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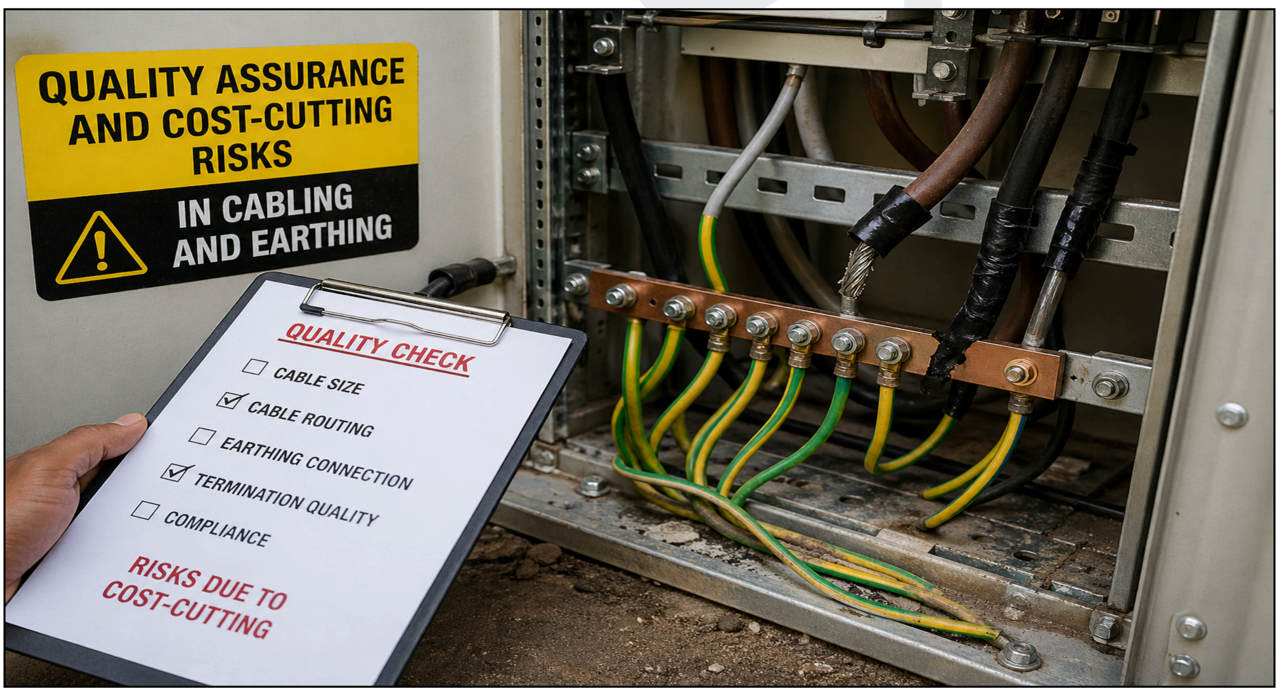
Topic 2

Topic 2

Quality Assurance and Cost-Cutting Risks in Cabling and Earthing

This section covers two major risk areas in Indian solar EPC projects: undersized DC/AC cabling and poor grounding/earthing. It includes cause-effect-mitigation analysis, lifecycle controls, worked calculation examples, typical layouts for LT rooftop and HT ground-mount plants, and Annexure A with ready-to-use examples, diagrams, mitigation measures, and checklists. Design and installation practice should align with Indian earthing practice under IS 3043 and PV-specific IEC guidance such as IEC 62548 and IEC 60364-7-712, with lightning and surge protection coordinated in line with IEC 62305 and related IEC surge protection requirements.



2.1 Undersized DC/AC Cabling

A. Cause (with design calculation context)

Typical causes in Indian solar EPC practice include cable sizing based only on current-carrying tables at 30 °C while ignoring higher ambient temperatures, grouping derating, and installation conditions such as trays, conduits, and buried runs. Voltage-drop limits are often not controlled in design, and drops of 3-5% may be informally accepted to reduce cable costs in long DC string runs and AC feeders. Further risk is introduced during procurement and execution when cable cross-section is reduced, non-solar-rated or non-UV resistant cables are used, or extra joints and poor-quality terminations are allowed.

B. Effect (linked to numbers)

Voltage drop lowers operating voltage at the inverter and directly reduces energy yield. In a 1000 V DC system, a 3% drop means 30 V lost on the line, which can translate into roughly similar order-of-magnitude annual kWh loss. Undersized cables also run hotter, which accelerates insulation ageing, increases resistance further, creates hotspots at joints and terminations, and raises the risk of fire, failure, and nuisance tripping.

