ISSN No: - 2456-2165 https://doi.org/10.38124/ijisrt/26sep347

Earthing and Protection Design for Solar PV Power Systems

A Design Method for Rooftop and Ground-Mounted Installations

Pawan Bajpai[1]

[1] Independent researcher, Fiji

Publication Date: 2026/09/22

Abstract: Earthing and protection in a photovoltaic power system is a plant-wide network, not a set of isolated earth pits. This paper sets out a single design method that applies to both ground-mounted and rooftop installations, and identifies where the two diverge. The method proceeds from measurement of the earth termination environment, through equipotential bonding architecture, conductor sizing against the thermal limit, verification of touch and step voltage, lightning risk assessment and surge protective device coordination, connection technology, protection coordination, and commissioning verification. For ground-mounted plants the earth termination is a purpose-built buried grid sized from measured soil resistivity across the site. For rooftop plants a soil measurement is generally unavailable to the PV designer; the array is bonded into the existing earth termination and lightning protection system of the host building, which shifts the design problem from resistance reduction to equipotential bonding, separation distance and coordination with structures the PV contractor does not own. Comparison tables are given for each design step, together with a worked conductor sizing example for both system types and a commissioning checklist differentiated by installation type. The worked example shows that the thermal limit governs only the ground-mounted main grid; elsewhere the tabulated minimum of the wiring rules, or the minimum required of a lightning protection bonding conductor, governs instead.

Keywords: *PV Earthing; Equipotential Bonding; Touch and Step Voltage; Earth Grid; Lightning Protection System; Surge Protective Device; Rooftop PV; Ground-Mounted PV; Commissioning Verification.*

How to Cite: Pawan Bajpai (2026), Earthing and Protection Design for Solar PV Power Systems. *International Journal of Innovative Science and Research Technology* 11(9), 753-763. https://doi.org/10.38124/ijisrt/26sep347

I. INTRODUCTION

A photovoltaic power system distributes conductive material across its whole footprint. In a ground-mounted plant that footprint is tens of hectares of open ground carrying steel mounting structures, buried cabling, combiner boxes, inverter stations, transformers and switchyard steel. In a rooftop plant the same electrical equipment is mounted on a structure the PV contractor did not design, frequently with an existing lightning protection system, an existing earth termination and occupied space directly beneath the array. In both cases the earthing and protection system is what ties the conductive material to one potential, gives fault and lightning current a defined route to earth, and keeps people and equipment out of that route.

Practice in the field still treats earthing as a quantity item — a count of earth pits, a resistance figure recorded at handover. That framing omits most of what the system is required to do, and it omits almost everything specific to rooftop installations. Reviews of practice in the field reach the same conclusion [13], and impulse testing on individual modules shows that the equipment being protected is itself vulnerable to the transients in question [17]. This paper therefore sets out the design steps in the order they are actually performed, and at each step states the ground-mounted requirement, the rooftop requirement, and the reason they differ. The intent is a working reference for design, site and commissioning engineers rather than a derivation; the governing standards are cited at each step and the numerical examples are illustrative.

➢ *Scope and System Classification*

Two installation classes are considered. A *ground-mounted* system is one where the PV designer controls the earth termination and can construct it: the earth grid is a designed asset, buried in soil whose resistivity can be measured before layout is fixed. A *rooftop* system is one where the earth termination belongs to the host building: the PV designer inherits it, must verify it, and must bond into it without degrading it. The distinction is not the mounting method but the ownership of the earth termination, and it drives every subsequent difference in Table 1.

ISSN No: - 2456-2165 https://doi.org/10.38124/ijisrt/26sep347

Table 1 Design Framing by Installation Class.

Aspect	Ground-mounted	Rooftop
Earth termination	Designed and constructed buried grid	Existing building earth termination, inherited and verified
Governing input	Measured soil resistivity across the site	Measured resistance and continuity of the building earth
Primary design problem	Reduce earth resistance and control surface potential over a large area	Achieve equipotential bonding and maintain separation distance from the building LPS
Personnel exposure	Step and touch voltage on open ground within the plant	Touch voltage on accessible roof areas; occupied space beneath the roof deck
Lightning exposure	Open field of elevated steel rows; dedicated masts	Array raises the effective roof profile; must not compromise the building air termination network
Interfaces owned by others	Grid substation earth mat at the point of interconnection	Building LPS, main earthing terminal, structural steel, roof membrane warranty
Typical fault level at the earthing interface	High; set by the HT system and transformer	Lower; set by the building LT supply and inverter rating

➢ *Objectives of the Earthing System*

Seven requirements are placed on the earthing system, and each is a separate reason the system exists. A design that satisfies only a resistance target has addressed at most one of them. All seven apply to both installation classes; what changes is which of them dominates the design, as noted in the right-hand column.

- *Provide Low-Impedance Path for Fault Current.*

Governs conductor sizing and joint quality in both classes.

- *Maintain Same Potential.*

Dominant requirement on rooftops, where separated metalwork within reach is the principal hazard.

- *Minimize Touch & Step Voltage.*

Step voltage is a ground-mount concern; touch voltage applies to both.

- *Ensure Proper Operation of Protective Devices.*

Requires a fault loop impedance low enough for the device to see the fault.

- *Safely Dissipate Lightning & Surge Currents.*

On rooftops this is shared with the building LPS and constrained by separation distance.

- *Protect Personnel from Electric Shock.*

Includes maintenance personnel working on an energised DC array in both classes.

- *Reduce Equipment Damage.*

Achieved jointly with the SPD coordination of Section 9.

➢ *Items Requiring Bonding*

The bonding schedule is the design deliverable that most often carries an omission, and an omitted item becomes the one place at which a fault can raise a dangerous potential within reach. Table 2 lists the schedule for both classes. Items marked as not applicable are absent from that class; items marked as inherited exist but are provided and owned by the host building, and the PV designer's obligation is to verify and bond to them rather than to construct them.

Table 2 Bonding Schedule by Installation Class.

