Risk Control Guide RCG601

PHOTOVOLTAIC (SOLAR) SYSTEMS

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
    - Thick-film modules.
- 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 cell type is polycrystalline silicon, due to its overall efficiency versus cost, with mono-facial and bi-facial the main module types with Passivated Emitter and Rear Contact (PERC) and Interdigitated Back Contact (IBC) technologies option to improve overall efficiencies. Panels can be open or enclosed within a protective frame.

For larger systems weather/module monitoring may include:

- Pyranometers, wind speed/direction, ambient/module temperature,module cleanliness
- Albedometers where bi-facial modules are installed.

The document is intended to give guidance on:

- Design and Installation, Property Risks, Operation and Maintenance and Inspection.

The primary property risks are:

- Impact damage due to hailstorm, falling objects and inadvertent 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
    - Module hot spots
    - Damaged modules, cables or connectors
    - 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 or into the building and 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 Module: A number of cells (60-100) typically connected in series and protected by a light absorbing pane of glass, connected at a junction box including bypass diodes and +/- DC connectors.
- Shading occurs where dirt/debris prevents light reaching a PV cell. This reduces the voltage produced and other cells can become 'reverse biased'. Here rather than produce power they supply power to the shaded cell, which has to be dissipated as heat and causes 'hot spots' – a known fire risk.
- Bypass diodes isolate PV modules on fault and allow continued operation of PV modules in series. Preventing hot spots but with reduced output.
- Blocking diodes ensure that the electrical current only flows out of the system where PV strings are connected in parallel. Which prevents reverse flow and heat sinking through a shaded string.
- PV String: a linked collection of PV modules, usually wired by MC4/equivalent connectors. They are installed on structures that can be fixed or moving (trackers).
- Combiner box: an enclosure where modules and PV strings are interconnected – typically at DC, but also AC.
- Inverter: Power electronics equipment typically employing Insulated Gate Bi-polar Transistors which converts the direct current (DC) output of a PV array into a utility frequency alternating current (AC). A potential high source of harmonic interference.
- Transformer: equipment used to step up the AC voltage. They can be dry(resin) or oil-filled.
- UPS: uninterruptible power supply 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.

Potential applicable internationally recognised standards are as below:

- IEC 61730 Photovoltaic (PV) module safety qualification
- Part 1: Requirements for construction / Part 2: Requirements for testing
- IEC 61215 - Terrestrial photovoltaic (PV) modules - Design qualification and type approval
- Part 1 - Test requirements / Part 2 - Test procedures
- IEC 61701 - Photovoltaic (PV) modules – Salt mist corrosion testing
- IEC 62093 - Photovoltaic system power conversion equipment. Design qualification and type approval
- IEC 62109 -Safety of power converters for use in photovoltaic power systems
- Part 1 – General requirements / Part 2 - Requirements for inverters
- IEC 61140 - Protection against electric shock - Common aspects for installation and equipment.
- IEC 62446- Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance
    - Part 1 - Grid connected systems – Documentation, commissioning tests and inspection
    - Part 2 Grid connected systems – Maintenance of PV systems
- The IET PV Code of Practice

Design and Installation Considerations

There are important factors to consider during the design and installation of a PV system. These Factors affects both the system performance and control of risks.

A fire on the roof is difficult to control using manual firefighting and there is a significant risk of internal spread occurring. The PV modules will often have extensive plastic content, and some roofs are combustible. Fire spreading throughout the installation and involving the roof materials can be devastating.

The main considerations are:

Construction:

Ensure the roof loading capacity has been confirmed as adequate for the proposed PV installation. Both for loading (including maintenance activities) and wind uplift.

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

2. 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 an approved 2-hour rated fire-resistant roof covering (to be reviewed by Intact on a case-by-case basis), **or**
- An FM approved Class 'A' roof covering, **or**
- Ensure the PV modules are UL/IEC61730 fire Class A (or equivalent UL1703 'Type' rated) throughout.

Suppliers:

1. Use tier 1 PV module and inverter suppliers
2. Use approved installers/installation schemes such as:
    - UK – MCS (Competent person to NICEIC / <50KW)
    - France - RGE QualiPV (Competent person to Qualifelec)
    - Spain – Installers to follow CTE (National technical code for buildings) regarding PV loads
    - Netherlands - SCIOS - Scope 12
    - Belgium - General Regulations for Electrical Installations, abbreviated as AREI

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 modules over or within 1.2m of skylights. Any skylights to be covered by PV installations should be replaced with a fire resistive or non-combustible panel as agreed with Intact.
3. Do not install PV modules over roof or ground drains.
4. Provide a spacing of 1.2m every 45m in each direction and along 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 modules in place.
7. Where the fixing system allows. Ensure sufficient clearance between the modules and the roof for ventilation. To reduce potential fire radiant heat feedback and debris build up.
8. Wherever possible a 150mm gap clearance is preferred. Although proprietary fastening systems often will not provide this. Additional inspections for debris removal would be recommended.