C. Mitigation – technical and procedural controls

- Define design-stage voltage-drop limits by circuit type, for example DC string circuits at about 1.5-2%, LV AC feeders at about 2%, and overall plant limits as approved in the design basis report.
- Size cables using both voltage-drop and ampacity criteria, including temperature correction, grouping derating, installation method, and fault-level withstand requirements.
- Freeze minimum cable sizes, conductor material, insulation type, UV/weather resistance, and permissible joint philosophy in the DBR, BOQ, SLD, and approved cable schedule.

- Avoid unapproved value engineering that reduces conductor cross-section, increases joint count, or changes routing without recalculating losses and thermal performance.
- During installation, verify drum markings, cable tags, route length, bending radius, tray fill, gland/crimp quality, and tightening torque at all major terminations.
- During commissioning, perform insulation resistance, continuity, polarity, voltage-drop verification, and IR thermography at representative feeders and critical joints.
- During O&M, trend hot-joint observations, recurring alarms, feeder underperformance, and thermal images, and feed those findings back into future design standards.

D. Calculation examples

1) DC cable sizing example (string to inverter)

Assume:

- 1 string at 10 A
- DC system voltage ≈ 1000 V
- One-way cable length = 60 m
- Copper solar DC cable
- Design voltage-drop limit = 1.5%

Allowable voltage drop:

- 1.5% of 1000 V = 15 V

Use the DC voltage-drop relation:

$$\Delta V = 2 \times I \times L_{km} \times R_{per}$$

Rearranging:

$$R_{per} = \frac{\Delta V}{2 \times I \times L_{km}}$$

With $L_{km} = 0.06$:

$$R_{per} = \frac{15}{2\times10\times0.06} = 12.5$$

Typical copper cable resistances are approximately:

- 4 mm²: 4.6 Ω/km
- 6 mm²: 3.1 Ω/km
- 10 mm²: 1.8 Ω/km

All satisfy the voltage-drop criterion, so 4 mm² appears acceptable on voltage drop alone. However, current-carrying capacity must still be checked with derating.

Assume:

- 4 mm² cable rating = 37 A at 30 °C
- Temperature derating factor at 45 °C = 0.87
- Grouping factor for 6 bundled cables = 0.7

Then:

$$I_{effective} = 37 \times 0.87 \times 0.7 \approx 22.5$$

Design string current with 25% safety margin:

$$I_{design} = 10 \times 1.25 = 12.5$$

Since 22.5 A > 12.5 A, 4 mm² is acceptable in this specific case. If string current, grouping, or ambient temperature increases, 6 mm² or above may be required.

2) AC cable sizing example (inverter to LT panel)

Assume:

- Inverter = 250 kW
- Voltage = 415 V, 3-phase
- Power factor = 0.98
- One-way cable length = 80 m

- Allowable voltage drop = 2%

Full-load current:

$$I = \frac{250000}{1.732 \times 415 \times 0.98} \approx 355$$

Allowable voltage drop:

- 2% of 415 V ≈ 8.3 V

Use the 3-phase relation:

$$\Delta V = \sqrt{3} \times I \times L_{km} \times R_{per}$$

Rearranging:

$$R_{per} = \frac{8.3}{1.732 \times 355 \times 0.08} \approx 0.169$$

Approximate copper cable resistances:

