Risk Control Guide

# PHOTOVOLTAIC (SOLAR) PANELS

# Introduction and Scope

The purpose of this document is to give guidance to end-users of photovoltaic (PV) plants for roof and ground-mounted installations.

Photovoltaic is the term used to describe the direct conversion of light energy (photons) into electrical energy by means of semi-conductors. This enables the light energy received from the sun to be converted directly into a useful form of electrical power.

There are 2 recognised technologies:

- Crystalline Silicon PV Cells is the most common but requires a larger investment due to the high silicon content. Sub-types of this technology are (in decreasing order of efficiency): monocrystalline, polycrystalline and thick-film panels.
- Thin Film PV Cells is a newer development that requires only a fraction of the silicon content but does result in a lower electrical efficiency (around one half of crystalline ones).

The most common type is polycrystalline silicon.

The document is intended to give guidance on:

- Design and installation.
- Property risks.
- Operation.
- Maintenance and inspection.

The primary property risks are:

- Impact damage due to hailstorm, falling objects or malicious damage.
- Damage by extreme weather – wind, snowfall, lightning strike.
- Electrical failure and overheating leading to fire, caused by incorrect plant design, component corrosion, hot spots, damaged modules, loose/low quality connections, extreme hot weather, temperature cycling fatigue.
- Theft – especially copper cables.
- Fire resulting from electrical damage, arson, debris build up, or fire spread from the building/open field to the plant.

All items are relevant to both new and existing installations unless specified otherwise.

# System Components and Specifications

## Terminology

The main components of a PV plant are:

- PV cell: small electrical device (15cm x 15cm) that converts the energy of light into DC electricity.
- PV array: linked collection of PV modules, usually wired by MC4 connectors. They are installed on structures that can be fixed or moving (solar trackers).
- Junction box: enclosure where modules and PV arrays are interconnected.
- Inverter: power electronics equipment which converts the direct current (DC) output of a PV array into a utility frequency alternating current (AC).
- Transformer: passive equipment used to step up the AC voltage. They can be dry or oil-filled.
- UPS: uninterruptible power system including batteries mainly used to back up control systems.
- Wiring, grounding and metering equipment.

## Standards

Ensure the system is designed and installed according to internationally recognised standards and meets any relevant local standards.

# Design and Installation Considerations

There are important factors to consider during the design and installation of the PV panel system, which affect both the system performance and the control of risks. A fire on the roof is difficult to control using manual firefighting. The PV panels will often have extensive plastic content and some roofs are combustible. So, a fire spreading throughout the installation and involving the roof materials can be devastating.

The main considerations are:

Construction:

1. Ensure the roof loading capacity has been confirmed as adequate for the proposed PV installation.

2. Do not install PV systems on expanded polystyrene sandwich panel roofs.

3. For other combustible roofs (e.g. unapproved sandwich panels, felted steel/concrete deck roofs and other roofs with no full-scale fire test certification) or roofs with combustible coverings:

    - Apply a fire-resistant roof covering (these should be reviewed by RSA on a case-by-case basis) as:
        - Gypsum or calcium silicate barriers (this is ideal and should be used for combustible roofs with combustible insulation).
        - Fire protection blankets (these can be used for combustible roof membranes).

    OR

    - Ensure the panels are glass backed, UL Class A rated throughout.

Layout:

1. Provide a minimum distance of 2.5m between the PV modules on each side of any compartment/fire wall. A reduced distance of 1.2m is permitted if the potential for a fire to spread across a compartment boundary is considered low.

2. Do not install PV panels over or within 1.2m of skylights. Any skylights to be covered by PV installations should be covered with a fire resistive or non-combustible cover as agreed with RSA.

3. Do not install PV panels over roof or ground drains.

4. Provide a spacing of 1.2m every 45m in each direction and short of the roof edges for fire brigade access, access for gutter clearing and for inspection of roof drains & bolt fastenings.

5. Provide access and walkways to guttering and roof drainage to ensure inspections and debris clearance can be carried out.

6. Ensure smoke vents can open fully with the PV panels in place.

7. Provide 150mm clearance between the panels and the roof for ventilation and to reduce potential fire radiant heat feedback.

Cabling:

1. Limit the length of DC cabling as much as possible. Where DC cables are within occupiable areas, there should be appropriate mechanical protection (e.g. covered cable tray to protect firefighters and other occupants where the PV cables may still be live).

2. Provide earth cables to protect all metallic structures, components and cable trays. The earth cables should be at least 6mm$^2$ cross section. Lightning protection down-conductors must be at least 35mm$^2$.

3. Use cables that are UV and water resistant, or otherwise protected from direct sunlight to avoid UV damage. The preferred cable type is XLPE insulation, LSZH outer sheath, and steel armour.

4. Place all cables on mesh or perforated cable trays to avoid contact with any combustible roof membrane and to allow for adequate ventilation. If provided, tray covers must be at least 100mm from the tray top, otherwise they should be removed to allow heat dissipation. Install no more than 2-no cable levels in each cable tray. When pipes are used, check their deterioration and ensure they are filled within limits consistent with International or recognised local electrical codes.