Cabling:

1. Limit the length of DC cabling and route externally as much as possible.
2. Where DC cables are within occupiable/accessible areas. There should be appropriate mechanical protection. (e.g. covered cable tray to protect firefighters and other occupants when the PV cables are live).
3. Where possible, ensure positive and negative DC cable runs are segregated.
4. Provide earth cables to protect all metallic structures, components and cable trays. The earth cables should be at least 6mm2 cross section. Lightning protection down-conductors must be at least 35mm2.
5. 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.
6. Avoid contact with sharp points (i.e. rough concrete or metal edges) by using suitable cable containment.
7. For all external cable support, utilise weather resistance cable securing methods.
8. Place all cables on mesh or perforated cable tray containment. To avoid contact with any combustible roof membrane and to allow for adequate ventilation. Cables should not be sagging or laying flat on roofs, to prevent deterioration.
9. If provided, containment covers must be at least 100mm from the tray top. Otherwise, they should be removed to allow heat dissipation (unless the risk of UV degradation is higher).
10. Ensure cables are tied within cable trays to prevent excessive movement but not tied so tightly as to cause stress.
11. Ensure cable trays/containment routes are designated as ‘No Walkway’ areas to prevent cable damage from crush/impact.
12. Provide designated and marked authorised roof access routes where multiple providers have access. To ensure only designated routes are used. Where walkways cross cable routes. Ensure there is adequate impact protection provided through additional means.
13. Use ‘MC4’ type (or recognised local international equivalent) IP-68, UV resistant DC connectors, avoid pierced connectors. To protect connectors from water ingress, ensure they are laid horizontally. Due to the risk of electrical arcing use the same manufacturers connectors throughout the installation. Do not mix different manufacturers.
14. Route cabling through steel conduit through roof and walls to protect against mechanical damage. And to protect combustible construction materials. Roof penetrations for DC cabling are not preferred.

Electrical Installations:

1. For larger systems at installation stage, 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.
2. Inverters should be ground based in an external location. Either freestanding on a metal frame or mounted against a fire-resistive wall. Always more than 2m away from any combustible construction materials.

Alternatively, where they are located internally, they should be contained within a non-combustible, fully enclosed room (minimum 1 hour fire rated) and fitted with automatic smoke detection, which is linked to an existing fire alarm. Depending upon the criticality of the room/equipment, consideration should be given to installing a gaseous suppression system.

Inverters should be accessible for maintenance/isolation and preferably not located on the roof due to the increased fire risk/reduced fire brigade access. Where inverters are located on the roof a 1.5m segregation to other equipment should be provided, with a 2m2 two-hour fire rated board underneath and behind (unless the mounting board is already 2-hour fire rated).

Inverter types and protection should be selected to reduce and/or avoid harmonic effects and have ground-fault detectors/interrupters (GFDI) installed. Where inverters have optional DC isolators, these should be used. Some inverters may have arc flash detection integrated in the inverter. These are recommended to be used.

3. Oil filled 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 but will depend upon oil capacity.
4. The PV installation should have a single AC isolator, in a readily accessible location. For fire brigade use to isolate the AC of the PV installation.
5. For the UK, BS EN 7671 and the Regulatory Reform (Fire Safety) Order 2005 define exceeding 1000V AC or 1500V DC between conductors. Or 600V AC or 900V 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, or module-level power electronic (MLPE) systems that switch to ‘extra low voltage’ when the AC supply is disconnected.

For US applications only. These systems can also be adopted where string voltages are >30V DC and firefighters would be expected to enter the roof area to tackle a fire. Further guidance can be found 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 or use integrated invertor isolators.
7. Ensure by-pass diodes and blocking diodes are installed.

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 module/frame/roof fixings. The normal code used for roof applications in UK/Europe is BSEN1991 Eurocode 1.
- Note that it is likely that equipment located around the roof perimeter will require additional fixings.
- If wind resistance cannot be met, wind deflectors that prevent wind from penetrating underneath the module 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 design and that 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 that safety factors are not compromised.
- Whilst the roof loading may be adequate. Additional loading during maintenance should be evaluated. As may not have been calculated within original designs.

