1.5).

In a PV system without batteries, as the PV cells (and consequently PV arrays) behave like current sources under low impedance faults, much greater than normal full load currents will not always flow even under short circuit conditions.

The fault current depends on the number of strings, the fault location and the irradiance level. This makes short circuit detection within a PV array very difficult. Electric arcs can be formed in a PV array with fault currents that would not trip an overcurrent device.

The implications for PV array design that arise from these PV array characteristics are as follows.

- a) The possibility of line-to-line faults, earth faults and inadvertent wire disconnections in the PV array need to be minimized more than for conventional electrical installations. (Note that in conventional electrical installations the large inherent fault current capability of the system will generally blow a fuse, trip a circuit breaker or other protection system in case a fault occurs.)
- b) Earth fault detection and disable could be required as part the system protection functions, depending on the array size and location, to eliminate the risk of fire.

4.1.7 Considerations due to operating temperature

PV modules ratings are stated at standard temperature conditions (25°C).

Under normal operating conditions, 25°C is a common steady state temperature rise with respect to the ambient temperature for crystalline silicon PV modules operating at the maximum power point under 1 000 W/m² solar irradiance and with adequate ventilation. This temperature rise can go up to 35°C when modules are open circuited (i.e. the PV array has been disconnected due to a fully charged battery). The temperature rise can be even higher when irradiance levels are greater than 1 000 W/m² and when modules have poor ventilation.

The following two main requirements on the PV array design derive from this operating characteristic of PV modules.

- a) For some PV technologies, the efficiency reduces as the operating temperature increases (for crystalline silicon solar cells the maximum power decreases between 0,4 and 0,5 % per each °C rise in operating temperature). Therefore adequate ventilation of the PV array should be a design goal, in order to ensure optimum performance for both modules and associated components.
- b) All the components and equipment that may be in direct contact or near the PV array (conductors, inverters, connectors, etc.) need to be capable of withstanding the expected maximum operating temperature of the PV array.
- c) Under cold conditions, for crystalline silicon technology based cells, the voltage increases (see 4.1.8 for further considerations).

4.1.8 Component voltage ratings

Open circuit voltage is one of the normal operating conditions of any PV array. Open circuit voltage can be as large as twice the nominal d.c. bus voltage. PV array components shall be rated for at least 1,2 times the open circuit voltage for a module temperature equal to the lowest ambient temperature of the site.

4.1.9 Performance issues

A PV array's performance may be affected by many factors, such as:

- shading;
- temperature rise;
- voltage drop in cables;
- pollution of the surface of the array.

Care must be taken in selecting a site for the PV array. Nearby trees and buildings may cause shadows to fall on the PV array during some part of the day.

It is important that any shadowing be almost eliminated or at least reduced to a very small time period as even the smallest shadow on the array can severely limit its performance.

Issues of performance degradation due to temperature rise and the need for good ventilation are described in 4.2.2. Care should be taken to keep modules as cool as practicable.

In the design process the sizing of cables within the array and in cable connections from the array to the application circuit affect the voltage drop in those cables under load. This can be particularly significant in systems with low output voltage and high output current. It is recommended that under maximum load conditions the voltage drop from the most remote module in the array to the terminals of the application circuit should not exceed 5% of the nominal system voltage.

Pollution of the surface of PV modules caused by dust, dirt, bird droppings, snow etc. can significantly reduce the output of the array. Arrangements should be made to clean the modules regularly in situations where significant pollution may be a problem.

Suitable devices shall be fitted to the photovoltaic array in order to limit dirt building up as the result of bird droppings. Devices such as spikes or tubing-covered wires mounted on the apex of the array can be useful deterrents for birds.

Where such effects as sand winds or land animals may be present, the photovoltaic array shall be installed at suitable height above ground (typically 1,5 m to 2 m).

NOTE For cold climates, consider the maximum voltage rating of components for the maximum voltage expected increase at the lowest expected temperature of the PV modules.

4.2 Mechanical design

4.2.1 General

Support structures and module mounting arrangements should comply with applicable building codes (including earthquake requirements where relevant), regulations and standards.

4.2.2 Thermal aspects

Provisions should be taken in the mounting arrangement of PV modules to allow for the maximum expansion/contraction of the modules under expected operating temperatures, according to the manufacturer's recommendations.

NOTE Some types of PV modules degrade significantly in performance when inadequate ventilation allows the modules to operate at high temperature.

4.2.3 Mechanical loads on PV structures

The PV array support structures should comply with national standards and regulations with respect to loading characteristics. Particular attention should be given to wind loads on PV arrays.

NOTE Support structures are not usually a problem for small PV systems.

4.2.4 Wind

The indications provided under this heading are for quality guidance. Under no circumstances shall these instructions be used as a replacement for a case-by-case, detailed calculation.

Wind force applied to the PV array will generate a significant load for building structures. This overload should be accounted for in assessing the capability of the building to withstand the resulting forces.

On assessing this component, the maximum wind speed observed (or known) on site shall be used, with due consideration for punctual wind events (cyclones, tornadoes, hurricanes, etc.). The PV array structure shall be secured in an appropriate manner or in accordance with local building standards.

4.2.5 Material accumulation on PV array

Snow, ice or other material may build up on the photovoltaic generator and should be accounted for when calculating the supporting structure for the modules and likewise, when calculating the building capability to support the generator.

4.2.6 Corrosion

When possible all structures shall be made of corrosion resistant materials e.g. aluminium, galvanized steel, treated wood poles or structures, etc.

If the structure is metallic, aluminum or hot dipped galvanized steel are well suited to this type of use. If the array is installed in a marine or other highly corrosive environment, aluminum shall be anodized.

The same applies to all bolts, nuts and fasteners.

Provisions shall be made in order not to create electrochemical corrosion between the structures and the building on the one hand, and the structures and photovoltaic modules on the other. If the system is earthed, it is recommended that the negative conductor be connected to the earth electrode as this arrangement will reduce electro-chemical degradation of the electrode and other metallic parts.

5 Safety issues

5.1 General

Refer to the IEC 62257-5 technical specification.

5.2 Protection against electric shock and fire

For protection against electric shock the requirement of IEC 61140 shall apply.

Referring to the 62257-5 technical specification the following requirements shall be applied:

Protection by extra-low voltage systems (SELV and PELV systems) systems shall be classified as Class III or better.

For all other systems, protection by double or reinforced insulation between any live conductor and any earthed or exposed conductive part (i.e. Class II modules and double or reinforced insulation for the whole PV array) is required.

Earthing of one of the live conductors of the d.c. side is permitted, if there is at least simple separation between the d.c. side and the a.c. side.

5.3 Protection against overcurrent

5.3.1 General

Fault currents due to short circuits in modules, in junction boxes or in module wiring or earth faults in array wiring can result in overcurrent in a PV array.

PV modules are current limited sources but because they can be connected in parallel and also connected to external sources (e.g. batteries), they can be subjected to overcurrents caused by either multiple parallel adjacent strings or from external sources or both.

5.3.2 Number of parallel strings without overcurrent protection.

Fault current protection is irrelevant when there are only one to two strings in parallel, and there is no battery storage system, provided the PV modules are capable of withstanding a reverse current equal to their short circuit current.

If there are more than two strings in parallel then the maximum fault current which can flow in any one string is equal to the (number of strings – 1) times the short circuit rating of one of the strings. Therefore if there are three or more parallel strings, the PV modules could be subjected to reverse currents of two or more times their nominal short circuit current. It is for this reason that the number of strings able to be connected in parallel without overcurrent protection in each string is linked to the reverse current rating of a module.

The maximum number of strings connected in parallel without overcurrent protection shall be n_p where n_p is related to the PV modules' reverse current rating and is given by Table 3.

Table 3 – Number of parallel strings without overcurrent protection, n_p

n_p	Module reverse current rating $I_{MOD_REVERSE}$
1 (i.e. no paralleling)	$I_{MOD_REVERSE} < I_{SC\ MOD}$
2	$1 \times I_{SC\ MOD} \leq I_{MOD_REVERSE} < 2 \times I_{SC\ MOD}$
3	$2 \times I_{SC\ MOD} \leq I_{MOD_REVERSE} < 3 \times I_{SC\ MOD}$
4	$3 \times I_{SC\ MOD} \leq I_{MOD_REVERSE} < 4 \times I_{SC\ MOD}$
5	$4 \times I_{SC\ MOD} \leq I_{MOD_REVERSE} < 5 \times I_{SC\ MOD}$

NOTE 1 For systems including batteries, see 5.3.4.3.

NOTE 2 For cable ratings, see 6.1.4.1.2.

5.3.3 Discrimination

Overcurrent protection within the PV array shall be graded in such a way that lower level protection trips first in the event of fault currents flowing from higher current sections to lower current sections of the PV array.

NOTE When circuit breakers with overcurrent protection elements are used, they also provide the disconnecting means required in 6.2.1.

5.3.4 Overcurrent protection sizing

5.3.4.1 PV string overcurrent protection

In ELV PV arrays where PV modules are mounted in such a way and location that fire cannot be caused by an arc or melted metal coming out of the back of the PV module, PV string overcurrent protection is not required.

NOTE 1 The requirement of this subclause may be fulfilled by ensuring that no combustible material is directly behind or under the PV module and that means of prevention of accumulation of combustible material (e.g. leaves) is installed.

NOTE 2 It is impossible to guarantee that no fire hazard is possible (caused by modules or string cables).

In other cases where there are more than n_p parallel-connected strings (see 5.3.2), each PV strings shall be protected with a fault current protection device.

NOTE 3 Where circuit breakers are used as the overcurrent protection device these may also fulfil the role of a disconnecting means as required by 6.2.1.

NOTE 4 String fuses are still very useful even though not absolutely required. The fuses protect against reverse current flows in the event of an array fault.

The rated tripping current (I_{TRIP}) of overcurrent protection devices for PV strings shall be as specified by the PV module manufacturer. If the manufacturer does not give any recommendation, I_{TRIP} shall be determined with the following formula:

$$1,25 \times I_{SC\ MOD} \leq I_{TRIP} \leq 2 \times I_{SC\ MOD}$$

NOTE 5 the tripping current is the current which activates the protection device.

NOTE 6 In some PV module technologies $I_{SC\ MOD}$ is higher than the nominal rated value during the first weeks or months of operation. This should be taken into account when establishing overcurrent protection and cable ratings.

