XL Risk Consulting

Property Risk Consulting Guidelines

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PHOTOVOLTAIC SYSTEMS

INTRODUCTION

Electricity can be generated by many means: coal-, gas-, oil-burning boilers, wind, hydro, and photovoltaic (PV). From a property hazard each has their own issues.

The photovoltaic systems for buildings were first seen in the 1970s. These systems were installed after the building was built. In the 1990s systems were constructed to be part of the building, roof covering and exterior wall panels. Later the systems were constructed to replace the window and skylight glazing material.

The PV system creates DC current and converts it to AC current to be used in a building. A typical PV system comprises the following components: PV modules that produce DC power, interconnecting cables, combiner boxes, inverters that convert DC to AC, disconnecting devices, and the electric meter. The excess power produced can be either sold back to the power grid or stored in batteries.

There are three types of photovoltaic installations, building applied (BAPV); building integrated (BIPV); and ground mounted units. The BAPV or roof mounted arrays can be held in place by either securing the array to the roof structure or have the array held down with ballast material. The building integrated can be the roof covering or a film attached to the side of a building. The ground mounted units are typically found on PV farms, producing power for the grid.

The majority of the PV installations on the roof installed as BAPV systems. Newly constructed buildings would have BIPV systems. While not widely used, there are some building wall BIPV systems.

The two main types of panels are rigid and flexible. Most widespread are rigid modules but the use of flexible modules is increasing.

There is still widespread misunderstanding that these systems only produce low voltages and current. Depending on the local legal requirements, these systems can produce up to 1800 V DC. With an increasing number of modules in series, the voltage (V) increases. Increasing the number of parallel modules increases the current (A).

The number of PV systems installed worldwide has grown exponentially in recent years. Extensive positive and negative experience has been gained over the last couple of years and is ongoing. A large number of new standards and guidelines have been introduced and are updated on a regular basis.

This section will address the background and protection issues of the roof mounted photovoltaic arrays.

HAZARDS

There are many hazards associated with the installation of photovoltaic systems. They include:

- Building construction
- Electrical
- Fire
- Roof access

There have been numerous incidents where the PV installation has caused damage to buildings based on some and even all of the above notes hazards.

Building Construction

The installation of a PV system on the roof can cause many issues including:

- Overloading the roof
- Creating a fire hazard to the roof
- Cutting the roof cover
- Problems when re-roofing
- Hail damage
- Earthquake damage

The overloading of the roof could be caused by too much ballasting material used to hold the panels from moving. It could be the roof was not designed for the additional weight of the panels. It could come from the effect the panels have from the wind.

The roof covering is tested using a fire brand of wood, some of the older panels have a plastic on the bottom side of the panels that can catch on fire and expose the roof covering and roof insulation. There have been electrical shorts in systems that have caused the roofing material to ignite.

Tests have shown that ballasted systems, if not properly installed, can slid across the roof covering material and cut holes in the material. This allows water to enter the roofing system and start to deteriorate the roof insulation and decking.

A typical roofing system could last 20 years. If the system is installed on an existing roof system, re-roofing would require the PV system to be removed from its position and extend the time to re-roof and increase the cost of re-roofing.

Hail can crack the face of the panels, causing shorts and fire.

Arrays not properly secured can come loose during an earthquake, creating a short circuit and fire. They can also damage the roof covering, and depending on the location on the roof or if the roof is sloped, slid off the roof and cause additional damage.

Electrical

Fires have been started when the array was not properly protected against ground fault. Fires have also occurred because the conduit and junction boxes were not properly secured and due to expansion/contraction caused by the temperature change, or the panels shift due to wind, the end of the conduit pulls away and starts cutting the insulation on the wires, creating a short and fire.

The PV panel can produce power even under very low light conditions. This makes isolating the power created by the panel into the DC system very hard.

Even when the PV system did not start the fire, if damaged by the fire, it could energize the roof deck material, especially if the roof system is a metal roof system. This makes firefighting operations harder.

Fire

Fire is a major concern with PV systems. Since they are installed on the roof, surveillance and detection of a fire is left to observation. There have been many fire on roofs were passer-by have contact the fire department and not the facility. Fighting a fire on the roof with the arrays on it is usually conducted with ladder trucks and master hose streams. Typically the arrays take up most of the roof area, along with the conduit, junction and collector boxes installed just above the roof cover, firefighters could have a hard time fighting the fire without getting hurt.

A fire starting in a panel can create a fire more intense than the burning brand used to test the roof covering material when it obtained the Class A rating.

Roof Access

Most arrays take up a majority of the roof. This make conducting a roof covering and roof drainage system inspection difficult and time consuming. Care must also be taken when installing the panels that vent lines are not blocked.

POSITION

General

Use modules, components, and other parts of the installation that have been tested for quality, performance, and electrical safety to an internationally recognized standard by an independent, recognized testing laboratory such as UL or FM. The International Electrotechnical Commission (IEC) publishes standards that are used in many countries. Most of these standards are also published as EN standards.

Follow proper working procedures relating to: safe electrical maintenance, lock out / tag out, working at height and roof access, permit to work, and control of contractors.

Use people that are experienced in the installation of these types of systems for the planning and installation of the system.

Use certified planners and installers in countries that have such schemes.