Item	Ground-mounted	Rooftop
PV module frames	Required	Required
MMS (mounting structure)	Required, per row to the grid	Required; each rail run bonded and cross-bonded between rows
DC combiner boxes	Required	Required where fitted
Inverters / PCUs	Required, at the inverter station	Required; string inverters bonded at their mounting position
ACDB & LT panels	Required	Required, to the building main earthing terminal
HT panels & switchgear	Required	Not applicable in most cases
Transformers	Required	Not applicable in most cases
Transformer neutral	Required, separate dedicated electrodes	Not applicable; supply neutral earthed by the distributor
SCADA & control panels	Required, with clean-earth reference as specified	Required where fitted
Lightning protection system	Required, dedicated masts and earth paths	Inherited; bond or isolate per Section 9
Cable trays & metallic structures	Required, bonded at both ends	Required, including roof-level tray and conduit

ISSN No: - 2456-2165 https://doi.org/10.38124/ijisrt/26sep347

Control room / substation equipment	Required	Not applicable
Switchyard structures	Required	Not applicable
Metal roof sheeting and standing-seam cladding	Not applicable	Required where the array is mounted on or clamped to it
Building structural steel and reinforcement	Not applicable	Inherited; used as a natural component where continuity is proven
Roof-level handrails, walkways, plant and ductwork	Not applicable	Required where within reach of the array
Roof penetration sleeves and cable entry glands	Not applicable	Required where metallic; see Section 6.3

II. CHARACTERISING THE EARTH TERMINATION ENVIRONMENT

➢ *Ground-Mounted: Soil Resistivity Measurement*

Measured soil resistivity is the input from which the whole earth termination is sized. It is taken on site, at depth, before any layout is fixed, and it is based on actual site conditions rather than assumed values. The four-electrode method of Fig. 1 is used: four electrodes are driven at equal spacing *a*, current is injected across the outer pair and the potential difference is read across the inner pair, and an apparent resistivity is derived for each spacing. Repeating the measurement over a range of spacings profiles the strata, since larger spacings sample deeper soil. For the equal-spacing (Wenner) arrangement shown, the apparent resistivity follows from the measured resistance $R = V/I$ by Eq. (1), in which a is the electrode spacing.

$$\rho = 2\pi a R \quad (1)$$

Because the depth of soil sampled increases with *a*, repeating the measurement over a range of spacings yields a curve of apparent resistivity against spacing from which a layered soil model is fitted. That fitting is an inverse problem and is non-unique: several layer structures can reproduce the same sounding curve within measurement error [18], which is the technical reason a single traverse is insufficient and why the profiles of Section 5.1 are taken at several locations. Measurement practice and the interpretation of the resulting profile follow IEEE Std 81 [2]; IS 3043 [11] gives comparable guidance together with tabulated resistivity ranges by soil type.

Resistivity varies across a large site and with season and moisture content, so the design uses measured profiles taken at several locations across the plant area rather than a single spot reading. From the profile follow the earth electrode configuration, the grid spacing, the number of electrodes, the conductor size, the grid area and the expected resistance to earth.

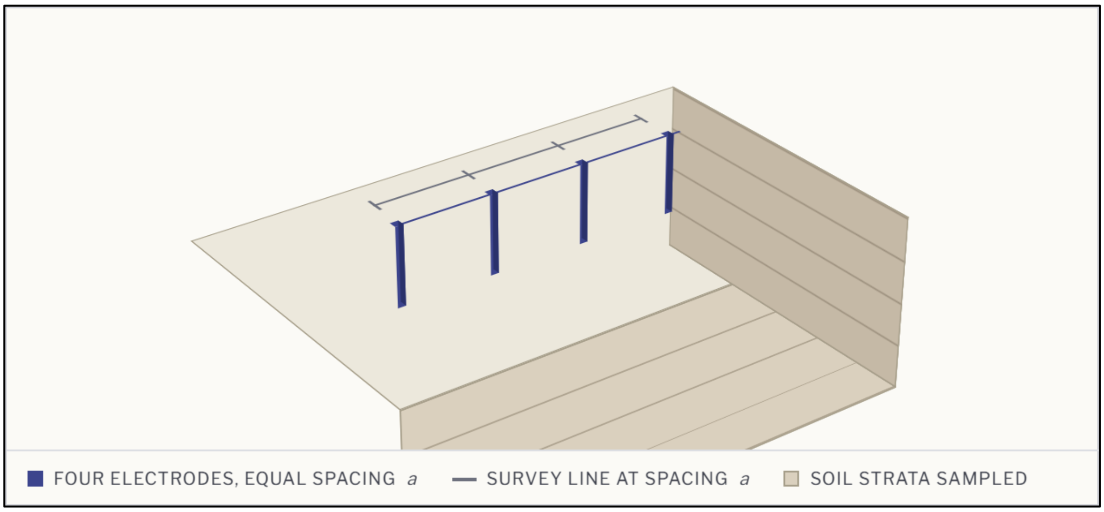

Fig 1 Four-Electrode Soil Resistivity Measurement, Shown in Plan on the Site with the Sampled Strata Exposed.

The four electrodes are driven into the survey line at equal spacing *a*. In use, current is injected across the outer pair and potential is read across the inner pair; the instrument and test leads are omitted for clarity. Apparent resistivity is derived per spacing to profile the strata.

➢ *Rooftop: The Inherited Building Earth Termination*

A rooftop PV designer has no access to a soil resistivity test, and in a retrofit no realistic prospect of obtaining one: the ground around the building is developed, and the earth termination is already installed and buried. The characterisation step therefore changes in kind rather than in detail. What is measured is the existing installation: the resistance to earth of the building earth termination, the continuity of its down-conductors, the integrity of its test links and inspection pits, and the resistance between the main earthing terminal and the roof-level metalwork the array will be bonded to.

ISSN No: - 2456-2165 https://doi.org/10.38124/ijisrt/26sep347

Two consequences follow. First, the earth resistance of a rooftop installation is largely a given, not a design variable; where it is found to exceed the value the building's own installation requires, the remedy is a matter for the building owner and must be raised as a design constraint rather than absorbed into the PV scope. Second, because the resistance cannot be reduced by the PV works, the design effort transfers to equipotential bonding: the requirement is that all metalwork within reach on the roof rises and falls together, whatever the absolute potential of the building earth during a fault or a strike. Table 3 states the substitution.