5.3.4.2 PV sub-array overcurrent protection

The rated trip current (I_{TRIP}) of overcurrent protection devices for PV sub-arrays shall be determined with the following formula:

$$1,25 \times I_{SC\ S-ARRAY} \leq I_{TRIP} \leq 2 \times I_{SC\ S-ARRAY}$$

5.3.4.3 PV array overcurrent protection

PV array cable overcurrent protection is only required for systems connected to batteries or where other sources of current may feed into the PV array under fault conditions. The trip current (I_{TRIP}) of PV array overcurrent protection devices shall be rated as follows:

$$1,25 \times I_{SC \text{ ARRAY}} \leq I_{TRIP} \leq 2 \times I_{SC \text{ ARRAY}}$$

NOTE 1 The PV array overcurrent protection devices are commonly installed between the battery and the charge controller as close as possible to the battery. If these devices are appropriately rated, they provide protection to both, the charge controller and the PV array cable. In such cases, no further PV array cable overcurrent protection between the PV array and the charge controller is required.

NOTE 2 The current rating of string cables must be much higher in battery systems if no individual o/c protection is provided (see 6.1.4.1.2/Table 5). In this case, the nearest downstream o/c protection may be the battery fuse.

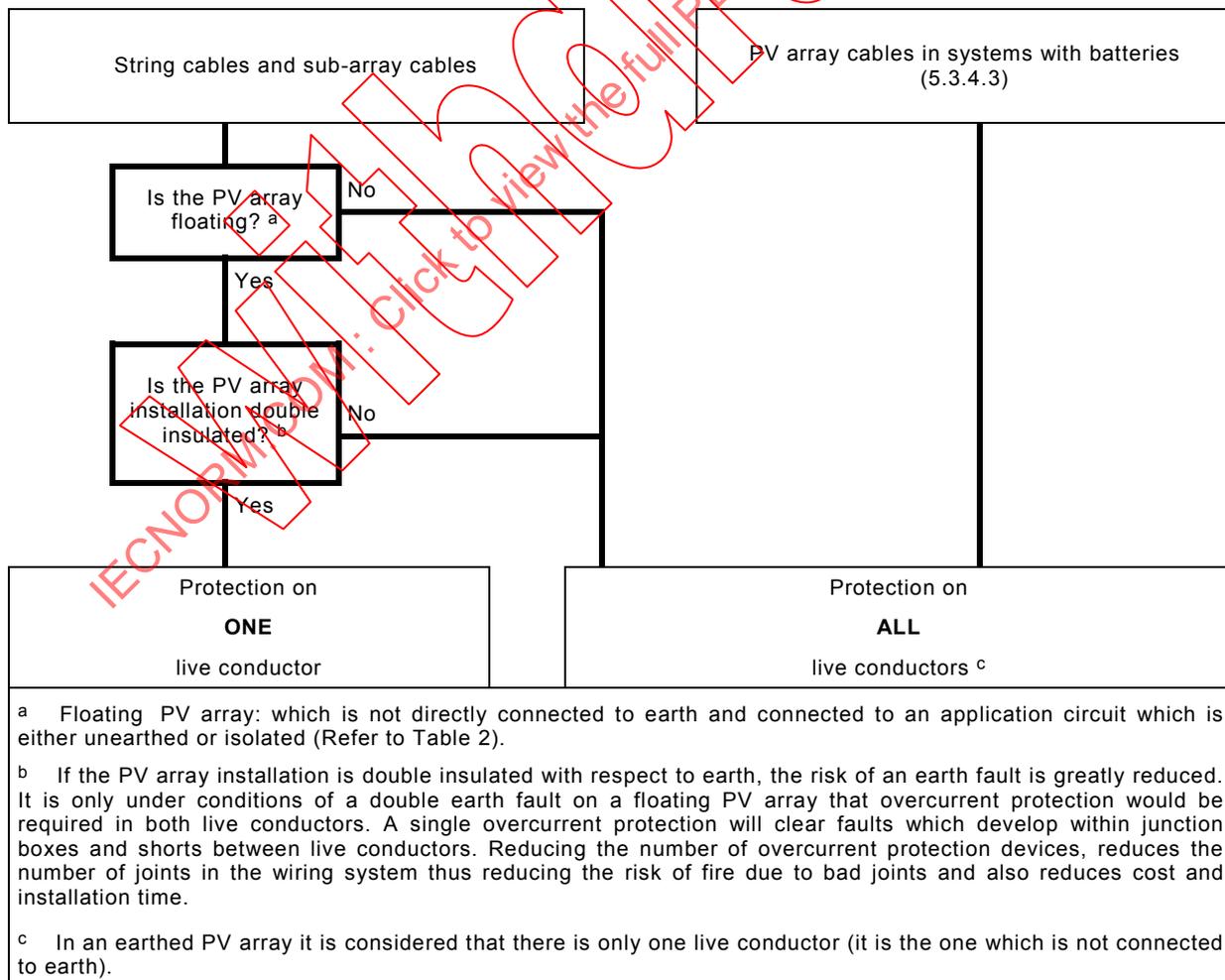
5.3.5 Overcurrent protection location

Overcurrent protection devices where required by 5.3 for PV array, PV sub-array, and PV strings shall be placed electrically at the load end of those cables.

NOTE The location of the overcurrent protection devices at the load end of the wiring is to protect the system and wiring from fault currents flowing from other sections of the PV array or from other sources such as batteries.

Overcurrent protective devices location requirements are introduced in Table 4.

Table 4 – Requirements for location of overcurrent protective devices according to the earth configuration



5.4 Protection against effects of lightning and over-voltage

5.4.1 General

For protection against over-voltages refer to IEC 61173 , IEC 62305-2 and IEC 62305-3.

5.4.2 Protection against direct stroke from lightning

A lightning protection system has the task of preventing severe damage caused by fire or mechanical destruction in case of a direct lightning strike in a building or structure. Lightning protection systems consist of three essential components:

- a) an air termination system, consisting of metallic masts or rods of sufficient height to divert lightning currents through their structure;
- b) a down conductor of sufficient cross sectional area to conduct lightning currents to earth; and
- c) an earth termination system.

For ground mounted or freestanding PV arrays, the need for a lightning protection system should be assessed in accordance with IEC 62305-2, and if required, it should be installed in compliance with IEC 62305-3 (see also IEC 61173).

The installation of a PV array on a building has a negligible effect on the probability of direct lightning strikes; therefore it does not necessarily imply that a lightning protection system should be installed if none is already present. However, if the physical characteristics or prominence of the building do change significantly due to the installation of the PV array, it is recommended that the need for a lightning protection system be assessed in accordance with IEC 62305-2 and, if required, it should be installed in compliance with IEC 62305-3.

If a lightning protection system is already installed on the building, it should be verified that the PV array and associated equipment are within the protection zone of the system. If the PV array is not within the protection zone of the existing lightning protection system, additional air termination(s) in accordance with IEC 62305-3 should be provided.

When a PV array is protected by a lightning protection system, the metal structure of the PV array should be bonded to the lightning protection system, unless the minimum safety clearances as specified in IEC 62305-3 can be achieved.

5.4.3 Protection against over-voltage

5.4.3.1 Equipotential bonding

Damage caused by over-voltage is ultimately due to the failure of insulation between live parts or between live parts and earth. The intention of over-voltage protection is to equalize all exposed metallic sections of an installation to a common potential during the event of an over-voltage, to prevent insulation flashover. Equipotential bonding is therefore a most important over-voltage protection measure and shall be done in accordance with national standards or IEC 60364-5-54 (see also IEC 62257-5, IEC 61173).

To avoid the formation of wiring loops between earthed conductors and d.c. cabling, equipotential bonding conductors should run parallel and as close as possible to the d.c. cabling. It is also recommended to branch the bonding conductor to run parallel with all the d.c. cabling branches.

5.4.3.2 Surge arresters

5.4.3.2.1 General guide

Surge arresters are a very common method of protecting electrical systems and equipment against over-voltages. When these devices are used the recommendations of IEC 61643-12 should be observed.

Over-voltage protection with surge arresters should be provided when the PV power system meets any of the following criteria:

- a) supply of critical loads (e.g. telecommunication repeater stations), or
- b) the PV array has a rated capacity greater than 500 W, or
- c) the PV array is protected with a lightning protection system.

Many commercial PV inverters and charge controllers are fitted with surge arresters on the PV input terminals, therefore this should be considered when specifying the over-voltage protection of the PV array.

5.4.3.2.2 Recommended specifications

The recommended specifications for surge arresters to protect PV arrays from over-voltages caused by indirect lightning strikes are as follows: (refer to list of parameters for surge arrester selection in IEC 61643-12):

- a) maximum continuous operating voltage (U_C): $U_C > 1,3 \times V_{OC\ STC\ GEN}$
- b) maximum discharge current (I_{max}): $I_{max} \geq 5\ kA$
- c) voltage protection level (U_p): $U_C < U_p < 1,1\ kV$

6 Selection and erection of electrical equipment

6.1 Component requirements

6.1.1 PV modules

6.1.1.1 Operational conditions and external influences

Crystalline silicon PV modules shall comply with IEC 61215. Thin film PV modules shall comply with IEC 61646.

6.1.1.2 Equipment Class

PV modules should be Class II.

6.1.2 PV array and PV sub-array junction boxes

6.1.2.1 Environmental effects

PV Array and PV Sub-array junction boxes exposed to the environment shall be at least IP 54 compliant in accordance with IEC 60529, and shall be UV resistant.

6.1.2.2 Location of PV array and PV sub-array junction boxes

PV array and PV sub-array junction boxes, where installed, shall be readily available.

6.1.3 Switching devices

6.1.3.1 General

All switching devices, shall comply with the following requirements:

- be rated for d.c. use (especially when voltage is over 30 V due to the risk of arcs);
- have a voltage rating equal to or greater than $1,2 \times V_{OC\ ARRAY}$;
- not have exposed live metal parts in connected or disconnected state;
- interrupt all poles, except in the case of a pole connected either to earth or to a protective conductor.

6.1.3.2 Disconnectors

In addition to the requirements of 6.1.3.1, disconnectors (see IEC 811-29-17) shall have a current rating equal to or greater than the associated overcurrent protection device, or in the absence of such device, have a current rating equal to or greater than the required current carrying capacity of the circuit to which they are fitted. (refer to Table 5)

In addition, circuit breakers and any other load breaking disconnection devices used for protection and/or disconnecting means shall comply with the following requirements:

- not be polarity sensitive (Fault currents in a PV array may flow in the opposite direction of normal operating currents);
- be rated to interrupt full load and prospective fault currents from the PV array and any other connected power sources such as batteries, generators and the grid if present;
- when overcurrent protection is incorporated, the trip current shall be rated according to 5.3.4.

Plug connections for interruption under load may also be used if equivalent level of safety can be assured.