- 150 mm²: 0.125 Ω/km
- 120 mm²: 0.153 Ω/km
- 95 mm²: 0.195 Ω/km

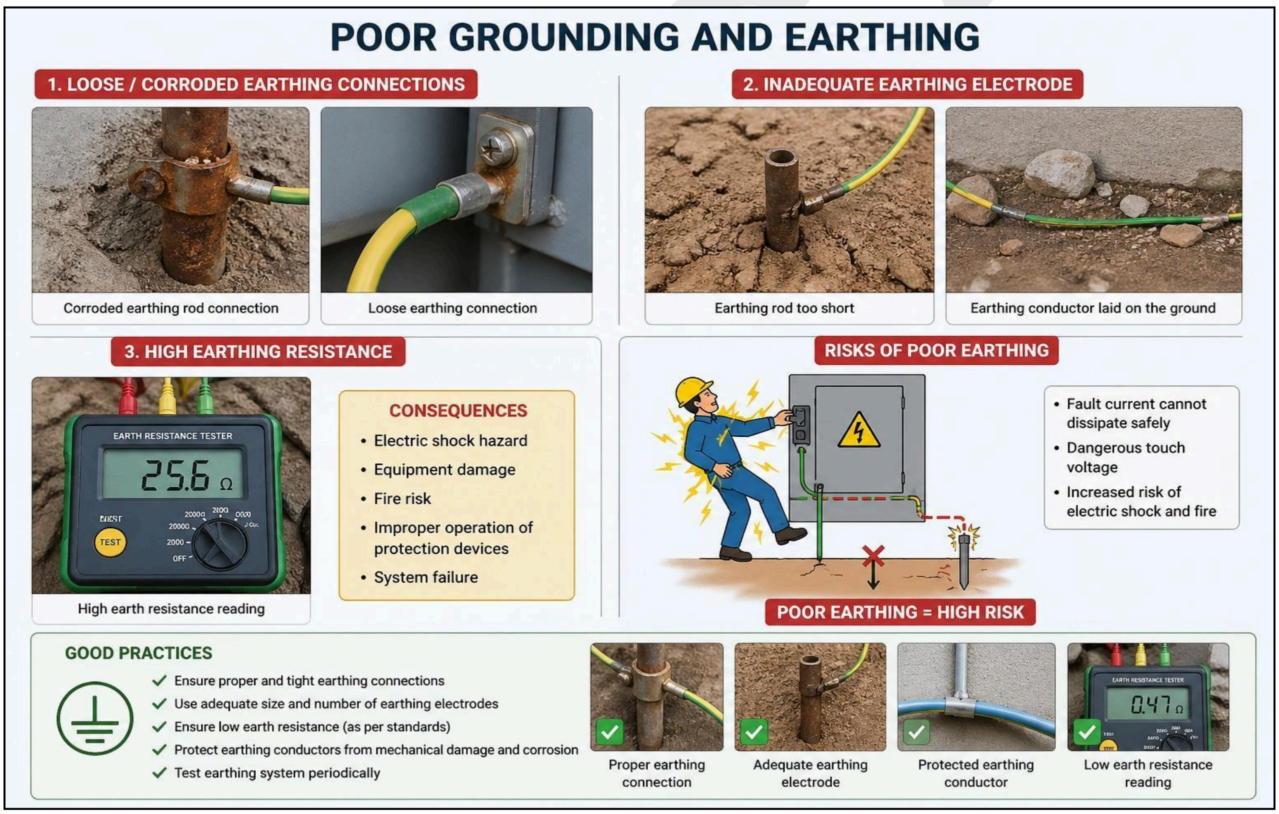
For voltage drop, 120 mm² and 150 mm² pass, while 95 mm² fails. Final selection should also consider ampacity after derating and short-circuit withstand.

E. Lifecycle Control – what to formalise

- Design:
  - Use standard calculation templates or software for DC and AC cable sizing.
  - Define standard voltage-drop limits by circuit type.
  - Ensure documentation reflects IEC 62548 requirements for PV array wiring, protection, switching, and earthing where applicable.
- Procurement:
  - Require manufacturer resistance and ampacity tables with derating factors.
  - Lock minimum cable sizes in the BOQ and DBR.

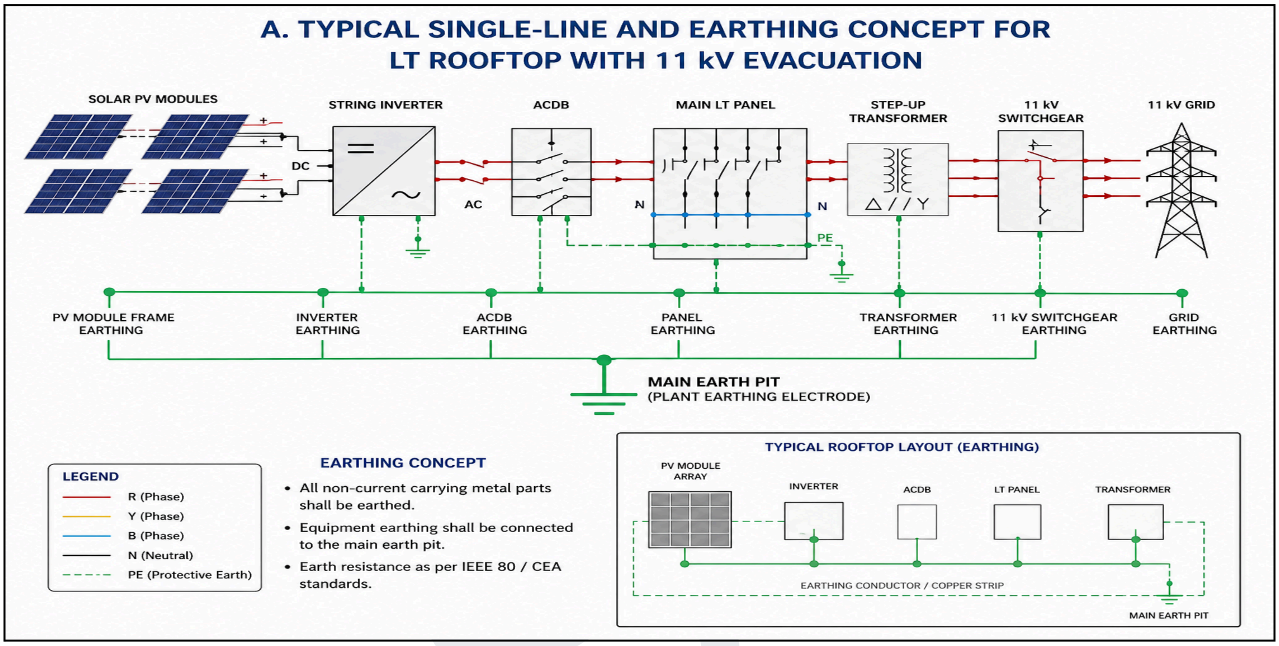
- Construction and commissioning:
    - Use checklists covering route, grouping, joint count, termination quality, and test results.
    - Record measured voltage drop and conduct IR thermography of key joints.
- O&M:
    - Maintain a log of thermal scans, torque checks, and overheating incidents, and compare them with original design assumptions.