Table 3 Characterisation Inputs and what Each Determines.

Determines	Ground-mounted input	Rooftop input
Earth electrode configuration	Measured resistivity profile	Existing building earth termination, as verified
Grid spacing	Resistivity and target surface potential	Replaced by bonding-conductor routing between array rows
Number of electrodes	Resistivity and required R_g	Fixed by the building; not part of the PV scope
Conductor size	Fault current and clearing time	Fault current and clearing time; same method, lower current
Grid area	Plant layout	Roof area within the array boundary
Expected earth resistance	Calculated from the design	Measured on the existing installation before design

III. BONDING ARCHITECTURE

➢ *Ground-Mounted: The Buried Earth Grid*

The ground-mounted earth termination is a single hierarchy, not a set of independent earth pits. A buried conductor mesh spans the plant area with vertical electrodes at grid nodes, as shown in Fig. 2. Mesh spacing and electrode count follow the measured resistivity and the fault current the grid must carry; the mesh is what limits surface potential gradients between adjacent points, and closer spacing is the principal means of reducing step and touch voltage where resistivity is high. Above the mesh the hierarchy runs main earth grid, then equipment earthing, then MMS and DC earthing, with AC equipment, transformer, HT system and switchyard all referred to the same network. The design outcome is stated simply: an interconnected earth grid is an equipotential network.

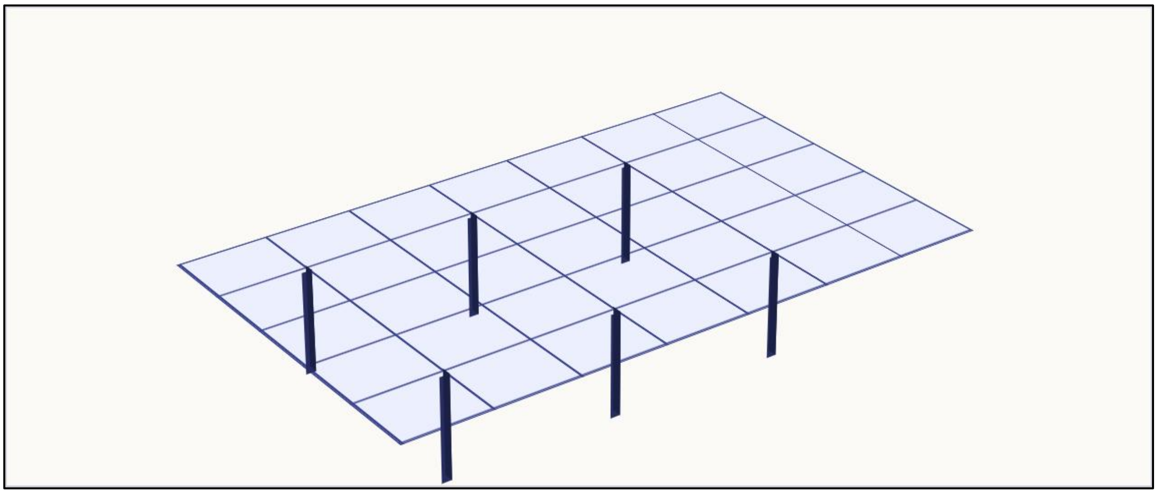

Fig 2 Ground-Mounted Earth Termination: Buried Conductor Mesh with Vertical Earth Electrodes at Grid Nodes. Mesh Spacing and Electrode Count Follow the Measured Resistivity and the Fault Current the Grid Must Carry.

➢ *Rooftop: Equipotential Bonding to the Building System*

On a rooftop the mesh is not buried; it is formed at roof level by the bonding conductors that tie the array together, and it terminates at the building's existing earth termination rather than in soil. Fig. 3 shows the arrangement. Each MMS rail run is bonded along its length so that a single lost clamp does not isolate a section, and adjacent rows are cross-bonded so that the array behaves as one plane; the effect of that group bonding on the potential rise across the panels during a strike has been measured and simulated by Mohamed *et al.* [16]. That plane is carried to the building main earthing terminal by a bonding conductor of its own, routed alongside — not through — the LPS down-conductors, and terminated at a labelled test point so that continuity can be re-verified in service without dismantling the array.

Where the array is clamped to metal roof sheeting or standing-seam cladding, the sheeting is itself a conductive plane within reach and must be bonded. Where the building structural steel or reinforcement is used as a natural component of the earthing installation, its continuity must be proven by measurement and recorded, not assumed from drawings. In both cases the accepted principle is that bonding conductors are additional to, and do not replace, the protective conductors of the electrical installation, which remain subject to the requirements of IEC 60364-7-712 [5] and, where the AS/NZS series applies, AS/NZS 3000 [9] and AS/NZS 5033 [8].