Module mounting:

- Mount the module 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. Use of self-sealing fasteners accepted. Otherwise use clips which are approved by the roof manufacturer. Or appoint a structural engineer to complete calculations to provide fixing adequacy.
- Where periodic re-tightening is not possible, provide double nutting for the module securing bolts. Using a stainless-steel lock nut with a nylon insert for the second nut, or anti-theft torque screws

Lightning:

- Provide lightning protection for 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 existing/new 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 bonding between grounding systems with lightning (surge) protection devices.

Operational Considerations

- For new installations ensure module covers remain in place until the arrays are fully connected.
- Many systems offer remote continuous monitoring, which are beneficial both from a commercial perspective, but also provides prompts for cleaning, fault alerts and maintenance when installed.
- 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 modules and electrical cable is relatively common. The risk is further increased during installation. Provide the following:

- 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 24/7 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.
- Consider ‘tighten and break’ anti-theft screws to fasten modules to mounting frames for new installations and provide forensic marking of cables for new installations, unless 24/7 security guarding is provided.

Emergency Planning

Ensure an 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 supplies and electrical shutoffs are available to allow firefighting, 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 unit/fire brigade isolation switch.

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 Intact.

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.

For larger systems consider installing automatic fire detection such as linear heat detection to the PV cable trays and modules and IR and CCTV to the module roof areas, to aide early detection of any roof fires involving PV equipment.

For combustible roofs – consider installing a fire protection system (Minimax PVProtector or similar), although note the current available systems are wet protection and are only suitable for climates where freezing will not occur, or additives are included.

Where roof access for the fire brigade is readily available. Consider installing dry risers for manual firefighting on the roof. Space and arrange in line with recognised standards.

Maintenance and Inspections

PV installations should 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 guarantee requirements.

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

Cleaning:

- Regular cleaning (e.g. dust, bird guano etc.). The cleaning intervals should be based upon the results of inspections and commensurate with local conditions. The modules should be cleaned with clean water to remove surface dirt and salt. It is essential to clean modules regularly as partial shading can lead to hot spots. These cause the module to deteriorate leading to faults that cause fires. Annual cleaning is considered best practice, although continuous monitoring systems may support increased periodicities.

For ground-based systems or where roof access is permanently provided to roof arrays:

Complete quarterly and for roof mounted systems following any works / activities undertaken within the vicinity of the PV installation, or following heavy wind/rain:

- Visual inspections including modules, electrical/grounding cables and connections, junction boxes, invertors, fuses and isolators for signs of deterioration, dirt or overheating. Any damage must be addressed promptly.
- Visual inspections should ensure cables are not trapped beneath PV modules or cable tray lids. Cable tray lids are secured and there is no evidence of damage.
- Inspections for debris, deterioration and removal of any loose objects, leaves, debris. 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.

For larger installations these inspections may represent a percentage of the actual installed, although the entire systems should be checked at least annually.

Also, 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*, unless the invertors have this functionality already built-in, or a dedicated PID monitoring system is installed.

*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.

Complete (at least) annually:

- Visual inspection of the condition of all PV modules, electrical/grounding cables and connections, junction boxes, switchgear, DC/AC invertors and auxiliary components such as fuses and isolators, for signs of deterioration, dirt, corrosion or overheating. Any damage to be addressed promptly.
- Checking of the electrical connections for tightness, deterioration and corrosion.
- Infrared thermographic surveys, including all electrical equipment such as PV modules, inverters, cables, connectors, junction boxes, switchboards, transformers, etc. The inspections to be done at a time when there is a significant module loading (i.e. clear weather and peak generation times). Such inspections are useful for identifying hotspots in PV arrays and slowly developing faults in electrical equipment such as cable joint and termination deterioration, and wear and tear on switchgear. This may include aerial drone photography of the installed PV modules.
- Check the condition of the support structure and complete 5-10% tightness checking of the frame/PV module fasteners.
- Check//replacement/cleaning of inverter air filters if installed.
- Remove debris and any loose objects, leaves, etc under or on PV modules and check/ensure all gutters and drains are clear.
- Oil analysis on any oil-insulated transformers including dissolved gas in oil (DGA) analysis.

Complete (at least) every 5 years:

- A formal electrical inspection and testing on the condition of the PV electrical system in accordance with BS7671 (EICR) through a NICEIC or equivalent approved contractor. Such testing to include PV strings, invertors, switchgear, fuses/protective devices and earthing.

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