NOTE Only specially constructed plugs and sockets are capable of interrupting load safely. All systems with an open circuit voltage greater than 30 V can experience d.c. arcs. Plugs and sockets which are not specially constructed for load interruption if disconnected under load represent a safety risk and generally incur damage to the connection which will compromise the quality of the electrical connection and could lead to overheating of the connection.

6.1.4 Cables

6.1.4.1 Size

6.1.4.1.1 General

Cable sizes for PV string cables, PV sub-array cables and PV array cable shall be determined with regard to both, the minimum current capacity and the maximum voltage drop requirements according to 6.1.4.1.2 and 4.1.9. The larger cable size obtained from these two criteria shall be applied.

6.1.4.1.2 Current carrying capacity (CCC)

The minimum cable sizes for PV array wiring, based on CCC, shall be based upon a current rating calculated from Table 5, and the current carrying capacity of cables as specified in IEC 60287 series.

NOTE In some PV module technologies $I_{SC\ MOD}$ is higher than the nominal rated value during the first weeks or months of operation. This should be taken into account when establishing cable ratings.

Table 5 – Current rating of PV array circuits

Type of cable	Minimum current upon which cable cross sectional area should be chosen ^{a, b}
PV string cable (PV string overcurrent protection not provided)	Trip current ^c of the nearest downstream overcurrent protection device + $1,3 \times I_{SC\ MOD} \times (S_{PO} - 1)$ Where: S _{PO} is the number of parallel connected strings protected by the nearest overcurrent protection device. NOTE When no overcurrent protection is used S _{PO} is the total number of parallel connected strings in the PV array; and the trip current of the nearest overcurrent protection device is replaced by zero.
PV string cable (PV string overcurrent protection provided)	Trip current ^c of the PV string overcurrent protection device (refer to 5.3)
PV sub-array cable (PV sub-array overcurrent protection not provided)	The greater of the following: a) Trip current ^c of the PV array overcurrent protection device + $1,3 \times$ Sum of short circuit current of all other sub-arrays b) $1,3 \times I_{SC\ S-ARRAY}$ (of relevant array) NOTE When PV array overcurrent protection is not used, the corresponding parameter is replaced by zero in equation (a).
PV sub-array cable (PV sub-array overcurrent protection provided)	Trip current ^c of the PV sub-array overcurrent protection device (refer to 5.3)
PV array cable (PV array overcurrent protection not provided)	$1,3 \times I_{SC\ ARRAY}$
PV array cable (PV array overcurrent protection provided)	Trip current ^c of the PV array overcurrent protection device (refer to 5.3)
<p>^a The operating temperature of PV modules and consequently their associated wiring can be significantly higher than the ambient temperature. A minimum operating temperature of maximum expected ambient temperature + 40° C should be considered for cables installed near or in contact with PV modules.</p> <p>^b The location and method of installation (i.e. enclosed, clipped, buried etc) of cables also needs to be considered in establishing a cable rating. Cable manufacturers' recommendations need to be taken into account in establishing the rating according to installation method.</p> <p>^c Trip current is the nominal current at which the overcurrent protection device is calibrated to operate. The current at which the device trips will generally be greater than the nominal rated current.</p>	

6.1.4.2 Insulation

The insulation of cables used within the PV array shall:

- have a voltage rating of at least $1,2 \times V_{OC\ ARRAY}$,
- NOTE The use of single core insulated and sheathed cable is recommended for wiring of LV PV arrays, to minimise the risk of faults within the wiring.
- have a temperature rating according to the application,
- NOTE PV modules frequently operate at temperatures of the order of 40 °C above ambient temperature. Cable insulation of wiring installed in contact or near PV modules shall be rated accordingly.
- if exposed to the environment, be UV-resistant, or be protected from UV light by appropriate protection, or the cables be installed in UV-resistant conduit;
- be fire resistant.

6.1.5 Plugs, sockets and couplers

Plugs, sockets and couplers shall comply with the following requirements:

- be rated for d.c. use;
- have a voltage rating equal or greater than $1,2 \times V_{OC \text{ ARRAY}}$;
- be protected from contact with live parts in connected and disconnected state (e.g. shrouded);
- have a current rating equal to or greater than the cable to which they are fitted;
- require a deliberate force to disconnect;
- have a temperature rating suitable for their installation location;
- if multipolar, be polarised;
- comply with Class II;
- if exposed to the environment, be rated for outdoor use, be UV-resistant and be at least IP 54 compliant.
- plugs and socket outlets normally used for the connection of household equipment to low voltage a.c. power shall not be used in PV arrays.

NOTE The purpose of this requirement is to prevent confusion between a.c. and d.c. circuits within an installation.

6.1.6 Fuses

Fuses used in PV arrays shall comply with the following requirements:

- be rated for d.c. use;
- have a voltage rating equal or greater than $1,2 \times V_{OC \text{ ARRAY}}$;
- be rated to interrupt full load and prospective fault currents from the PV array and any other connected power sources such as batteries, generators and the grid, if present.

NOTE When fuses are provided for overcurrent protection, the use of fused switch-disconnectors (fuse-combination units) is recommended.

6.1.6.1 Fuse holders

Fuse holders shall comply with the following requirements:

- have a voltage rating equal or greater than $1,2 \times V_{OC \text{ ARRAY}}$;
- have a current rating equal or greater than the corresponding fuse;
- provide a degree of protection not less than IP 2X.

6.1.7 By-pass diodes

By pass diodes may be used to prevent PV modules from being reverse biased and consequent hot spot heating. If by-pass diodes are used, and they are not embedded in the PV module encapsulation, they shall comply with the following requirements:

- have a voltage rating at least $2 \times V_{OC \text{ MOD}}$ of the protected module;
- have a current rating of at least $1,25 \times I_{SC \text{ MOD}}$;
- be installed according to module manufacturer's recommendations;
- be installed so no live parts are exposed;
- be protected from degradation due to environmental factors.

6.1.8 Blocking diodes

Blocking diodes may be used but they are not a substitute for overcurrent protection.

In systems containing batteries it is recommended that some device will be implemented to avoid reverse current leakage from the batteries into the array at night. A number of solutions exist to achieve this including blocking diodes.

If used, blocking diodes shall comply with the following requirements:

- have a voltage rating at least $2 \times V_{OC \text{ ARRAY}}$;
- have a current rating of at least 1,25 times the short circuit current at STC of the circuit that they are intended to protect; that is:
 - $1,25 \times I_{SC \text{ MOD}}$ for PV strings;
 - $1,25 \times I_{SC \text{ S-ARRAY}}$ for PV sub-arrays;
 - $1,25 \times I_{SC \text{ ARRAY}}$ for PV arrays;
- be installed so no live parts are exposed;
- be protected from degradation due to environmental factors.

If there is a special recommendation from the manufacturer or from local regulation to use blocking diodes in PV strings of the PV array, these diodes shall be installed as shown in the following Figure 8.

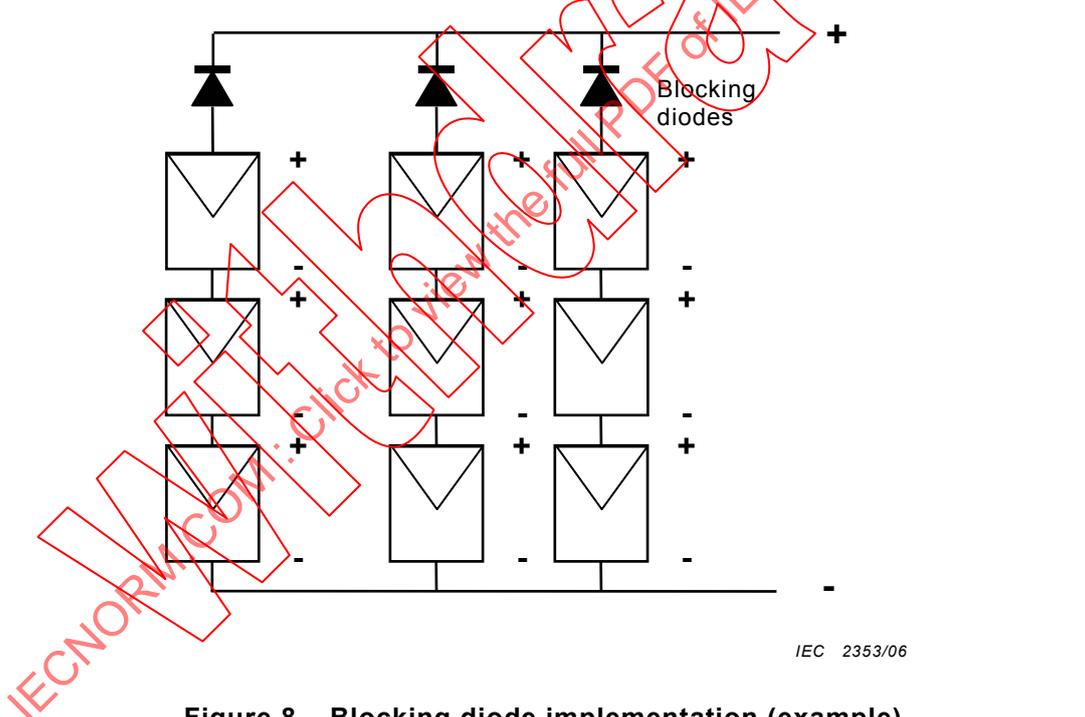


Figure 8 – Blocking diode implementation (example)

6.2 Location and installation requirements

6.2.1 Disconnecting means

6.2.1.1 General

Disconnecting means shall be provided in PV arrays according to Table 6 and Table 7 to isolate the PV array from the power conditioner and vice versa and to allow for maintenance and inspection tasks to be carried out safely.

NOTE This subclause does not apply to module inverters where the inverter is an integral part of the PV module.

6.2.1.2 Installation

Suitably rated circuit-breakers used for overcurrent protection may also provide load breaking disconnecting facilities.

Other disconnection and isolation devices having the characteristics described in 6.1.3.2 may be used as a disconnection means.

Fuse systems used for overcurrent protection are acceptable non-load breaking disconnecting means if they have removable fusing elements, preferably with a disconnection mechanism (fuse-combination unit).

For a reference to the location of disconnection devices see Table 6 (and Table 7 which indicates with respect to the system configuration where the disconnecting mean should be installed (on one or both live conductors of the cable) and which type is this connecting mean.