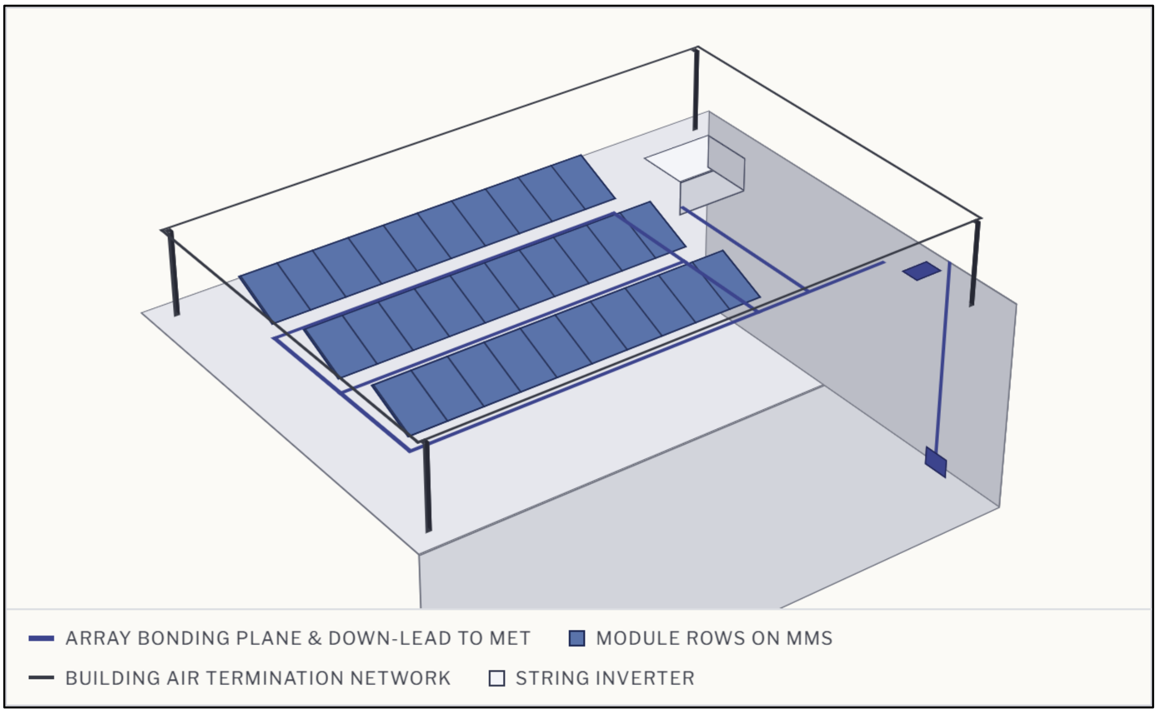

Fig 3 Rooftop Earthing Arrangement.

The array rows are bonded along each rail run and cross-bonded between rows to form one equipotential plane at roof level (accent conductors); the plane is carried down the building wall to the main earthing terminal, shown as the terminal block at the foot of the down-lead. The building air termination network and its corner rods (dark) remain the property of the host structure and are coordinated with, not replaced by, the PV works. Elements are shown schematically and not to scale.

➢ *Roof Penetrations and Cable Routing*

Every roof penetration is simultaneously a weatherproofing detail, a mechanical fixing and an earthing detail, and it is normally executed by a trade concerned with only the first two. Metallic sleeves, glands and cable trays passing through the roof deck are conductive parts that connect the roof-level plane to the interior of the building, and they are bonded on the roof side so that a surge does not find them the lowest-impedance route indoors. DC string cabling is routed to keep the loop area between positive and negative conductors small, since induced surge voltage scales with that area, and it is kept clear of LPS down-conductors by the separation distance of Section 9. Where routing inside a metallic tray or conduit is used to provide screening, the tray is bonded at both ends.

IV. EARTHING CONDUCTOR SIZING

Conductor sizing is governed by seven inputs: the maximum prospective fault current, the fault duration, the conductor material, the initial and final permissible temperatures, the short-circuit withstand requirement, the mechanical strength required of a buried or exposed conductor, and the corrosion environment. The thermal limit is expressed by the adiabatic relation of Eq. (2), in which the material constant K embodies the conductor material, its surrounding medium, and the initial and final permissible temperatures [1], [4]. The choice of final temperature is a design decision and not a property of the conductor: sizing to the melting point of copper gives a smaller conductor than sizing to the 500 °C limit tabulated for a bare protective conductor, and the lower limit is the appropriate one wherever the conductor is buried, in contact with a building surface, or expected to remain serviceable after the fault. Minimum sizes for the array and string cabling of the PV installation itself are separately specified in IEC 62548 [6] and AS/NZS 5033 [8].

$$A = \frac{I\sqrt{t}}{K} \tag{2}$$

Equation (2) returns a thermal minimum only. The selected conductor is the next standard size above that minimum once mechanical strength and corrosion allowance are applied, and it is then checked against the short-circuit withstand of the connected equipment and against any minimum size the project specification imposes on buried conductors. Table 4 works the calculation for a representative ground-mounted plant and a representative rooftop installation. The comparison makes a practical point that the equation alone conceals. On the ground-mounted main grid the thermal limit genuinely governs, and at 25 kA for 1 s it calls for a substantial conductor. Everywhere else in the table it does not: the array-frame and array-bonding conductors calculate at 2 mm^2 or less, far below the smallest size any wiring rule permits, so the selected size is set entirely by the tabulated minimum, by mechanical robustness, or — in the bonded lightning protection arrangement of Section 9 — by the minimum required of a conductor carrying partial lightning current. Applying Eq. (2) and stopping there is therefore a common way to arrive at a non-compliant design.

ISSN No: - 2456-2165 https://doi.org/10.38124/ijisrt/26sep347

Table 4 Worked conductor sizing for both installation classes. Bare copper conductor, K = 226 for an initial temperature of 30 °C and a final temperature of 500 °C, the value tabulated in IEC 60364-5-54 [4] for a bare protective conductor in non-combustible surroundings. Inputs are representative of typical projects; the arithmetic is exact.

Step	**GM main Grid**	**GM array Frame**	**Roof Main Earth**	**Roof Array Bond**
Fault current I	25 kA	1 kA	10 kA	1 kA
Fault duration t	1.0 s	0.2 s	0.1 s	0.1 s
Material constant K	226	226	226	226
Thermal minimum from Eq. (2)	110.6 mm^2	2.0 mm^2	14.0 mm^2	1.4 mm^2
Governing constraint	Thermal + corrosion	Tabulated minimum	Thermal	Tabulated / LPS minimum
Selected conductor	120 mm^2 Cu	6 mm^2 Cu	16 mm^2 Cu	6 mm^2 Cu *