2.2 Poor Grounding and Earthing

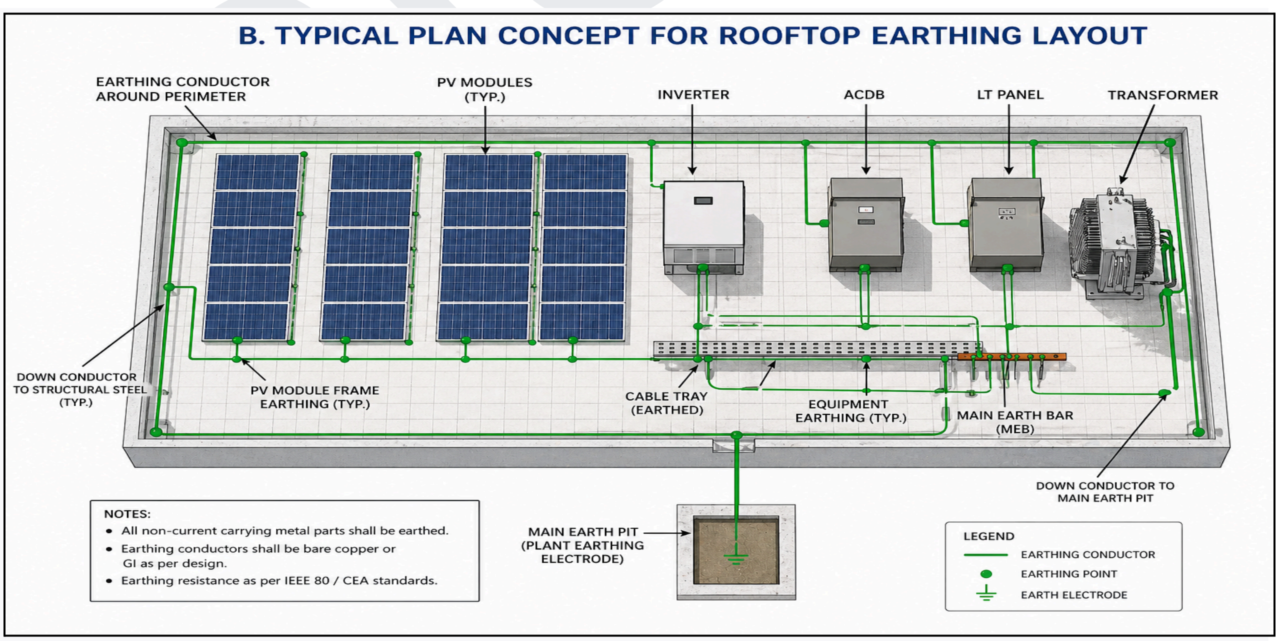


2.3 Typical diagrams for LT rooftop and HT ground-mount plants

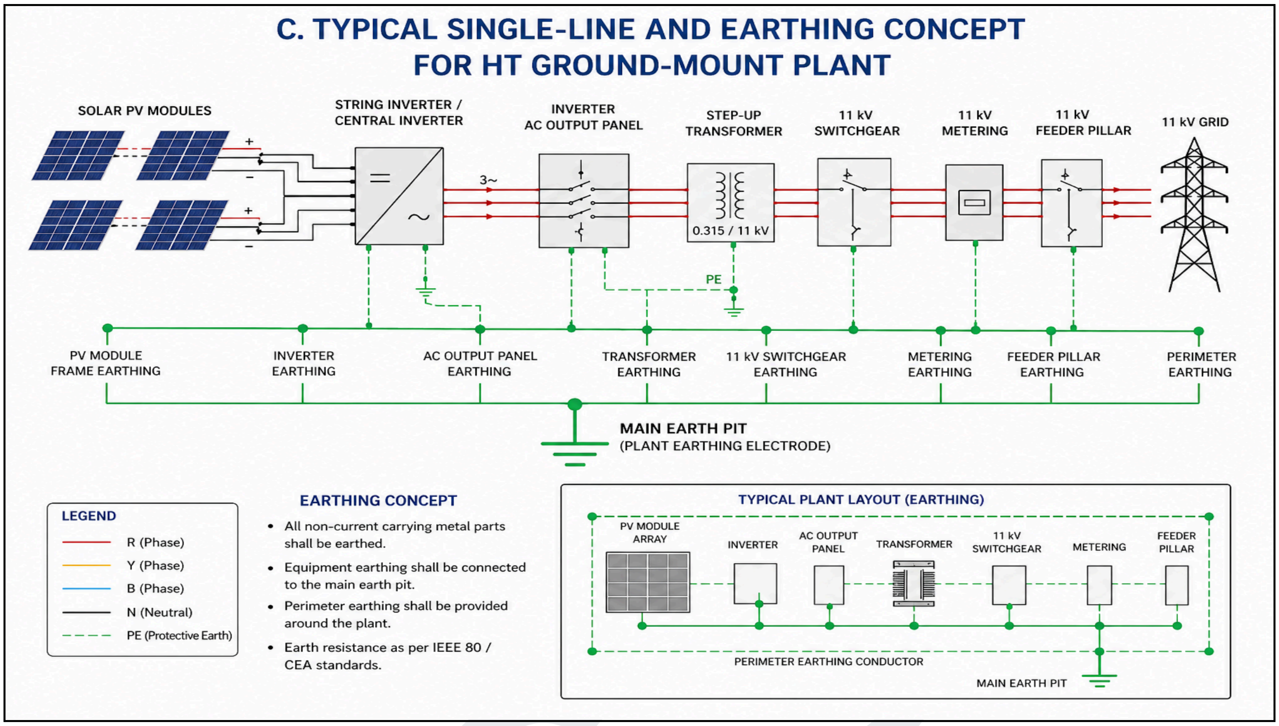