5. Avoid contact with sharp points (i.e. rough concrete or metal edges) by using suitable cable containment and weather resistance cable securing methods. Provide impact protection to cable connectors and over roof walkways.

6. Use MC4 type, IP-68 (or recognised local international equivalent), UV resistant DC connectors, avoid pierced connectors. Protect connectors from water ingress and ensure they are laid horizontally.

7. Route cabling through steel conduit through roofs and walls to protect against mechanical damage and to protect combustible construction materials against electrical incidents.

Electrical Installations:

1. Inverters should be freestanding on a metal frame or mounted against a fire-resistive wall, and always more than 2m away from any combustible construction materials. Alternatively, they should be contained within a non-combustible, fully enclosed room (1 hour fire rated), fitted with automatic smoke detection (and/or sprinkler protection, where this is provided elsewhere).

   Inverters should be accessible for maintenance/isolation and not located on the roof.

   Inverter types and protection should be selected to reduce and/or avoid harmonic effects and have ground-fault detectors/interrupters (GFDI) installed.

   Install arc flash detection integrated in the inverter.

2. Transformers should be physically or spatially separated from the surrounds due to their inherent fire risk. A 2 hour fire-rated room or 10m separation distance is recommended.

3. The PV installation should have a single AC isolator, in a readily accessible location, for Fire Department use to isolate the AC of the PV installation.

4. For the UK, BS EN 7671 and the Regulatory Reform (Fire Safety) Order 2005 define exceeding 1000 V AC or 1500 V DC between conductors, or 600 V AC or 900 V DC between conductors and earth as requiring fire protection. Such measures would include isolation of the DC strings at the modules via a remote switch accessible at a ground level location (see note below), or the use of micro-invertors that switch to ‘extra low voltage’ when the AC supply is disconnected.

5. Where micro-invertors are not used or string voltages are >30V DC and where firefighters would be expected to enter the roof area to tackle a fire, install module level rapid shutdown devices, as per The National Electrical Code (NEC) Section 690.12 – Rapid Shutdown Requirements.

6. Due to previous known history of fire losses, where possible eliminate the use/number of DC isolators, noting the above points 4 & 5.

7. Install by-pass diodes (optimiser) to isolate PV panels on fault and to continue operation of PV panels in series with it. This prevents hot spots whilst maintaining efficiency of the installation.

8. Use only one type of electrical connector throughout the installation as mixing connectors is known to cause electrical arcing.

Fire Protection:

1. Install dry risers for manual firefighting on the roof. Space and arrange in line with a recognised standard.

# Natural Hazards

Ensure the system is designed to withstand the local environmental conditions including:

- Nominal and maximum wind speeds.
- Hailstorm.
- Dust-storm.
- Earthquake.
- Lightning.
- Snow loading.

Wind loading:

- Use recognised International or local codes for the wind design of the fixings.
- Note that it is likely that equipment located around the roof perimeter may require additional fixings.
- If wind resistance cannot be ensured, wind deflectors that prevent wind from penetrating underneath the panel array should be evaluated and installed to provide sufficient wind resistance.
- Typical wind resistance for modules may be 2,400Pa (uplift); however this will increase depending on the wind exposure present.

Roof loading:

- Ensure the extra loads from the system on the roof do not affect the roof load design and safety factors are not compromised.
- Ensure any additional loads caused by snow loading, snow drifting, ice and sand do not affect the roof load design and safety factors are not compromised.

Panel mounting:

- Mount the panel support racks mechanically to the roof structure, avoiding adhesive and ballasts as they are known to be unreliable during heavy winds.
- Where ballast is used, ensure they are adequately secured and braced as a single unit.
- Fix to the main roof structure provided this does not breach the insulation/waterproofing membrane, otherwise use clips which are approved by the roof manufacturer or appoint a structural engineer to complete calculations to provide fixing adequacy.
- Provide double nutting for the panel bolts where periodic re-tightening is not possible, use a stainless-steel lock nut with a nylon insert for the second nut.

Lightning:

- Provide lightning protection (air-termination rods and conductors) for any roof-mounted PV plant if required by assessment or recognised international or local codes (e.g. IEC 62305 risk assessment tool and application of part 4).
- Separate PV systems by at least 1m from lightning protection. When this is not possible (i.e. insufficient distance or metal roofs), special high-voltage insulated lightning down conductors (e.g. HVI conductors) should be used to avoid dangerous sparking. Otherwise, they should be included in the equipotential bonding using suitable lightning current and surge arrestors at the entry to the building. All metallic components without a conductive connection into the building must be connected directly to the lightning protection.
- Provide inverters, junction boxes, communication lines, connections to the electrical grid and equipotential bondings between grounding systems with lightning (surge) protection devices.

# Operational Considerations

- Ensure panel covers remain in place until the arrays are fully connected.
- Ensure remote load monitoring and alarm management is provided, including the panels and inverters. The alarms should signal to a permanently manned station or to a cascade of site personnel contact numbers who can remotely check the plant condition.