Table 6 – Disconnecting means requirements in PV array installations

PV array Voltage	Circuit or sub-circuit	Type of disconnection device	Requirement
ELV	String cable	Disconnection device	Recommended
	Sub-array cable	Readily available disconnection device	Required
	Array cable	Readily available load-breaking disconnection device	Required
LV	String cable	Readily available disconnection device	Required
	Sub-array cable	Readily available load-breaking disconnection device	Required
	Array cable	Readily available lockable ^a load-breaking disconnection device	Required ^b

^a "Lockable" disconnection device is a switch or circuit breaker that has provision for insertion of a mechanical device to prevent the switch being closed by an unauthorized person. A mechanical device in this context could constitute sealing with plastic cord, a pin, a wire or other device that prevents operation of the switch.

^b A lockable disconnection device is not required if the whole circuit is visible from the location of the switch.

Table 7 – Location of disconnection devices according to system configuration, where required

System configuration (see Table 2)	Location of disconnecting devices		
	PV string cables	PV sub-array cables	PV array cable
Unearthed PV array	On all live conductors ^a		On all live conductors
Earthed PV array			On all current carrying conductors ^{b, c}

^a Live conductors are those not directly connected to earth.

^b The disconnection device is required in this situation to interrupt the earth conductor so that earth fault currents may be interrupted.

^c In earthed arrays the earthed conductor is a current carrying conductor and needs to be able to be disconnected to allow for interruption of any earth fault condition.

6.2.2 Extra low voltage segmentation

In low voltage PV arrays, means shall be provided to sectionalise each PV string into segments whose open circuit voltage at STC is within ELV.

6.2.3 Earthing system

6.2.3.1 Earthing electrode

If a separate earthing electrode is provided for the PV array, this electrode shall be bonded to the installation earth.

See recommendations on the design of electrodes for lightning protection.

6.2.3.2 Equipment earthing

Equipment earthing refers to the bonding to earth of all exposed conductive parts and frames of the PV array including any structural metalwork. PV array frame earthing shall be done in accordance with the array frame earthing decision tree presented in Figure 3.

Exposed conductive parts of the PV array need not be earthed if the PV array installation complies with any of the following provisions:

- a) double insulation (applies only if the PV array complies with all 1), 2) and 3):
 - 1) general. PV modules complying with class II in accordance with the relevant product standard;
 - 2) wiring outside junction boxes. Where cables may come into contact with accessible PV array conductive parts, the cables shall be of a type affording double insulation;
 - 3) wiring inside junction boxes. Conductors within junction boxes having double insulation shall be protected, secured or insulated so that, if any one conductor becomes detached from its termination, neither the conductor nor its functional insulation can come into contact with accessible metal. The attachment of one conductor to another by tying, lacing, clipping or the like, in such a manner as to prevent either conductor coming into contact with accessible conductive parts if it becomes detached from its termination, shall be deemed to comply with this requirement;
- b) protection by electrical separation in accordance with IEC 60364-4-41;
- c) protection by SELV or PELV in accordance with IEC 60364-4-41.

6.2.3.3 Earthing conductors

All PV array earthing conductors shall comply with the material, type, insulation, identification, installation and connection requirements specified in IEC 60364-5-54.

6.2.3.3.1 Earthing terminal of PV system

When the PV array is earthed, the connection to earth shall be made at a single point and this point shall be bonded to the installation earth.

In systems without batteries, this connection point shall be between the PV array disconnection device and the power conditioning unit and as close as possible to the power-conditioning system.

In systems containing batteries, this connection point shall be between the charge controller and the battery protection device.

NOTE This is to allow for interruption of any earth fault current.

6.2.3.3.2 PV system earthing conductor

If the PV array is earthed, the PV system earthing conductor shall be sized to carry $1,25 \times I_{SC\text{ ARRAY}}$ continuously, and comply with the provisions for earthing conductors specified in national wiring standards or in absence of such standards, with the provisions set out in IEC 60364-5-54 with respect to material and type, insulation, identification, installation, connections and aluminium conductors.

6.2.4 PV array production optimization

To optimize the PV array production it is necessary to fulfil the following requirements:

6.2.4.1 Orientation, tilt angle and flatness

In so far as possible, the orientation and tilt angle of the modules shall optimize the production of energy in relation to the needs. The north or south orientation of the modules is hemisphere dependent. However, the building may not necessarily allow ideal orientation of these two parameters (roof not orientated south or north, vertical front...) and therefore they shall be clearly accounted for in the production calculation at the sizing design phase.

Whatever the array latitude, it is generally recommended that the slope shall keep to a minimum value of ten degrees (10°) in relation to the horizontal, thus preventing stagnation and allowing rain water to carry away dust deposits. Moreover, periodical cleaning actions shall be performed, however, as need be.

The surface for fitting photovoltaic modules to structures shall be perfectly flat in order not to induce mechanical stresses on securing the modules in order to avoid risks of module rupture.

6.2.4.2 Location: accounting for shadow

6.2.4.2.1 Environmental

Shadowing of the PV array should be minimized or preferably eliminated over the whole day with consideration given to all seasons of the year.

A shadow blanking off a photovoltaic cell may cause loss of almost the whole production of this module, significantly reducing the performance of a string of modules.

6.2.4.2.2 One line of photovoltaic modules over the other

On flat roofs, photovoltaic modules are arranged in rows. The first row is fully exposed to sunshine and therefore, the shadow thus generated may affect the next row and so on.

As a basic rule, no shadow should be generated from one row to another.

It may occur that the available space will not allow to have this rule readily applied: an energy production study versus the various structure configurations should be conducted (e.g., more or less high, hence more or less spaced structures, acceptance of shadow early in the morning and end of the afternoon, change of orientation and/or of slope...).

A compromise should be retained allowing to best fulfill the site requirements for useful energy site.

NOTE Where a row comprises several modules along height, care shall be exercised in order to connect the modules to one another as a function of their height along this row. For example, lower modules will constitute a branch and upper modules will constitute another branch. This will make it possible for upper modules to continue producing energy even though lower modules are in the shadow.

6.2.4.3 Location: other recommendations

Prior to implementing a solar generator, it is important to know the behavior and habits of the users and neighborhood. Some locations shall be avoided, especially those exposed to damage that could occur to modules.

Due consideration for environmental risks provides for system durability and is directly linked to the project designers' knowledge of the local social canvas.

6.2.4.4 Maintaining the integrity of the covering

The attachment of structures to the building must keep to the sealing efficiency of the covering and mechanical integrity of the building.

Special care shall be exercised with terrace fitted units where the quality of the covering and related structure is often very poor. It is advisable to have structures laid onto the building instead of attached to it.

6.2.4.5 Theft prevention devices

Where building maintenance does not oblige to remove the modules and if the latter are accessible, theft prevention bolt and nuts shall be adopted. In the opposite case, standard bolting will be used. Where small structures (a few modules per structure) are used, a theft prevention device shall also be used for securing structures to the building.

6.2.5 Array voltage

6.2.5.1 General

$V_{OC\ ARRAY}$ shall not exceed the maximum allowed operating voltage of the PV modules (as specified by the manufacturer).

6.2.6 Wiring system

6.2.6.1 General

Wiring of PV arrays shall be laid in such a way that the possibility of line to line and line to earth faults occurring is minimised.

All connections shall be verified for tightness and polarity during installation to reduce the risk of faults and possible arcs during commissioning and operation.

6.2.6.2 Compliance with wiring standards

The PV array wiring shall comply with the wiring requirements mandated by local standards and regulations. In absence of national standards and or regulations, wiring systems used in PV arrays shall comply with the IEC 60364 series.

NOTE Particular attention needs to be given to the protection of wiring systems against external influences.

6.2.6.3 Wiring loops

To reduce the magnitude of lightning-induced over-voltages, the PV array wiring should be laid in such a way that the area of conductive loops is minimum (e.g. by laying cables in parallel as shown in Figure 9).

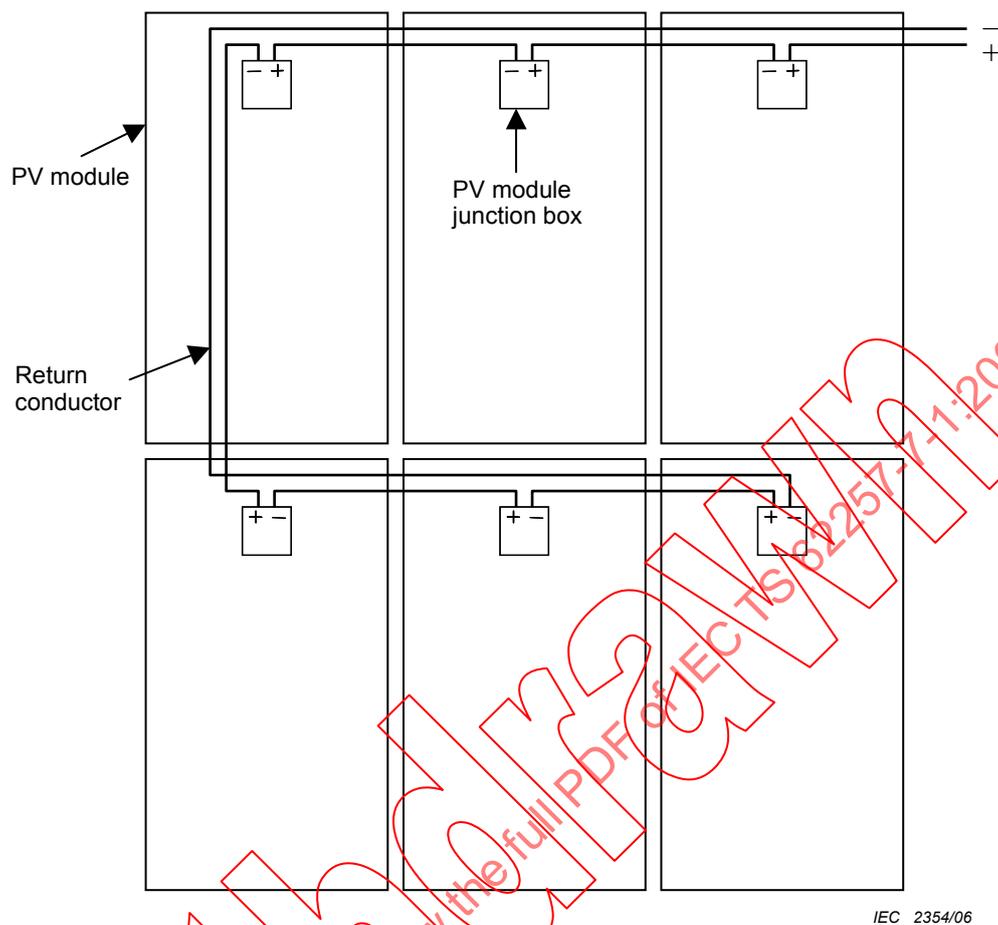


Figure 9 – PV string wiring with minimum loop area

6.2.6.4 String wiring

Wiring of PV strings between modules may be done without laying cables in conduit, provided that the following requirements shall be met:

- insulated and sheathed cables are used, and
- cables are protected from mechanical damage, and
- the cable is clamped to relieve tension in order to prevent the conductor from coming free from the connection.