A. Typical single-line and earthing concept for LT rooftop with 11 kV evacuation



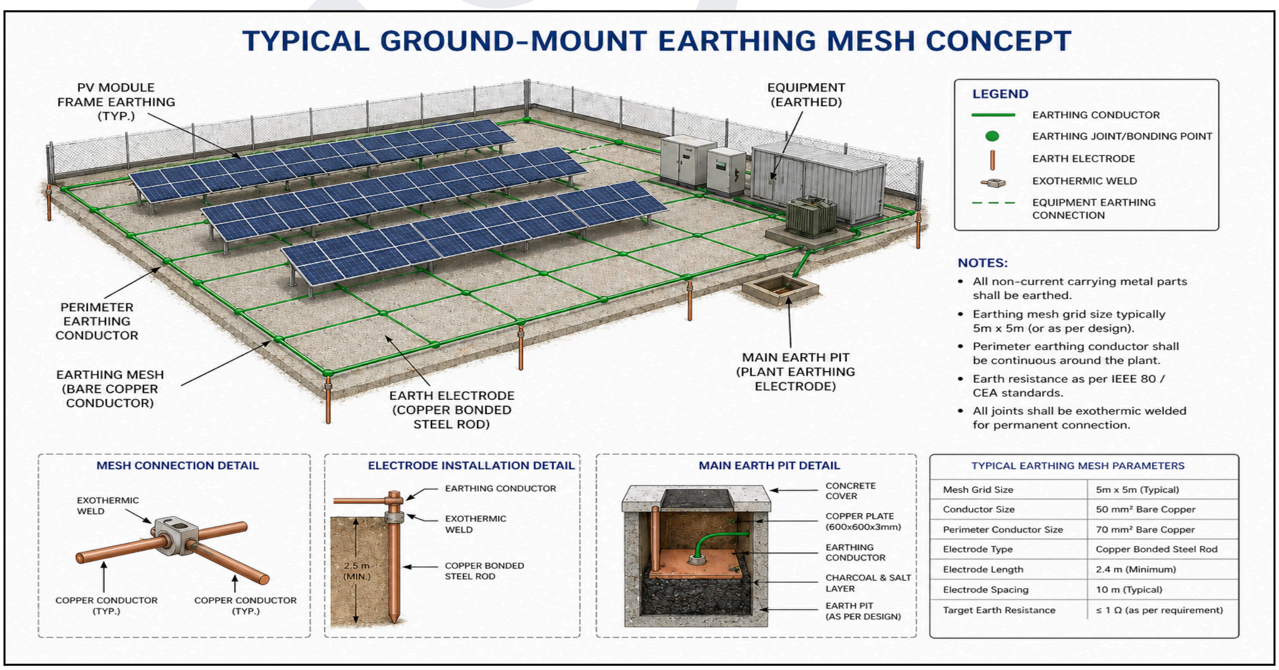
B. Typical plan concept for rooftop earthing layout