➢ *Note.*

* 16 mm^2 Cu where the array bond also carries partial lightning current in the bonded arrangement of Section 9. The inputs are representative values, not measurements from a specific installation. The ground-mounted columns take a 25 kA, 1 s fault rating at a 33 kV point of interconnection — a common utility switchgear rating — and a string-level fault on the array frame. The rooftop columns take a 400 V point of connection with a 10 kA prospective fault current cleared in 0.1 s by the building's main protective device. Two of the four results are not set by Eq. (2) at all: the array-frame conductors calculate at 2.0 and 1.4 mm^2, well below the smallest size any wiring rule permits, so the tabulated minimum governs. Those tabulated minima are deliberately not reproduced here; read them from the applicable edition of AS/NZS 3000 [9] and AS/NZS 5033 [8], or the equivalent national code, since they differ between editions and jurisdictions. Where a bonding conductor also carries partial lightning current in the bonded arrangement of Section 9, the larger minimum of AS/NZS 1768 [10] or IEC 62305-3 [3] applies instead and generally governs. Substitute the site's own fault level, protection clearing time and soil or roof-environment corrosivity before using any figure here. Where a conductor also serves as a lightning protection bonding conductor, the minimum cross-section required by IEC 62305-3 applies in addition to Eq. (2) and frequently governs. One further conservatism should be noted: the ground-mounted column applies the full prospective fault current to the grid conductor, whereas in practice only a share of it returns through the earth grid, the remainder returning via overhead earth wires, cable sheaths and the neutral. IEEE Std 80 [1] treats this as a current division or split factor, and applying it reduces the calculated minimum. Table 4 omits it deliberately, since the split factor is specific to the interconnection arrangement and cannot be assumed.

V. TOUCH AND STEP VOLTAGE

During an earth fault the earth surface does not sit at one potential. Two potential differences are of interest: the *touch voltage*, between earthed equipment and a person in contact with it, and the *step voltage*, between two points one step apart. Both must be within the permissible limits derived in IEEE Std 80 [1], which are functions of body current tolerance, fault duration and the resistivity of the surface layer. Enrique and Walsh [15] analyse touch potentials specifically in solar farms and report a result worth carrying into commissioning: because the resistivity of the upper soil layers varies across a solar farm's footprint, the resistance measured on the as-built grid can come out higher than the design predicted, and the designer is then obliged to modify the grid until touch potential is back within the applicable limits. Fig. 4 shows the mechanism: surface potential falls away from the point of injection, so a person bridging two points at different potentials is exposed to the difference, not to the absolute earth potential rise.

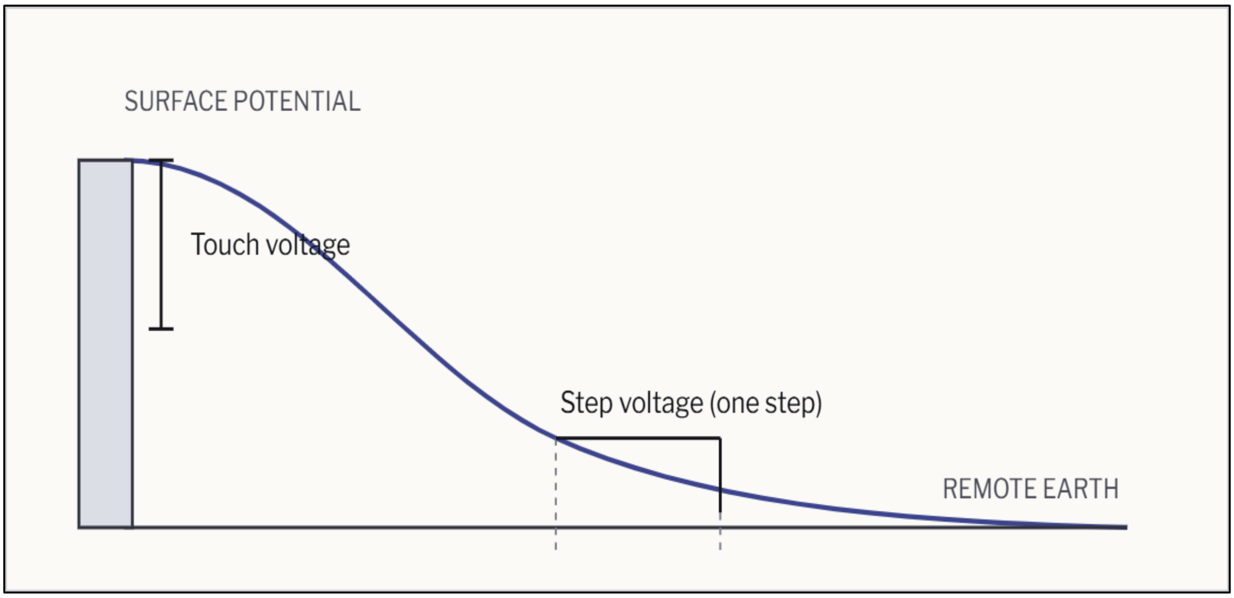

Fig 4 Surface Potential Falling Away from Earthed Equipment During a Fault.

ISSN No: - 2456-2165 https://doi.org/10.38124/ijisrt/26sep347

Touch voltage is the difference between the structure and the surface where a person stands; step voltage is the difference between two points one step apart.

The rooftop case differs in exposure geometry rather than in principle. A roof surface is not a soil surface with a potential gradient across it, so step voltage is rarely the governing quantity; what governs is touch voltage between adjacent items of metalwork on an accessible roof — array frames, handrails, walkway gratings, plant enclosures, ductwork and cladding. Where a roof is accessible for maintenance, the design objective is that any two conductive items a person can bridge are bonded together, so that the potential difference across the body is the volt drop along a bonding conductor rather than the earth potential rise of the building. Where the roof is accessible to the public, the same requirement applies with the additional expectation that verification is documented. Reduction of the surface layer resistivity, which is a standard remedy on a ground-mounted site through crushed rock, has no rooftop equivalent.

VI. LIGHTNING PROTECTION AND SURGE PROTECTIVE DEVICES

Neither installation class should proceed to lightning protection design without first performing the risk assessment of IEC 62305-2, or of AS/NZS 1768 [10] where that series applies. The assessment determines whether an LPS is required at all and, if so, the protection level to be achieved; it is the step most often skipped, and skipping it leaves the rest of the design without a stated basis. In Fiji and comparable tropical maritime locations the ground flash density and the exposure of an open site make a positive outcome likely, but the calculation still has to be recorded.