# Crime

Theft of solar panels and electrical cable is relatively common, and the risk is further increased during installation. Provide the following:

- Provide perimeter fencing to ground installed PV systems to prevent access to yard areas and PV compounds.
- Ensure points of entry to the roof are controlled and monitored. Internal roof access doors should be normally locked and external access points such as ladders should have access restricted using ladder guards that are locked in position.
- Provide remotely monitored closed circuit television (CCTV) at access points as a minimum.
    - Unless 24-hrs/day and 7-days per week security guarding is provided, the CCTV should include detection of human intrusion, such as via video analysis and a clear response plan detailing actions to be taken after an activation.
- Provide ‘tighten and break’ anti-theft screws to fasten panels to mounting frames for new installations unless 24-hrs/day and 7-days per week security guarding is provided.
- Provide forensic marking of cables for new installations unless 24-hrs/day and 7-days per week security guarding is provided.

# Emergency Planning

Ensure the Emergency Response Plan includes:

- Details of the location of the main electrical components, isolation points and roof access locations.
- A list of people that can attend rapidly in the event of a fire to assist the fire service in ensuring that the installations are disconnected.

Complete pre-planning with the local public fire service. This must ensure that adequate access, water supply and electrical shut-offs are available to allow fire-fighting and that the fire service are familiar with these features.

The presence of a PV system on a building is not always obvious from ground level. ‘PV on the roof’ signage should be clearly visible for the Fire Service upon arrival at the building. A prominent sign measuring at least 100 mm × 100 mm should be displayed at the consumer units or supplier’s cut-out.

# Protection and Detection

Assess the financial impact of a fire in important areas. Review the need for the installation of automatic gaseous fire suppression for areas such as electrical rooms and cabinets, for example rooms housing inverters and switchgear. Install where the cost of fire protection is cost effective in agreement with RSA.

Provide automatic fire detection linked to a constantly attended location in electrical rooms and cabinets, including rooms or cabinets containing inverters, transformers, batteries, power factor correction equipment and switchboards.

# Maintenance and Inspections

PV installations shall be serviced and maintained in accordance with the installer's instructions and to BS EN IEC 62446-2 or other international standards that may apply. The schedule of maintenance should follow the service contract, warranty conditions, and/or performance guarantees.

Implement documented maintenance procedures covering all aspects of the system including the panels, support structures, trackers, electronics, electrical cables and components.

Complete based on local conditions:

- Regular cleaning (e.g. dust, bird dropping, etc.). The cleaning intervals should be modified based on the results of weekly inspections. The panels should be cleaned with clean water to remove surface dirt and salt. It is essential to clean panels regularly as partial shading can lead to hot-spots that cause the panel to deteriorate leading to faults that cause fires.

Complete weekly:

- Visual inspections including; panels, electrical/grounding cables and connections, junctions boxes, diodes, switchgears, DC conditioners, transformers, UPS, DC/AC invertors and auxiliary components such as fuses and switches for signs of deterioration, dirt or overheating. Any damage must be addressed promptly.

Complete 3-monthly and before heavy wind or rain storm:

- Inspections for debris, deterioration and peeling and removal of any loose objects, leaves, debris etc. Check that gutters and drains are clear of debris. Check that safety barriers are in good condition and firmly fixed in place.
- Remove vegetation from around ground installations to reduce the fire load in dry weather conditions.

Complete (at least) annually:

- Formal inspection of the condition of all electrical/grounding cables and connections, junction boxes, diodes, switchgears, DC conditioners, transformers, UPS, DC/AC inverters, plus auxiliary components such as fuses and switches.
- Checking of the electrical and control connections for tightness, deterioration and corrosion.
- Infrared thermographic surveys (at least twice per year where combustible roof materials are present) including all electrical equipment such as inverters, wire connectors, junction boxes, switchboards, transformers, modules, etc. The inspections to be done at a time when there is a significant panel loading (i.e. clear weather and peak generation times)*. Such inspections are useful for identifying hotspots in PV arrays and slowly developing faults in MV equipment such as cable joint and termination deterioration and wear and tear on switchgear. This can include aerial drone photography of the installed PV modules, but only where access is difficult.
- Check the panel structure including condition of the support structure and tightness of fasteners.
- Oil analysis on any oil-insulated transformers including dissolved gas in oil (DGA) analysis.
- Replacement of air filters on invertors if in dusty environments.
- Check the operation of by-pass diodes by injecting current outside daylight hours and check the diodes become active.
- For larger systems consider checking harmonic measurements using an appropriate test methodology (per IEC 61000-3-12:2011 Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase) to establish harmonic pattern development and whether filters may be required.
- For larger systems consider monitoring/testing for potential induced degradation (PID) in accordance with the recommendations of IEC Technical Specification 62804-1: Photovoltaic (PV) modules – Test methods for the detection of potential induced degradation.

*IEC TS 62446-3:2017(E) defines outdoor thermographic inspection of PV modules and plants in operation and includes Balance of Systems (BOS) & Balance of Plant (BOP). This document lays down requirements for the measurement equipment, ambient conditions, inspection procedure, inspection report, personnel qualification, and a matrix for thermal abnormalities as a guideline for close-up inspections and drone inspections.

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