C. Typical single-line and earthing concept for HT ground-mount plant



D. Typical ground-mount earthing mesh concept

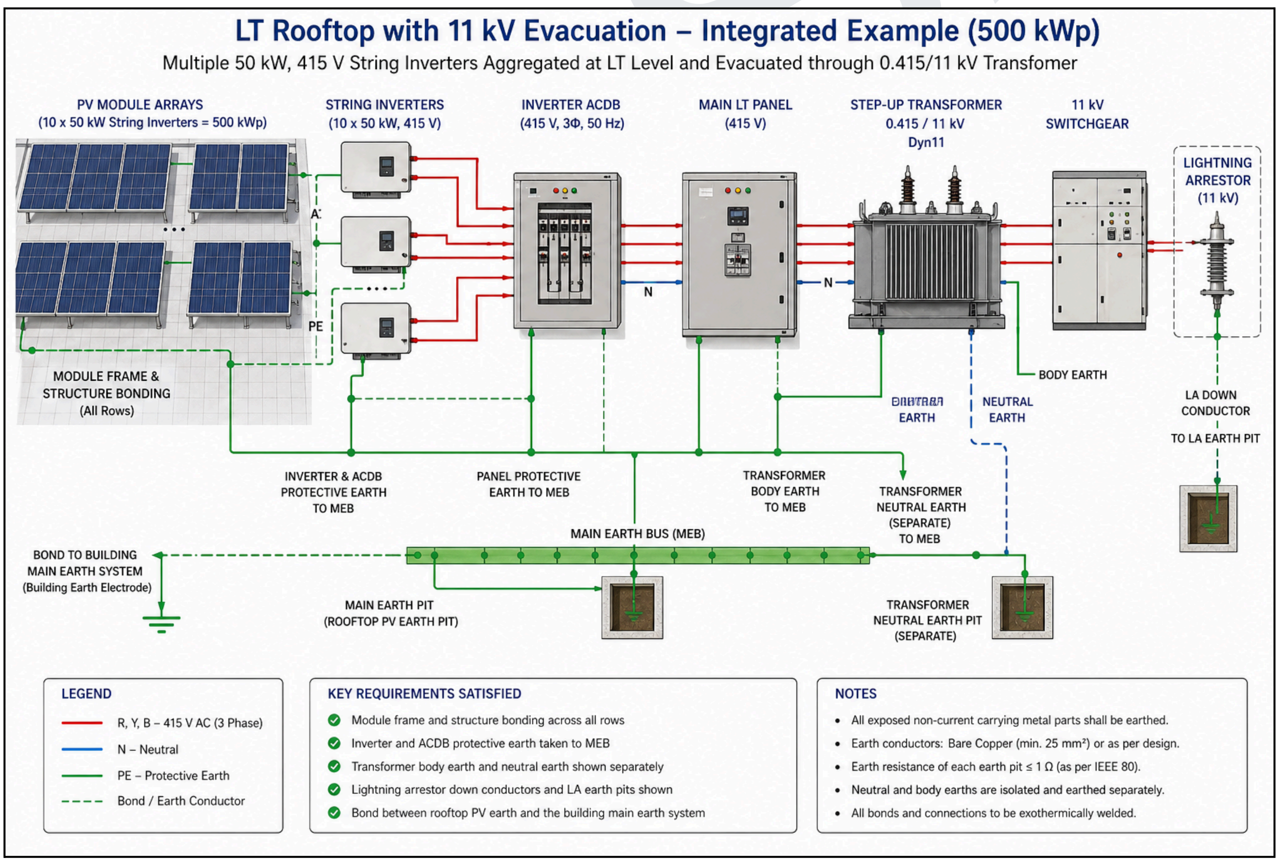


2.4 LT Rooftop with 11 kV Evacuation – Integrated Example

Assume a 500 kWp rooftop plant using multiple 50 kW, 415 V string inverters, aggregated at LT level and evacuated through a 0.415/11 kV transformer.