A PV installation requires both an intercepting system for direct strikes and surge protection for the transients that follow, whether the strike is direct, nearby or remote. For a ground-mounted plant the exposure is an open field of elevated steel rows: the intercepting system is a set of dedicated masts with their own down-conductors and earth paths, bonded to the main grid, and the design elements are the lightning protection system, DC SPDs, AC SPDs, the Type 1 and Type 2 classification of those SPDs, bonding of metallic structures and dedicated earth paths. External lightning protection and grounding at this scale is treated in detail by Charalambous *et al.* [12].

For a rooftop plant the intercepting system already exists and belongs to the building. Adding an array changes the roof profile and can place conductive parts inside the volume the existing air termination network was designed to protect, or leave them outside it. Two arrangements are recognised in IEC 62305-3 [3], and their relative performance has been simulated for a range of soil structures and separation distances by Damianaki *et al.* [14]. In an *isolated* arrangement the array is kept outside the LPS by maintaining the calculated separation distance *s* of Eq. (3) from air terminations and down-conductors, so that lightning current does not flash across to the PV metalwork; this preserves the building LPS as designed but constrains array layout and often costs roof area. In a *bonded* arrangement the array metalwork is deliberately connected to the LPS, accepting that part of the lightning current will flow in the PV structure and therefore requiring bonding conductors rated for that current and Type 1 SPDs at the DC and AC boundaries. The choice is a design decision to be recorded with its calculation, not a site-level improvisation, and it must be agreed with the party responsible for the building LPS.

The separation distance itself is given in IEC 62305-3 [3] by Eq. (3), where k_i depends on the class of LPS, k_c on the division of lightning current between down-conductors, k_m on the insulating material in the gap, and l is the length along the air termination and down-conductor from the point of proximity to the nearest equipotential bonding point. Two consequences are practical rather than arithmetic. Because s scales with l, a tall building drives a large separation distance at roof level, and on a roof of limited area the isolated arrangement can become geometrically impossible — which is the usual reason a bonded arrangement is adopted, and it should be recorded as such rather than presented as a preference. And because k_c falls as the number of down-conductors rises, adding down-conductors is a legitimate means of reducing the required separation where roof area is the binding constraint.

$$s = \frac{k_i k_c l}{k_m} \quad (3)$$

Values for the three coefficients are tabulated in IEC 62305-3 and are not reproduced here. The failure mode the separation distance exists to prevent — sparking between the external lightning protection system and adjacent conductive parts of the structure — has been examined directly by Panicali *et al.* [19], and the practical difficulties of applying the IEC 62305 framework to generation facilities designed to other national conventions are discussed by Brandon [20]. General treatment of bonding and grounding practice across both power and signal systems is given by Joffe and Lock [21].

SPD placement on a rooftop follows from cable length rather than from a station layout. Where the DC cable run between the array and a string inverter is short, a single SPD position at the inverter may suffice; where it is long, or where it passes near a down-conductor, an additional DC SPD is required at the array end so that the protected cable length is not exceeded. String inverters mounted at roof level shorten the DC run but place a surge-exposed enclosure in the same volume as the array, and its bonding and its AC-side SPD are part of the same coordination exercise. SPD selection, rating and application for the DC side of a PV installation are specified in IEC 61643-31 and IEC 61643-32 [7]. Requirements are summarised in Table 5.

ISSN No: - 2456-2165 https://doi.org/10.38124/ijisrt/26sep347

Table 5 Lightning Protection and SPD Requirements by Installation Class.

Element	Ground-mounted	Rooftop
Risk assessment	Required, for the plant as the structure to be protected	Required, and re-run for the building as modified by the array
Air termination	Dedicated masts sized to protect array rows and equipment	Existing building network; re-assess protected volume after the array is added
Down-conductors	Dedicated, to the main grid	Existing; PV cabling and bonding routed clear of them
LPS relationship	Single system, bonded throughout	Isolated (maintain *s*) or bonded (rate conductors for partial lightning current) — a recorded decision
Separation distance *s*	Applies between masts and array structures	Governing layout constraint in the isolated arrangement
DC SPD	At combiner and inverter DC input	At inverter DC input, plus array end where the run is long or passes near a down-conductor
AC SPD	At inverter AC output and LT board	At the point of connection to the building installation
SPD class	Type 1 where direct current share is possible; Type 2 downstream	Type 1 mandatory in the bonded arrangement; Type 2 otherwise

VII. CONNECTION TECHNOLOGY

Welded connections are used where a joint must last the life of the plant and stay at low resistance through fault current and corrosion. Exothermic welding fuses the conductors into one continuous metal path, as in Fig. 5, and is applied to earth grid joints, electrode connections, equipment bonding and grid-to-structure connections. Its properties are that it is permanent, of low resistance, and reliable over the design life.

On a rooftop the technique is generally unavailable and undesirable: a molten-metal process on a combustible or membraned roof is a fire and warranty risk, and joints must in any case remain inspectable. Rooftop practice therefore uses proprietary mechanical bonding — certified lugs, tooth-washer clamps and rail-bonding jumpers — selected for compatibility with the metals being joined, installed to a specified torque and recorded. The consequence is that rooftop joints are a maintenance item where welded joints are not, and periodic re-verification of continuity forms part of the operation and maintenance schedule.