6.2.6.5 Wiring installation in junction boxes

The following provisions apply to the installation of wiring systems in junction boxes:

Where conductors enter a junction box without conduit, a tension relief system shall be used to avoid cable disconnections inside the junction box (for example by using a gland connector).

All cable entries when installed shall maintain the IP rating of the enclosure.

NOTE Water condensation inside junction boxes may be a problem in some locations; provision may need to be provided to drain water build-up.

For LV PV arrays, where any return conductor is routed through module junction boxes, such return conductor(s) shall be a single-core double-insulated cable, and the cable and its

insulation shall maintain double insulation status over its entire length, particularly through junction boxes (i.e. these provisions also apply to any joints).

6.2.6.6 Wiring identification

Appropriate identification shall be provided for PV array cabling where it can be confused with other wiring systems.

6.2.6.7 Over-voltage protection

6.2.6.7.1 Surge arresters

6.2.6.7.1.1 Selection

The preferred type of surge arresters for over-voltage protection of PV arrays is metal-oxide varistors (MOVs). These devices are voltage dependent resistors that have a high resistance at normal circuit operating voltage, but their resistance reduces continuously with increased surge voltage and current. Spark gap devices are not suitable for use in d.c. circuits as once conducting, they won't stop conducting until the voltage across their terminals is typically less than 30 volts.

Because the performance of MOVs deteriorates with repeated operation (their resistance decreases), it is usual to allow a high safety margin in the selection of the device rating in lightning prone areas. Alternatively, facilities should be provided to give an indication of device failure. The use of thermally monitored MOVs is recommended to avoid excessive system losses and troubleshooting time caused by device failure.

6.2.6.7.1.2 Usage and installation

The following recommendations should be observed for the utilization and connection of surge arresters to protect PV arrays:

A surge arrester should be connected between each pole of the PV array cable and earth. Differential mode protection is not required unless the voltage protection level (VP) of the surge arresters is greater than 1 100 V.

In sub-divided PV arrays, the provision of surge arresters in both poles of each PV sub-array cable is recommended.

The cable distance between the surge arresters and the PV modules should not exceed 15 m.

When the PV array cable exceeds 20 m, surge arresters should be connected at each end of the cable, one set next to the PV array, and the other one next to the power conditioning device. For this purpose, it should be verified if the power conditioning equipment is already fitted with surge arresters.

Junction boxes are a good place to install the surge arresters. Care should be taken to connect them on the PV module side of any disconnecting devices.

The common terminal of surge arresters should be connected to both, conductive PV array frames and structures, and to the equipotential bonding system.

Cables for connecting surge arresters should be as short as possible and have a cross sectional area not less than 6 mm².

6.2.6.7.2 Shielding

When the PV array frame is bonded to a lightning protection system, the PV array cable should be shielded by one of the following methods, and the shielding conductor should be connected to earth at both ends:

- with a metallic cable armour or shield with an equivalent cross sectional area of 6 mm² Cu; or
- with a metallic conduit suitable as a bonding conductor; or
- with an equipotential bonding conductor with a cross sectional area of 6 mm².

6.2.6.8 Automatic disconnection devices

Earth fault detection installed on the d.c. side shall cause disconnection of the PV array from the application circuit. The disconnecting device shall be located between the PV array and the earthing point of the PV array as shown in Figures 2e to 2h.

6.2.7 Surge protective devices

Refer to 5.4.3.2.

6.2.8 Earthing arrangement, protective conductors

Refer to 6.2.3.

7 Acceptance

7.1 General

PV array acceptance procedure will refer to the IEC 62257-6 technical specification.

Commissioning tests are specified in 7.3 to 7.4 to ensure that the PV array complies with the requirements of this standard. The tests specified in 7.5 to 7.6 are additional recommended tests for commissioning of PV arrays larger than 10 kW.

7.2 Conformance with system general specification

The PV array shall be inspected for conformity with the general ratings and technical specifications stated in the contract.

7.3 Wiring and installation integrity

7.3.1 Compliance with wiring standards

The PV array wiring shall be inspected for compliance with wiring standards and regulations in accordance with 6.2.6.

7.3.2 Compliance with this standard

The PV array installation shall be inspected for compliance with the requirements set out in this standard and corrected if necessary.

7.4 Open circuit voltage

This subclause discusses open circuit voltage for

- a) systems with less than 20 strings;
- b) systems with more (see 7.5).

7.4.1 General

This test is intended to ensure that wiring polarity and continuity of the PV array are correct.

7.4.2 Procedure

The open circuit voltage of every string shall be measured before connecting to other strings. All PV string open circuit voltages shall be within 5 % variation; otherwise the connections shall be verified for polarity, continuity and possible faults and repaired. Once the verification is complete and satisfactory, the PV strings can be connected in parallel.

The same procedure shall be carried out to verify PV sub-array open circuit voltages (if relevant) and PV array open circuit voltage before connecting to the PV array to the power conditioning unit.

NOTE 1 All measurements should be made when practicable under stable irradiance conditions. Conditions close to solar noon are preferable.

NOTE 2 A guideline on open circuit voltage measurements for large PV arrays (> 20 strings) where the environmental conditions may change significantly during measurements is given in Appendix G.

7.5 Open circuit voltage measurements for large PV arrays

7.5.1 General

This procedure is a guide on open circuit voltage measurements for PV arrays with a large number of PV strings (20 or more) where the environmental conditions and PV array operating conditions are likely to change significantly during the measurements due to the time required for each measurement.

7.5.2 Procedure

Before closing any switches and installing fuses, the open circuit voltage of each PV string should be measured. The measured values should be compared with the expected value. Temperature corrections should be applied where required according to manufacturers specification. Module temperature should be measured in the back of one of the central modules of each string. Voltage measurements should be made with an accuracy of 2 %; temperature measurements should have an accuracy of 1°C.

NOTE 1 Voltages less than the expected value may indicate one or more modules connected with the wrong polarity, or a partial line-to-line or line-to-ground fault due to insulation damage and/or water accumulation inside conduits.

NOTE 2 High voltage readings are usually the result of wiring errors.

The measured open circuit voltage of each PV string should be within 3 % of the expected value. If there are larger differences, the PV string should be verified for any of the conditions in Note 1 above and the wiring corrected. Once every string has been verified and if necessary corrected, they should be parallel connected via switching devices and/or by installing fuse elements.

7.5.3 PV arrays and sub-arrays measurement

Once the PV strings have been verified and connected in parallel, the open circuit voltage of each PV sub array (if relevant) and of the PV array should be measured using the same procedure as with PV strings.

The measured values should be within 3 % of the expected value; otherwise the wiring should be verified and corrected if necessary. In addition to wrong polarity and insulation faults, defective surge protection devices could be the cause of lower than expected voltage readings in the case of PV arrays and sub-arrays.

NOTE Line-to-ground voltages in bipolar arrays should be relatively balanced around zero with one line above zero (positive) and one line below zero (negative).

7.6 Short circuit current measurements

7.6.1 General

PV array short circuit measurements should be included in the acceptance of large PV arrays to further verify that there are no faults within the PV array wiring and that the PV modules and other components are in good condition.

It is very difficult to obtain accurate results under variable irradiance conditions. It is recommended to use this method only under stable irradiance conditions. Under these stable conditions, it is possible to compare current measurements in different strings to check for major wiring faults.

It can be dangerous to interrupt short circuit currents in PV arrays. The recommended procedure should be carried out in order to prevent injuries.

7.6.2 Procedure

▪ Procedure 1: Current measurement under normal application circuit load using clip-on ampere meter

The first recommended procedure is to connect the array to the application circuit and use a clip-on ampere meter to compare current measurements in each string.

▪ Procedure 2: Short circuit current measurement using clip-on ampere meter

- (1) If there is any current source (e.g. batteries) in the application circuit, these sources should be isolated and any precaution taken to prevent any switch-on of these sources (the same person must switch off the sources and switch them on again after measurement).
- (2) Ensure PV array load-breaking disconnecting device or load-breaking switch is open.
- (3) Connect a short circuit between positive and negative terminals on the application side of the disconnecting device.
NOTE The conductor used for this short circuit must be rated equal to or greater than the current rating of the PV array cable. It must be securely connected (e.g. screwed connections).
- (4) Close all arrays disconnection devices.
- (5) Close the load-breaking disconnecting device or switch.
- (6) Use a clip-on ampere meter to compare current measurements in each string.
- (7) After measurement completed, open the load breaking disconnection switch.
- (8) Remove short circuit.

▪ Procedure 3: Short circuit current measurement when a clip on ampere meter is not available

- (1) If there is any current source (e.g. batteries) in the application circuit these sources should be isolated and any precaution taken to prevent any switch on of these sources. (the same person must switch off the sources and switch them on again after measurement).
- (2) Ensure PV array load breaking disconnecting device or load breaking switch is open.
- (3) Connect a ampere meter between positive and negative terminals on the application side of the disconnecting device.
NOTE The conductor and the Amp meter must be rated equal to or greater the current rating of the PV array cable. It must be securely connected (e.g. screwed connections).
- (4) Open all arrays disconnection devices.
- (5) Switch on one string.
- (6) Close the load-breaking disconnecting device or switch.

- (7) Measure the short circuit current.
- (8) Open the load-breaking disconnecting device.
- (9) Switch off the string.
- (10) Repeat steps 5 to 9 for each string.
- (11) After measurement completed, open the load breaking disconnection switch.
- (12) Remove Amp meter.

Where large discrepancies are found between string currents under stable irradiance conditions, the strings with low measured current should be investigated for faults.

It is very difficult to carry out these procedures for very large arrays due to the main difficulty to have stable irradiance conditions over the period of measurement.

For larger arrays a possible procedure is to use procedure 1 and compare the current supplied to the application circuit with N times the current in a single string.

Where a significant discrepancy is observed, the currents have to be compared at the sub-array level and so on.

NOTE The expected short circuit current of an array may be estimated more accurately if a measurement of in plane irradiance is available, e.g. using a pyrometer or reference cell.

Use the formula below to estimate the short circuit current:

$$I_{SC \text{ EXPECTED}} = n \times I_{SC \text{ MOD}} \times G_1 \times 0,95$$

where:

- $I_{SC \text{ EXPECTED}}$ = expected short circuit current of the segment under test (A);
 n = number of parallel connected strings in the segment under test;
 G_1 = plane of array irradiance (kW/m²);
 0,95 = factor to account for mismatch.