Key requirements:

- Module frame and structure bonding across all rows
- Inverter and ACDB protective earth taken to a main earth bus
- Transformer body earth and neutral earth shown separately
- Lightning arrestor down conductors and LA earth pits shown clearly
- Bond between rooftop PV earth and the building main earth system

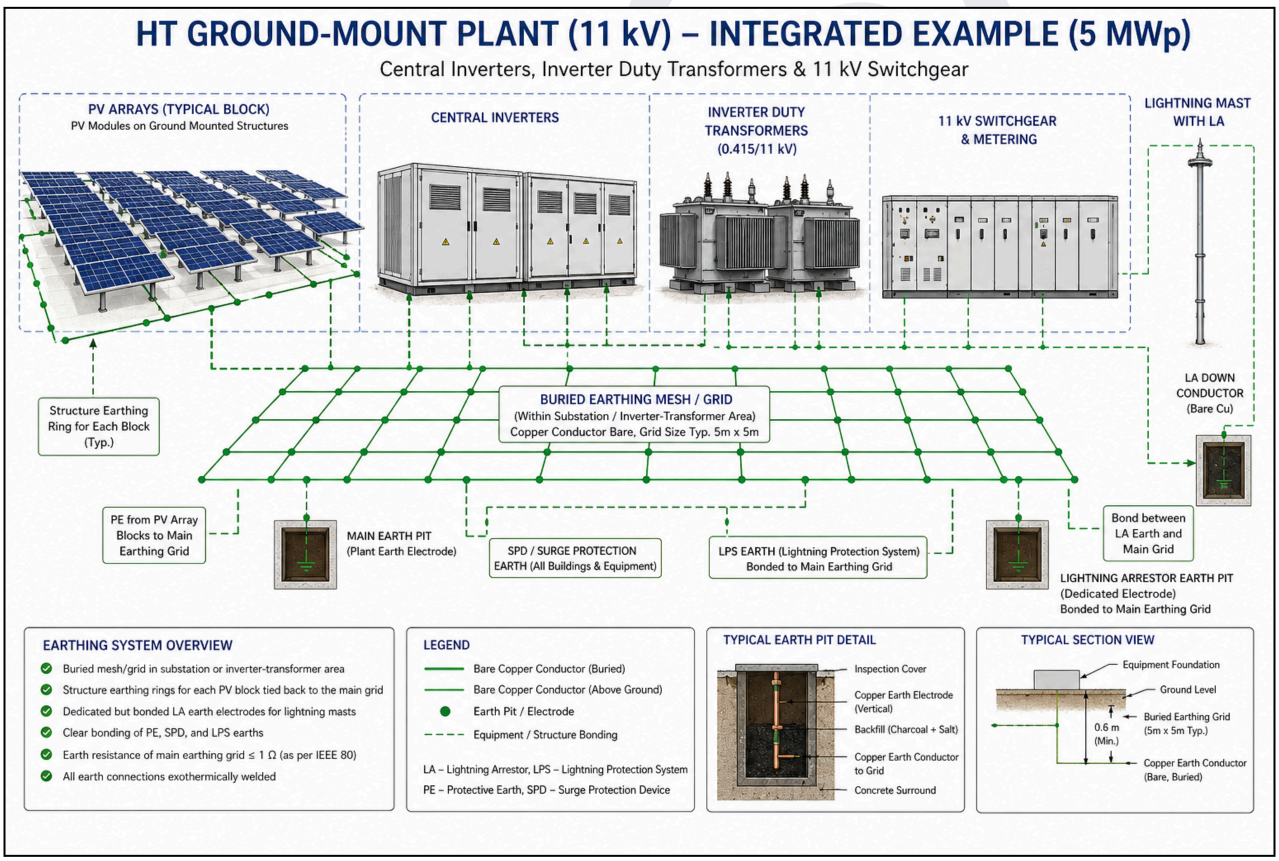


2.5 HT Ground-Mount Plant (11 kV) – Integrated Example

Assume a 5 MWp ground-mount plant with central inverters, inverter duty transformers, and 11 kV switchgear.

Key requirements:

- Buried mesh/grid in substation or inverter-transformer area
- Structure earthing rings for each PV block tied back to the main grid
- Dedicated but bonded LA earth electrodes for lightning masts
- Clear bonding of PE, SPD, and LPS earths



2.6 Common Earthing Drawing Mistakes

Rooftop

- Separate pits shown for inverter, SPD, transformer, and LA without clear bonds into one common earth system.
- Module frames and structures not explicitly shown as earthed.
- No visible bond between rooftop PV earth and building main earth bus.
- The transformer body and neutral earth merged into one symbol.
- LA down conductors and terminations not shown.

Ground-mount

- Star arrangement to isolated pits instead of a meshed buried grid.
- Structure earthing rings not tied to the main grid.
- Lightning masts shown without down-conductor routes and earth terminations.
- Earthing conductor size, material, and burial depth omitted.
- Test links and measurement points not shown.