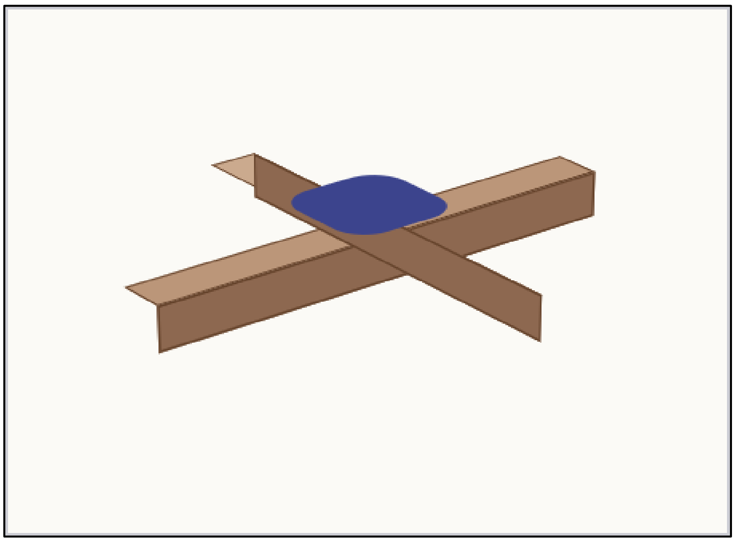

Fig **5** Exothermic Cross Joint.

The weld fuses the two conductors into one continuous metal path, giving a permanent connection whose resistance does not degrade with corrosion or thermal cycling.

VIII. PROTECTION COORDINATION

Earthing gives the fault a path; coordination decides which device clears it and how fast. The ground-mounted chain runs from the earth system through the current transformers to the relays, and from the relays to the circuit breaker and transformer, and the design intent is safe fault isolation and reliable operation: the device nearest the fault operates first, and upstream devices grade behind it with sufficient margin that a single fault does not trip the plant.

On a rooftop the chain is shorter and largely inherited. Protection is provided by the inverter's own protective functions, the AC-side overcurrent device and residual current protection where the installation requires it, all grading against the building's existing distribution board and, beyond it, the distributor's protection. Two constraints follow. Coordination must be checked against the building's existing settings rather than designed from a clean sheet, and the earth fault loop impedance from the array back to the building's protective device must be low enough for that device to

ISSN No: - 2456-2165 https://doi.org/10.38124/ijisrt/26sep347

operate within the required disconnection time — which is the practical reason a rooftop bonding conductor is sized and tested rather than merely fitted. Where the inverter is transformerless, the DC side is galvanically connected to the AC side and the functional earthing arrangement of the array must be confirmed against the inverter manufacturer's requirements before any DC conductor is earthed.

IX. TESTING AND COMMISSIONING

The design is only proven once measured. Eight checks close out the earthing and protection scope of a ground-mounted plant: earth resistance measurement, continuity testing, earth conductor inspection, bonding verification, earth grid inspection, lightning protection continuity, SPD verification and visual inspection. Table 6 sets these against their rooftop equivalents and adds the checks specific to a rooftop installation. Two rooftop items have no ground-mount counterpart and are frequently omitted: recording the pre-existing condition of the building earth termination before the PV works begin, which is the only defence against later dispute over a fault that was already present; and verifying that the separation distance or bonding decision of Section 9 was actually built as designed, which cannot be inferred from a continuity reading.

Table 6 Commissioning Verification by Installation Class.

Check	Ground-mounted	Rooftop
Earth resistance measurement	On the completed grid, against the design value	On the building earth termination, before and after the PV works
Continuity testing	Grid runs, downleads and equipment connections	Every rail run, cross-bond and downlead to the main earthing terminal
Earth conductor inspection	Size, route and joint quality before backfill	Size, route, fixing and clearance from LPS down-conductors
Bonding verification	Against the bonding schedule of Table 2	Against Table 2, including roof plant, handrails and cladding
Earth grid inspection	Trench depth, spacing and electrode installation	Roof-level bonding layout against the as-designed drawing
Lightning protection continuity	Masts, downleads and earth rings	Building LPS re-tested after the array is installed
SPD verification	Type, rating, indicator status and connection length	As left, plus confirmation of protected cable length on the DC side
Visual inspection	Full plant walkdown	Full roof walkdown including penetrations and membrane condition
Pre-existing condition record	Not applicable	Required, before any bonding is added
Separation distance or bonding decision, as built	Not applicable	Required, measured against the calculation
Torque and joint record for mechanical bonds	Where mechanical joints are used	Required for all rail and clamp bonds

X. LIMITATIONS AND FURTHER WORK

This paper is a practice-oriented synthesis, and three limitations should be stated. The inputs to Table 4 are representative rather than measured, and the tabulated minimum sizes that govern two of its four columns are cited rather than reproduced; a reader applying the method must recompute from the site's own fault level and clearing time and read the minima from the applicable edition of the governing code. The treatment of touch and step voltage is qualitative: the permissible-limit derivation of IEEE Std 80 is cited but not reproduced, no current division factor is applied, and the layered soil model that Eq. (1) is used to fit is not carried through to a grid resistance calculation. A design following this paper therefore still requires the full IEEE Std 80 analysis, ordinarily by numerical simulation, before the earth grid can be signed off. The rooftop material assumes a commercial or industrial building with an existing lightning protection system and a maintained earth termination; small residential installations, and buildings with no LPS at all, present a different and in some respects harder problem that is not addressed here.

Three lines of further work would improve on this. First, measured field data comparing the earth potential rise and touch voltage actually observed on rooftop arrays in bonded and isolated arrangements, since the choice between them is currently made on calculation and simulation alone [14]. Second, a quantitative treatment of the rooftop earth fault loop impedance across representative building types, which would let bonding conductor sizes be selected on evidence rather than on tabulated minima, and would establish how often the isolated arrangement is genuinely achievable once Eq. (3) is evaluated against real roof geometries. Third, degradation data on mechanical rooftop bonds under thermal cycling and, in coastal and island environments, salt exposure — the case for periodic re-verification is currently qualitative.

ISSN No: - 2456-2165 https://doi.org/10.38124/ijisrt/26sep347

XI. CONCLUSION

A single design sequence serves both installation classes: characterise the earth termination environment, establish the bonding architecture, size the conductors against the thermal limit, verify touch and step voltage, coordinate lightning protection and SPDs, select connection technology, coordinate protection, and verify by measurement. What differs between a ground-mounted and a rooftop installation is not the sequence but the ownership of the earth termination, and every practical difference tabulated in this paper follows from that one fact. Where the designer owns the termination, the work is resistance reduction and surface potential control. Where the designer inherits it, the work is verification, equipotential bonding and coordination with a system belonging to somebody else — less visible work, more easily omitted, and no less load-bearing for the safety case.