NOTE 1 I_{SC} of the PV array or array segment should be measured with the array not shaded under clear sky, and as close as possible to noontime conditions.

NOTE 2 The short circuit current of crystalline silicon-based PV devices is relatively insensitive to variations in ambient temperature over a wide operating range (-10 °C to 40 °C), increasing slightly with increasing temperature.

NOTE 3 Other PV cell technologies may be more sensitive to temperature or to other conditions such as spectral content. Additional constraints may have to be observed or modifications made to the above equation.

NOTE 4 Some PV module technologies have a settling time period when the output electrical parameters are significantly higher than the nominal values. This fact should be taken into account to modify the above equation accordingly.

NOTE 5 Low I_{SC} measurements can indicate the presence of circulating ground fault currents in the array due to multiple ground faults or shading.

Higher than expected measurements can indicate an array configuration other than expected or increased irradiance on the array not being sensed by the pyranometer.

7.7 Commissioning records

The inspecting personnel shall prepare a commissioning report that includes the applicable records from the list of items a) to e) below:

- a) a report that states whether the PV array complies with the general ratings and technical specifications established in the contract;
- b) a certificate stating if the work done on the installation meets the requirements of this standard and either those of local wiring codes or the IEC 60364 series according to 6.2.6.2
- c) A table with the final open circuit voltage measurements for each string, sub array and array; and a statement with the condition of the PV array wiring after the test, including

any repairs and corrections carried out as a result of the inspections. When temperature measurements were carried out, these values should also be tabulated along with the actual voltage readings and the expected voltage values.

- d) When relevant, a report with the measured trip values of current and/or resistance of the earth fault protection system before and after any adjustments to the calibration.
- e) When short circuit current measurements are made as part of the acceptance process, a report that includes the test procedures used and the current measurements, stating the condition of the PV array wiring after the test, including any repairs and corrections carried out as a result of the inspections.

This report shall be given to the owner, and if necessary to the relevant authorities. Examples of commissioning records are given in Annex A.

8 Operation/maintenance

8.1 General

This clause gives general guidance for the preparation of operation and maintenance procedures for PV arrays. Examples of such procedures are given in Annex C.

8.2 Safety

Attention should be given in the operation and maintenance procedures to the following safety requirements:

- a) emergency shutdown procedure;
- b) obey all warning signs;
- c) shut system down and interrupt PV array currents according to the manual shutdown procedure;
- d) split strings into extra low voltage sections (if relevant);
- e) warn of the live parts that cannot be de-energised during daylight.

8.3 Operation and maintenance procedures

PV arrays do not generally require control actions in normal operation. The most important operation procedures for PV arrays are those related to switching and shutdown for emergency and maintenance purposes.

Operation and maintenance procedures should include the following:

- a) a short description of the function and operation of all installed equipment. More detailed information should be available from the manufacturer's documentation (see Item d);
- b) emergency and maintenance shutdown procedures;
- c) periodic maintenance requirements including procedures and schedule. Annex B gives an example of a maintenance schedule;
- d) equipment manufacturer's documentation (data sheets, handbooks, etc.) for all equipment supplied.

9 Replacement

For each project the project implementer will have to list the replacement criteria.

Some guidance for criteria can be found in the maintenance schedule (see Annex B). Particular attention is drawn to the measurement of short circuit current of the array, which may give an indication of deterioration in performance for which replacement criteria thresholds could be specified, provided measurements of irradiance are available.

10 Marking and documentation

10.1 Equipment marking

All electrical equipment shall be marked according to the requirements for marking in IEC or to local standards and regulations when applicable. Markings should be in the local language or use appropriate local warning symbols. English examples of sign texts are included here.

10.2 Requirements for signs

All signs required in this clause shall:

- a) comply with IEC;
- b) be indelible;
- c) be legible from at least 0,8 m unless otherwise specified in the relevant clauses (or see examples of signs in Annex D);
- d) be constructed and affixed to remain legible for the life of the equipment it is attached or related to;
- e) be understandable by the operators;

Examples of signs are given in Annex D.

10.3 Labelling of PV array and PV sub-array junction boxes

A sign containing the text 'SOLAR d.c.' shall be attached to PV array and PV sub-array junction boxes as well as labels indicating "live during daylight" to d.c.junction boxes and switches.

10.4 Labelling of disconnection devices

10.4.1 General

Disconnection devices shall be marked with an identification name or number according to the PV array wiring diagram.

All switches shall have the ON and OFF positions clearly indicated.

10.4.2 PV array disconnecting device

The PV array main switch shall be provided with a sign affixed in a prominent location with the following text: 'PV ARRAY MAIN SWITCH'.

10.5 Fire emergency information signs

10.5.1 General

For PV arrays installed on buildings that have a PV array voltage greater than 120 V, a sign shall be displayed next to the main building switchboard. This sign shall state 'Warning: Electric Solar Array' and give an indication of its location. This sign shall be legible from at least 1,5 m.

The sign shall also include the following PV array information:

- a) open circuit voltage;
- b) short circuit current.

NOTE In small installations the indication of location may be simple, e.g. "On Roof". In larger installations more detail should be provided.

10.6 Documentation

The PV system designer shall prepare the following documents and a copy shall be handed to the PV system owner:

- a) A basic circuit diagram that includes the electrical ratings of the PV array, including the information required by 10.5.
- b) PV system or parts certification as required by relevant authorities and provided by manufacturer.
- c) A copy of the emergency shutdown procedure including the location of relevant switching devices.
- d) A copy of the operation and maintenance procedures in accordance with Clause 8.

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Annex A
(informative)

Examples of commissioning records

Verification of PV array general ratings and technical specifications

	Characteristic	Reference value	Conform Yes/No	Remarks
PV modules	Nominal power			
	Technology			
	Quantity			
	Manufacturer			
	Model			
	Standards	IEC 61215 / IEC 61646		
	Equipment class			
	Reverse current withstand	$2,6 \times I_{SC\ STC\ MOD}$		
	Cell appearance	No defects		
	Sealing	No defects		
	Frames	No corrosion or defects		
	By-pass diodes			
	PV array	Total rated power		
Nominal voltage				
Nominal current				
V _{OC} ARRAY		7.4 and 7.5		
I _{SC} ARRAY				
No. of series modules				
No. of parallel strings				
Inclination				
Azimuth				
Total area				

Verification of compliance with the requirements of IEC 62257-7-1

	Characteristic	Reference Value	Conform Yes/No	Remarks
Protection against electric shock and fire	Insulation system	5.2		
Protection against overcurrent	Strings	5.3.2 and 5.3.4		
	Sub-arrays	5.3.2 and 5.3.4 (if relevant)		
	Array	5.3.2 and 5.3.4		
	Discrimination	5.3.3		
	Location	5.3.5		
Lightning and over-voltage protection	Lightning protection	IEC 62305-2 and IEC 62305-3 recommended		
	Equipotential bonding	4.1.2 and 5.4.3.1		
	Wiring loops	5.4.3.1 and 6.2.6.3 recommended		
	Surge arresters	5.4.3.2 and 6.2.6.7.1 recommended		
	Shielding	6.2.6.7.2 recommended		
Selection and erection of equipment	Components requirements			
	PV modules	6.1.1		
	Junction boxes	6.1.2 (if relevant)		
	Switching devices	6.1.3 (if relevant)		
	Plugs, sockets and couplers	6.1.5 (if relevant)		
	Fuses	6.1.6 (if relevant)		
	By pass diodes	6.1.7 (if relevant)		
	Blocking diodes	6.1.8 (if relevant)		
	Wiring installation			
	String wiring	6.2.6.4		
	Junction boxes wiring	6.2.6.5		
	Junction boxes location	6.1.2.2		
	Wiring identification	6.2.6.6		
	Cable selection			
	Cable size	6.1.4.1		
	Insulation	6.1.4.2		
	Disconnecting means	6.1.3.2 and 6.2.1.2		
	ELV segmentation	6.2.2 (if relevant)		
	Earthing			
	Electrode	6.2.3.1		
Equipment earthing	6.2.3.2			
System earthing	6.2.3.3			
Operation and maintenance	Safety and procedures	8.2 recommended		

	Characteristic	Reference Value	Conform Yes/No	Remarks
Marking and documentation	Marking			
	Equipment	10.1		
	Signs requirements	10.2		
	Junction boxes	10.3		
	Disconnection devices	10.4		
	PV array main switch	10.4.2		
	Fire emergency information	10.5		
	Documentation	10.6		
Mechanical	Ventilation	Recommended		
	Wind loading	Recommended		

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Annex B (informative)

Example of maintenance schedule

Sub-system or component	Maintenance action	Freq.	Remarks
Array field	Verify cleanliness (accumulation of dust or other shading materials)	Quarterly	The array field should be cleaned if necessary
PV modules	Check for visual defects <ul style="list-style-type: none"> • Fractures • Browning • Moisture penetration • Seal integrity • Frame corrosion 	1 yr	Modules with visual defects should be further inspected for performance and safety to determine the need for replacement
	Inspect junction boxes <ul style="list-style-type: none"> • Tightness of connections • Water accumulation/buildup • Integrity of lid seals • Integrity of cable entrance and/or conduit sealing • Integrity of clamping devices • Verify by-pass diodes 	1 yr	Any defective seals, clamps and by-pass diodes should be replaced
Wiring installation	Mechanical integrity of conduits	5 yr	Any damaged conduit should be replaced
	Insulation integrity of cables installed without conduit	5 yr	Any damaged cable should be replaced
	Junction boxes <ul style="list-style-type: none"> • Tightness of connections • Water accumulation/buildup • Integrity of lid seals • Integrity of cable entrance and/or conduit sealing • Integrity of clamping devices • Verify blocking diodes • Verify surge arresters for degradation 	1 yr	Any defective seals, clamps blocking diodes and surge arresters should be replaced
	Earthing connections <ul style="list-style-type: none"> • Tightness of connections • Corrosion 	1 yr	
Electrical characteristics	Measurement of open circuit voltages	1 yr	According to 7.4 and 7.7
	Measurement of short circuit currents	1 yr	According to 7.6
	Measurement of insulation resistance in dry and wet conditions	1 yr	If the recorded values of insulation resistance drop significantly (20 % or more), special attention shall be paid to the variation of the values. If the value of the resistance continues to decrease, check the wiring and installation.
	Measurement of earth resistance	1 yr	
	Measurement of I-V characteristics	5 yr	Refer to IEC 61829
Protective devices	Verification of fuses	1 yr	

Sub-system or component	Maintenance action	Freq.	Remarks
	Verification of CBs and RCDs	1 yr	
	Verification of earth fault protection system	1 yr	According to 7.7
Mounting structures	Verify tightness and integrity of bolts and other fastening devices	5 yr	
	Verify if there is significant corrosion	5 yr	

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Annex C (informative)

Replacement

PV module(s) and structures should be replaced if considered unsafe. This may occur due to extreme climatic conditions or through age and corrosion of structural materials.