2.7 Key standards and code practice

The following standards and code frameworks should be referenced in the policy document, design basis report, and QA/QC checklists:

- **IS 3043**: Indian Code of Practice for Earthing, used for earthing philosophy, conductor practice, electrodes, testing, and maintenance expectations in Indian projects.
- **IEC 62548**: PV array design requirements covering DC array wiring, electrical protection devices, switching, and earthing provisions.
- **IEC 60364-7-712**: Requirements for solar photovoltaic power supply systems, including installation and surge protection coordination.

- **IEC 62305**: Lightning protection standard used for external lightning protection and risk-based protection measures for buildings and ground-mounted PV plants.
- **IEC 60364-4-44 / IEC 60364-5-53 Section 534**: Surge protection measures and SPD application practice relevant to PV installations.

Annexure A: Worked Examples, Diagrams, Mitigation Measures and Earthing Checklist

This annexure provides worked examples, typical layout guidance, mitigation measures, and a review checklist that supports implementation of Section 6.1 in policy documents, training manuals, and engineering reference notes.

A.1 Cable Sizing Worked Examples

A.1.1 DC string cable (1000 V system)

- String current = 10 A
- Voltage = 1000 V
- One-way length = 60 m
- Voltage-drop limit = 1.5%

Allowable drop = 15 V.

$$R_{per} = \frac{15}{2\times10\times0.06} = 12.5$$

A 4 mm² copper cable at about 4.6 Ω/km passes voltage-drop criteria and, after applying derating, remains suitable in the example case.

A.1.2 AC feeder (250 kW, 415 V)

- Power = 250 kW
- Voltage = 415 V
- PF = 0.98
- One-way length = 80 m

- Voltage-drop limit = 2%

$I \approx 355$

$R_{per} \approx 0.169$

This allows 120 mm² or 150 mm² copper, while 95 mm² fails on voltage drop.

A.2 Earthing Worked Examples

A.2.1 Earth grid target

- Single pit = 20 Ω
- Target combined = 2 Ω

$n = \frac{20}{2} = 10$

This shows why multiple pits plus a grid are needed rather than isolated pits alone.

A.2.2 Conductor sizing concept

Select main earthing conductors from fault current and clearing time using standard tables. A training example may use 10 kA for 1 s to illustrate conductor selection, but final design must be based on actual calculated fault levels.

A.3 Typical Earthing Diagrams

A.3.1 Rooftop

Use the rooftop diagrams in Sections 6.1.3 and 6.1.4 as the reference layout for a 415 V rooftop plant with 11 kV evacuation. Ensure the final drawing shows MEB, building earth bar, LA down conductor, transformer body earth, transformer neutral earth, and structure bonding.

A.3.2 Ground-mount

Use the ground-mount diagrams in Sections 6.1.3 and 6.1.5 as the reference layout for a utility or C&I ground-mount plant with 11 kV evacuation. Ensure the final drawing shows buried mesh/grid, structure ring continuity, lightning mast earth path, and equipment body earth connections.

A.4 Mitigation Matrix

Risk	Common failure mode	Typical mitigation
Undersized DC cabling	Excessive voltage drop, heating, hot joints	Fix minimum cable size, apply derating, limit joints, verify by IR and voltage-drop test
Undersized AC feeder	Feeder losses, overheating, trips	Check ampacity and voltage drop together, standardise feeder sizes, verify short-circuit withstand
Isolated earthing pits	Potential differences, ineffective fault return path	Interconnect pits into ring or grid, define common bond point
Poor structure bonding	Shock risk, PID risk, inconsistent reference	Bond all frames and structures to the designated earth ring
Poor SPD / LA integration	Surge bypass, inverter/SCADA damage	Coordinate SPD earth, equipotential bonding, and lightning down conductors
No testing plan	Defects remain hidden until failure	Include resistance, continuity, IR scan, and periodic inspection requirements

A.5 Review Checklist

Drawing review

- Is the common earth bonding path visible?
- Are transformer body earth and neutral earth shown separately?
- Are module frame, structure, PE, SPD, and LA earth connections clearly identified?
- Is the mesh/grid shown for HT plants rather than only isolated pits?
- Are conductor size, material, and burial details noted?
- Are test points and measurement locations identified?
- Are standards references noted in general notes or design basis documents?

Construction review

- Do installed conductor sizes match drawings and BOQ?
- Are all earth bonds physically continuous and tagged?
- Are pit locations and grid routes recorded in as-built drawings?
- Are commissioning test values recorded and within target?
- Are lightning protection conductors and SPD earth bonds installed exactly as shown?

O&M review

- Are annual or pre-monsoon earth resistance tests completed?
- Are inverter earth-fault alarms trended and investigated?
- Are lightning protection conductors and accessible earth joints inspected periodically?
- Are thermal scans and torque checks linked to recurring failures?
- Is the earthing maintenance history retained for audits and future plant upgrades?