➢ *Acknowledgements*

The author would like to thank colleagues across the renewable energy industry for the discussions and field observations that informed this paper.

➢ *Declaration of Generative AI use*

During the preparation of this work the author used a generative AI assistant to structure the manuscript, draft and edit prose, prepare the figures, and assemble the data supplied by author. The author reviewed and edited the output, is responsible for all technical content, and takes full responsibility for the content of the publication.

Table 7 Nomenclature

A	Minimum cross-sectional area of the earthing conductor, mm^2
I	Prospective earth fault current through the conductor, A
t	Fault duration, taken as the protection clearing time, s
K	Material constant for the conductor, its insulation or surrounding medium, and the initial and final permissible temperatures, $A \cdot s^{½}/mm^2$
ρ	Apparent soil resistivity, Ω·m
a	Electrode spacing in the four-electrode resistivity test, m
R	Resistance indicated by the four-electrode test at spacing *a*, Ω
R_g	Resistance to earth of the complete earth termination system, Ω
s	Separation distance between the lightning protection system and conductive parts, m
k_i, k_c, k_m	Coefficients in the separation-distance relation, for the class of LPS, the division of lightning current between down-conductors, and the insulating material in the gap respectively
l	Length along the air termination and down-conductor from the point of proximity to the nearest equipotential bonding point, m
Abbr.	LPS lightning protection system · SPD surge protective device · MMS module mounting structure · ACDB alternating-current distribution board · PCU power conditioning unit · EPR earth potential rise · CT current transformer

REFERENCES

[1]. IEEE Std 80-2013, *IEEE Guide for Safety in AC Substation Grounding*, IEEE, New York, 2013.
[2]. IEEE Std 81-2012, *IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System*, IEEE, New York, 2012.
[3]. IEC 62305-1 to -4, *Protection against lightning*, International Electrotechnical Commission, Geneva. Part 3, *Physical damage to structures and life hazard*, governs air terminations, down-conductors, bonding and separation distance.
[4]. IEC 60364-5-54, *Low-voltage electrical installations — Part 5-54: Selection and erection of electrical equipment — Earthing arrangements and protective conductors*, IEC, Geneva.
[5]. IEC 60364-7-712, *Low-voltage electrical installations — Part 7-712: Requirements for special installations or locations — Solar photovoltaic (PV) power supply systems*, IEC, Geneva.
[6]. IEC 62548, *Photovoltaic (PV) arrays — Design requirements*, IEC, Geneva.
[7]. IEC 61643-31 and IEC 61643-32, *Low-voltage surge protective devices — SPDs for photovoltaic installations*: requirements, test methods and selection and application principles, IEC, Geneva.
[8]. AS/NZS 5033, *Installation and safety requirements for photovoltaic (PV) arrays*, Standards Australia / Standards New Zealand.
[9]. AS/NZS 3000, *Electrical installations (known as the Australian/New Zealand Wiring Rules)*, Standards Australia / Standards New Zealand.
[10]. AS/NZS 1768, *Lightning protection*, Standards Australia / Standards New Zealand.
[11]. IS 3043, *Code of Practice for Earthing*, Bureau of Indian Standards, New Delhi.
[12]. C. A. Charalambous, N. Kokkinos and N. Christofides, "External lightning protection and grounding in large-scale photovoltaic applications," *IEEE Transactions on Electromagnetic Compatibility*, vol. 56, no. 2, pp. 427–434, 2014. doi:10.1109/TEMC.2013.2280027
[13]. N. I. Ahmad, M. Z. A. Ab-Kadir, M. Izadi, N. Azis, M. A. M. Radzi, N. H. Zaini and M. S. M. Nasir, "Lightning protection on photovoltaic systems: A review on current and recommended practices," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 1611–1619, 2018. doi:10.1016/j.rser.2017.07.008

ISSN No: - 2456-2165 https://doi.org/10.38124/ijisrt/26sep347

[14]. K. Damianaki, C. A. Christodoulou, C.-C. A. Kokalis, A. Kyritsis, E. D. Ellinas, V. Vita and I. F. Gonos, "Lightning protection of photovoltaic systems: Computation of the developed potentials," *Applied Sciences*, vol. 11, no. 1, art. 337, 2021. doi:10.3390/app11010337

[15]. E. H. Enrique and J. D. Walsh, "Analysis of touch potentials in solar farms," *IEEE Transactions on Industry Applications*, vol. 51, no. 5, pp. 4291–4296, 2015. doi:10.1109/TIA.2015.2438258

[16]. F. P. Mohamed, W. H. Siew and S. Mahmud, "Effect of group grounding on the potential rise across solar PV panels during lightning strike," in *Proc. 11th Asia-Pacific International Conference on Lightning (APL)*, Hong Kong, 2019, pp. 1–5.

[17]. I. Naxakis, E. Pyrgioti, V. Perraki and E. Tselepis, "Studying the effect of the impulse voltage application on sc-Si PV modules," *Solar Energy*, vol. 144, pp. 721–728, 2017. doi:10.1016/j.solener.2017.01.072

[18]. R. L. Parker, "The inverse problem of resistivity sounding," *Geophysics*, vol. 49, no. 12, pp. 2143–2158, 1984.

[19]. A. R. Panicali, J. C. de Oliveira e Silva, C. F. Barbosa and N. V. B. Alves, "Preventing sparks between external LPS and structure conductive parts," *Electric Power Systems Research*, 2017.

[20]. G. T. Brandon, "Applicability of IEC 62305 for lightning protection of U.S. power generation facilities," in *Proc. 2020 IEEE Power & Energy Society General Meeting (PESGM)*, 2020.

[21]. E. B. Joffe and K.-S. Lock, *Grounds for Grounding: A Handbook from Circuits to Systems*, 2nd ed., Wiley–IEEE Press, 2023.