PV modules should be considered for replacement when they are no longer capable of supplying useful service. This can occur:

- after normal expected lifespan,
- deterioration of a module(s) under warranty, or
- deterioration of a module(s) due to fault conditions within the array.

PV field junction boxes may be prone to failure due to corrosion and should be replaced as needed.

When replacing a module(s) or the whole array it is important that:

- the array be shut down according to proper procedure;
- any LV strings within the array be sectionalized into ELV sections;
- the replacement be carried out by suitably qualified personnel;
- the module(s) or the whole array should be replaced by mechanically and electrically compatible parts.

Annex D (informative)

Examples of signs

This annex provides examples (see Figures D.1 to D.3) of appropriate signs as specified in Clause 10.



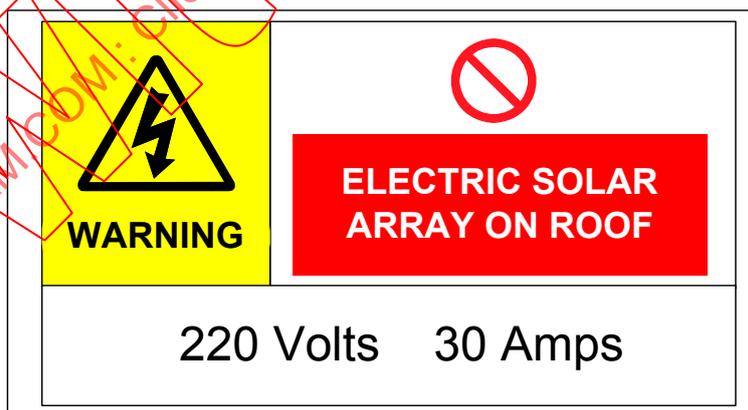
IEC 2355/06

Figure D.1 – Example of sign required on PV array junction box (10.3)



IEC 2356/06

Figure D.2 – Example of sign required adjacent to PV array main switch (10.4.2.)



IEC 2357/06

Figure D.3 – Example of fire emergency information sign required in main building switchboard (10.5.1)

Annex E (informative)

Case studies

Introduction

Case studies are presented here illustrating a range of applications. The systems shown illustrate different sized systems and different earthing arrangements, where $n_p = 3$ (see Table 3 for the calculation of n_p). The list of case studies is by no means exhaustive. They are included here to illustrate some of the principles of this standard. Table E.1 is a summary of the case studies included.

Table E.1 – Case studies overview list

PV system earthing configuration			Case studies description				
PV array earthing equipment	Application circuit	PV array earthing status	N°	PV array voltage	Number of parallel strings where $n_p=3$ (see 5.3.2 and Table 3)	Battery	
Ref: Table 2			Ref: Table 1				
Unearthed	Unearthed DC loads	Floating	A1	ELV	=3	No	
			A2	ELV	>3	No	
			A3	ELV	<3	Yes	
			A4	ELV	>3	Yes	
	Earthed DC loads	Fixed to earth	B1	ELV	>3	Yes	
			C1	LV	<3	No	
	AC loads connected via an isolated PCS	Floating	C2	ELV	>3	Yes	
			Fixed by the status of the neutral of the application circuit	D1	ELV	<3	No
				D2	ELV	>3	No
				D3	LV	>3	No
Earthed	Unearthed DC loads	Fixed to earth	E1	ELV ^a	>3	No	
			E2	ELV	>3	Yes	
	Earthed DC loads		E1	ELV ^a	>3	No	
			E3	ELV	>3	Yes	
	AC loads connected via an isolated PCU		E4	LV	<3	No	
			AC loads connected via a non-isolated PCU	Not permitted			

^a These two cases are identical as the earth is at the same point electrically in the system.

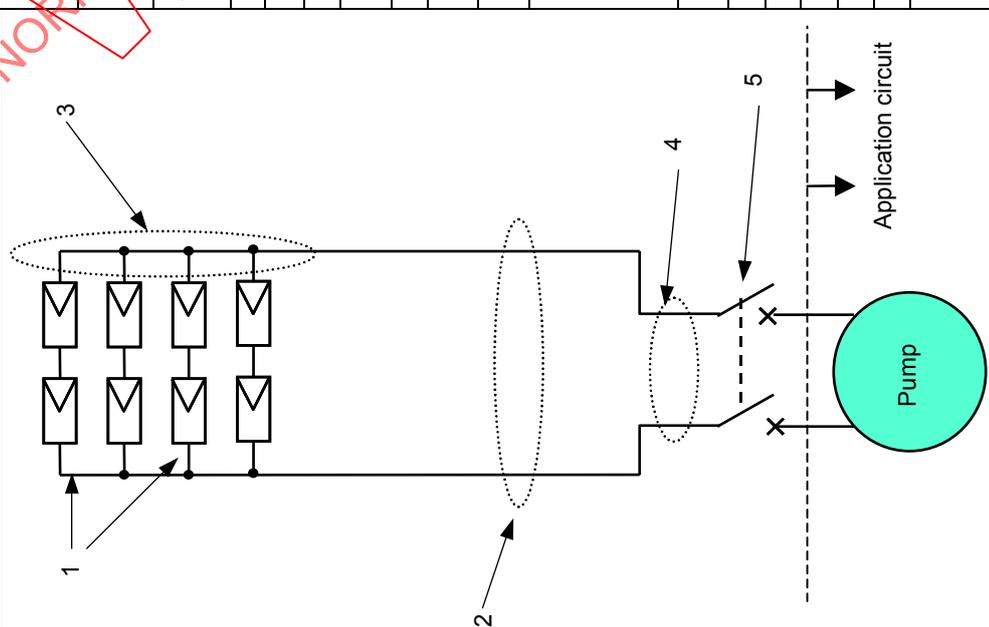
Case A1 -
Floating ELV array with number of parallel strings ≤ 3 , where $n_p = 3$

PV system earthing configuration Ref: Table 2			Case study description Ref: Table 1			
PV array earthing equipment	Application circuit	PV array earthing status	PV array voltage	Number of strings	Battery	Example of application ?
Unearthed	Unearthed DC loads	Floating	ELV 24 V nominal 44 V o/c	3	No	Pumping system
Array data						
$I_{SC MOD} = 5 A$	$V_{OD MOD} = 22 V$	$R_{MOD} = 85 W$	$I_{SC S-ARRAY} = NA$	$I_{SC ARRAY} = 15 A$	$V_{OC ARRAY} = 44 V$	$P_{ARRAY} = 510 W$
Protection devices						
Protection against overcurrent						
Ref	Value	Clause reference	Ref	Value	Clause reference	
3	No more than 3 strings- String fault current protection not required	5.3.2	5	Disconnecting means required.	6.2.1	
4	No battery- PV array cable fault current protection not required	5.3.4.3				
Cable rating						
Ref	Rating	Formula	Clause			
1	13 A	$1,3 \times I_{SC MOD} \times (S_{PO}-1)$	6.1.4			
2	19,5 A	$1,3 \times I_{SC ARRAY}$	6.1.4			

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**Case A2 -
Floating ELV array with number of parallel strings > 3, where $n_p = 3$**

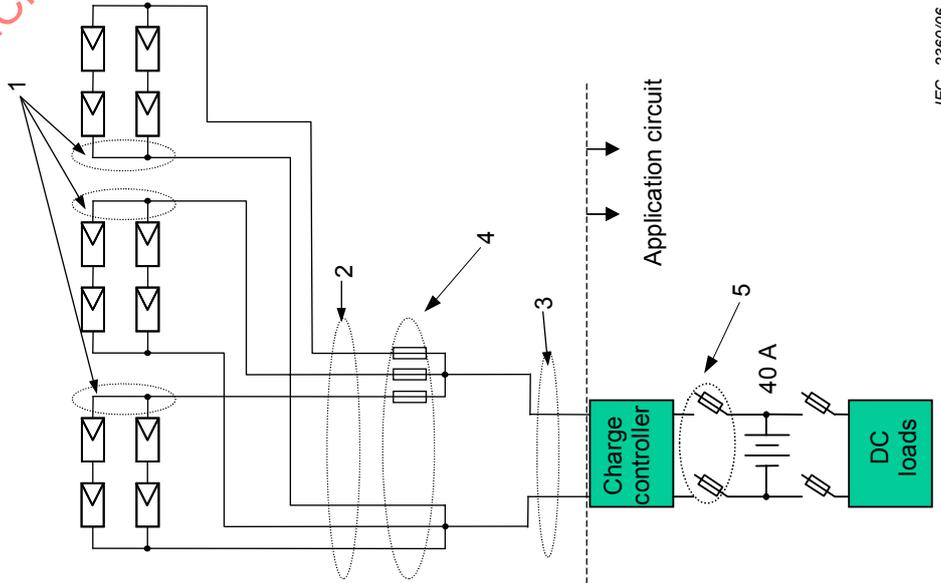
PV system earthing configuration Ref: Table 2		Case study description Ref: Table 1					
PV array earthing equipment	Application circuit	PV array earthing status	PV array voltage	Number of strings	Battery	Example of application ?	
Unearthed.	Unearthed DC loads	Floating	ELV 24 V nominal 44 V o/c	4	No	Pumping system	
Array data							
$I_{SC MOD} = 5 A$	$V_{OC MOD} = 22 V$	$P_{MOD} = 85 W$	$I_{SC S-ARRAY} = NA$	$I_{SC ARRAY} = 15 A$	$V_{OC ARRAY} = 44 V$	$P_{ARRAY} = 680 W$	
Protection devices							
Protection against overcurrent							
Ref	Valve	Clause reference	Ref	Value	Clause reference		
3	String fault current protection not required if PV array is fire safe.	5.3.4	5	Disconnecting means required.	6.2.1		
3	If array is not fire safe, it must be double insulated with respect to earth to allow single pole string fault current protection, otherwise double pole fault current protection is required on each string	5.3.5					
4	No battery- PV array cable fault current protection not required	5.3.4.3					
Cable rating							
Ref	Rating	Formula	Clause				
1	13 A	$1,3 \times I_{SC MOD} \times (S_{PO-1})$	6.1.4				
2	26 A	$1,3 \times I_{SC ARRAY}$	6.1.4				



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Case A3 - Floating ELV array with sub-arrays and battery and number of parallel strings ≤ 3, where $n_p = 3$

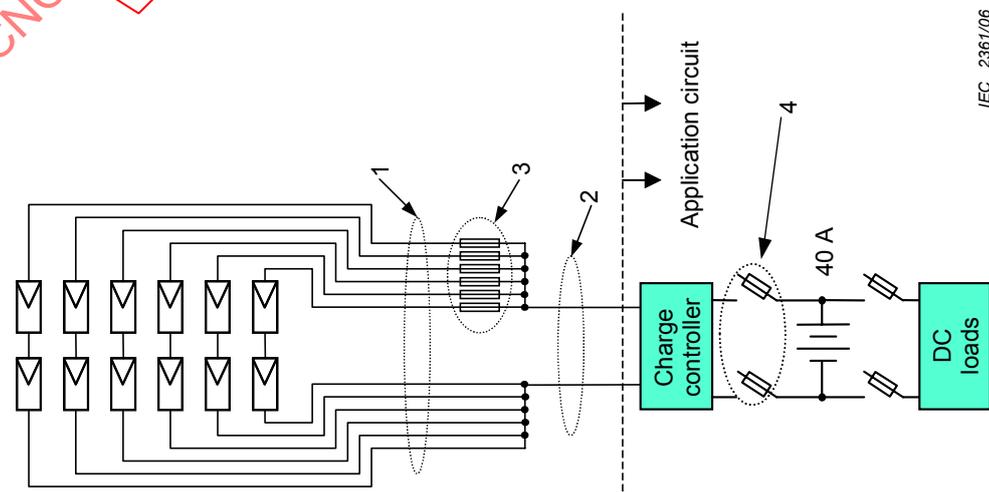
PV system earthing configuration Ref: Table 2		Case study description Ref: Table 1				
PV array earthing equipment	Application circuit	PV array earthing status	PV array voltage	Number of strings	Battery	Example of application ?
Unearthed	Unearthed DC loads	Floating	ELV 24 V nominal 44 V o/c	2	Yes	Stand alone power system with battery
Array data						
$I_{SC MOD} = 5 A$	$V_{OC MOD} = 22 V$	$P_{MOD} = 85 W$	$I_{SC S-ARRAY} = 10 A$	$I_{SC ARRAY} = 30 A$	$V_{OC ARRAY} = 44 V$	$P_{ARRAY} = 1020 W$
Protection devices						
Protection against overcurrent						
Ref	Value	Clause reference	Ref	Value	Clause reference	
1	String fault current protection not required if PV array is fire safe.	6.3.4	3	No disconnecting means requirement if provided between battery and charge controller	6.2.1	
4	Sub Array fault current protection = $1,3 \times I_{SC S-ARRAY} \leq I_{TRIP} \leq 2 \times I_{SC S-ARRAY}$	5.3.5				
5	Double pole PV array cable overcurrent protection required. Battery overcurrent protection fulfills this requirement	5.3.4.3				
Cable rating						
Ref	Rating	Formula	Clause	Comments		
1	21,5 A	Trip current of nearest downstream f/c prot. device + $1,3 \times I_{SC MOD} \times (S_{PO}-1)$	6.1.4	In this case study the designer has elected to use a sub array structure and put in sub array overcurrent protection. The array is fire-safe so no string fusing is required. The overcurrent protection of the PV array cable is provided by the overcurrent protection between the charge controller and the battery.		
2	15 A	Tied to PV sub-array fuse rating	6.1.4			
3	40 A	Trip current of the PV array overcurrent protection device - Tied to battery overcurrent rating	6.1.4			



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Case A4 – Floating ELV array with battery and with number of parallel strings > 3, where $n_p = 3$

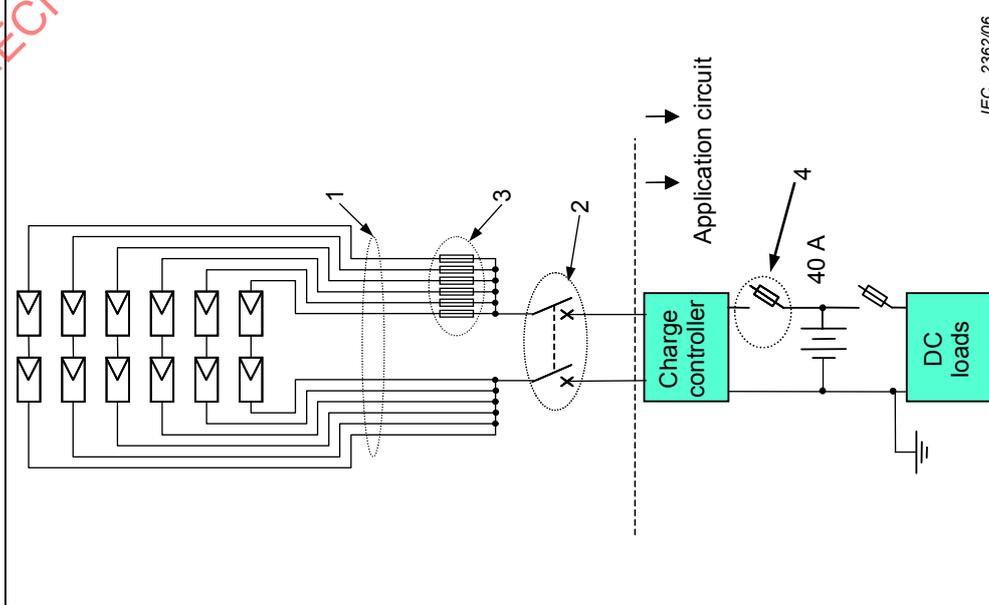
PV system earthing configuration Ref: Table 2				Case study description Ref: Table 1			
PV array earthing equipment	Application circuit	PV array earthing status	PV array voltage	Number of strings	Battery	Example of application ?	
Unearthed	Unearthed DC loads	Floating	ELV 24 V nominal 44 V o/c	6	Yes	Stand alone power system with battery	
Array data							
$I_{SC MOD} = 5 A$	$V_{OC MOD} = 22 V$	$P_{MOD} = 85 W$	$I_{SC S-ARRAY} = 10 A$	$I_{SC ARRAY} = 30 A$	$V_{OC ARRAY} = 44 V$	$P_{ARRAY} = 1020 W$	
Protection devices							
Disconnection devices Ref: Table 4							
Protection against overcurrent							
Ref	Value	Clause reference	Ref	Value	Clause reference		
3	String fault current protection 8 A	5.3.4	2	No disconnecting means requirement if provided between battery and charge controller	6.2.1		
3	If array is not fire safe, it must be double insulated with respect to earth to allow single pole string overcurrent protection as shown here, otherwise double pole fault current protection is required on each string.	5.3.5					
4	Double pole PV array cable overcurrent protection required. Battery overcurrent protection fulfils this requirement	5.3.4.3					
Cable rating							
Ref	Rating	Formula	Clause	Comments			
1	8 A	Tied to overcurrent protection rating.	6.1.4 Table 5	In this case study the designer has elected to use string overcurrent protection. The array is not fire-safe so string fusing is required. The overcurrent protection of the PV array cable is provided by the overcurrent protection between the charge controller and the battery.			
2	40 A	Trip current of the PV array overcurrent protection device - Tied to battery overcurrent rating	6.1.4				



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**Case B1 -
Earthed DC loads, ELV array with battery and with number of parallel strings > 3, where $n_p = 3$**

PV system earthing configuration Ref: Table 2			Case study description Ref: Table 1			
PV array earthing equipment	Application circuit	PV array earthing status	PV array voltage	Number of strings	Battery	Example of application ?
Unearthed	Earthed-DC loads	Earthed	ELV 24 V nominal 44 V o/c	6	Yes	Stand alone power system with battery
Array data						
$I_{SC MOD} = 5 A$	$V_{OC MOD} = 22 V$	$P_{MOD} = 85 W$	$I_{SC S-ARRAY} = 10 A$	$I_{SC ARRAY} = 30 A$	$V_{OC ARRAY} = 44 V$	$P_{ARRAY} = 1020 W$
Protection devices			Disconnection devices Ref: Table 4			
Protection against overcurrent						
Ref	Value	Clause reference	Ref	Value	Clause reference	
3	String fault current protection 8 A	5.3.4	2	Double pole disconnecting means required if the disconnection means provided between battery and charge controller is not double pole.	6.2.1	
3	If array is not fire safe, it must be have single pole string overcurrent protection as shown here.	5.3.5	1	Double pole, string disconnection devices recommended		
4	Single pole PV array cable overcurrent protection required. Battery overcurrent protection fulfils this requirement.	5.3.4.3				
Cable rating						
Ref	Rating	Formula	Clause	Comments		
1	8 A	Tied to overcurrent protection rating.	6.1.4 Table 5	In this case study the designer has elected to use string overcurrent protection. The array is not fire-safe so string fusing is required. The overcurrent protection of the PV array cable is provided by the overcurrent protection between the charge controller and the battery. Because it is an earthed system only single pole overcurrent protection is required.		
2	40 A	Trip current of the PV array overcurrent protection device - Tied to battery overcurrent rating	6.1.4			



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Case C1 - Floating LV array with battery and with number of parallel strings ≤ 3 , where $n_p = 3$, connected to AC loads via isolated PCS

PV system earthing configuration Ref: Table 2			Case study description Ref: Table 1			
PV array earthing equipment	Application circuit	PV array earthing status	PV array voltage	Number of strings	Battery	Example of application ?
Unearthed	AC loads connected via an isolated PCU	Floating	LV	2	No	Grid connected system
Array data						
$I_{SC_MOD} = 5\text{ A}$	$V_{OC_MOD} = 22\text{ V}$	$P_{MOD} = 85\text{ W}$	$I_{SC_S_ARRAY} = \text{NA}$	$I_{SC_ARRAY} = 10\text{ A}$	$V_{OC_ARRAY} = 220\text{ V}$	$P_{ARRAY} = 1700\text{ W}$
Protection devices						
Protection against overcurrent						
Ref	Value	Clause reference	Ref	Value	Clause reference	
3	String fault current protection not required.	5.3.4	4	Double pole readily available breaking disconnecting device	6.2.1, Table 6	
			5	Double pole readily available disconnecting device, lockable in the off position.	6.2.1, Table 6	
			6	String segmentation to ELV sections.	6.2.2	
Cable rating						
Ref	Rating	Formula	Clause	Comments		
1	6,5 A	Trip current of nearest downstream o/c protection. device + $1,3 \times I_{SC_MOD} \times (S_{PO} - 1)$	6.1.4	Array and wiring double insulated.	5.2	
2	13 A	$1,3 \times I_{SC_ARRAY}$	6.1.4			

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