Responding emergency services should be familiar with existing installations so that they can adapt their intervention plans accordingly. For new installations, they should already be involved in the planning phase so that possible necessary changes in layout to facilitate intervention can be made before actual installation.

Building Construction

Do not install PV systems on combustible roofs.

Use listed panels with a Class A rating that have been tested to ASTM E108, UL 1703, or equivalent.

Prior to installing the panels on a roof system, consider replacing the roof system since the installation of the PV array will inhibit the replacement in the future.

Do not use panels that contain plastics, unless the panels have been tested and listed for fire. If the plastic is on the bottom side of the panel, it should be tested to see that it will not expose the roof covering.

Do not install panels over roof assemblies that contain foam plastic insulation (polyethylene, polystyrene, polyisocyanurate) below the roof covering system.

Install a non-combustible material such as gypsum board, fiberglass or mineral wool insulation between the insulation and roof cover.

Do not install panels within 50 ft (15 m) of fire walls.

Use panels and securing techniques designed for wind speeds and surface roughness exposures in accordance with local building codes or wind code for the country,[1] or ASCE 7.

When possible, mechanically fasten the arrays to the roof system. For fully adhered and ballasted roof system, using concrete paver blocks to secure the array is acceptable. Caution must be observed as not to overload the roof system with the additional ballast material.

Install ballasted rigid systems on roofs with a roof slope of less than 2.4 degrees only. Remove all ballast material on the roof covering beneath the panel supports.

Do not install systems on roof that have large stone or pea gravel ballast and that are subject to high winds.

Arrange the PV panel as not to have any adverse effect on the roof draining systems.

In areas prone to earthquakes, secure PV panels to the roof deck or framing. Ballasted systems should not be used.

Electrical

Panels

Use panels that have been tested to either:

- IEC 61215/EN 61215 (rigid (crystalline) modules)
- IEC 61646/ EN 61646 (thin-film modules)
- IEC/EN 61730
- UL 1703.

Panels that will be susceptible to specific environments require additional testing. Two additional tests are:

- IEC 61701 – salt mist corrosion testing (durability for marine environments)
- IEC 62716 – ammonia corrosion testing (durability for farm or other conditions with ammonia)

A CE self-marking of the modules/panels to the above IEC/EN standards is not sufficient.

Provide by-pass diodes that are changeable on each PV panel to prevent module overheating in the event of partial shading of a PV generator.

Cabling

In Europe use the TÜV specification 2Pfg 1169/08.2007 or German DKE/VDE AK 411.2.3. For countries using NFPA 70 (NEC) refer to article 690-31 which specifies the use of USE-2 wire (TYLZ – UL 854) or PV wire (ZKLA – UL 4703).

Install cables in noncombustible cable trays/ trunking or metal conduit offset of the roof system. Cables should not be directly laid on the roof. Run cabling as much as possible on the outside of building.

Never run cabling over fire walls. Keep cables away from plastic illumination bands or skylights. If they have to be near the bands or skylights install them 6 ft (2 m) away and in non-combustible cable trays, trunking or use SWA steel wire armored cables.

Special cables or protection might be required where exposed to possible attack by rodents.

Cable Connectors

Use cable connectors that have been tested to EN 50521 (2013) or equivalent international recognized standard for UV and temperature resistance. Protected connectors against moisture ingress and have a low plug in and high pull out force arrangement.

Junction Boxes

Use junction boxes that have been tested and listed to EN 50548, IEC 62790, UL 1741, or UL 3730. They should be protected against moisture ingress and condensation formation caused by temperature changes. They should preferably not be exposed to direct sunlight and have UV resistance and be flame retardant.

Inverters

Use inverters tested and listed to EN/IEC 62109-1, EN/IEC 62109-2, UL 1741, or ANSI/UL 62109-1.

Install them in a centralized, non-combustible, cut-off location or room. Provide a fire detection system in that location. In large inverter rooms, provide a fixed fire protection system.

Roof Access

Provide roof access in accordance with NFPA 1.

Arrange the arrays so the maximum size does not exceed 150 ft (45 m) in length in either axis. Smaller if required so by local requirements.

Provide a minimum 4 ft (1.2 m) wide aisle between the arrays. Larger aisle may be required when the fire department intends to use vertical smoke ventilation techniques by cutting holes in the roofs or for large installations where the fire department would deploy hoses on the roof.

Provide a minimum 4 ft (1.2 m) wide aisle to skylights, light bands, and roof hatches.

Install the arrays at least 4 ft (1.2 m) from the edges of the roof for buildings with length or width of less than 250 ft (75 m) and 6 ft (1.8 m) for over 250 ft (75 m) in length or width. If local requirements require more space, install the arrays per those requirements.

Commissioning

Perform commissioning testing and inspecting and documentation of the entire system in accordance with EN 62446 or other applicable standard.

Maintenance

Perform an infrared thermograph survey of the electrical components on an annual basis.

Inspect wiring connections and terminations for corrosion and tightness on an annual basis. Replace or repair parts as needed.

Test inverters on an annual basis per manufacturer's instructions.

Perform a PV array insulation resistance test very three years. The resistance measured with the test voltage should not be less than the one specified in EN/IEC 62446

Annual inspect the mechanical connections between panels and supports, concrete paver blocks if used, and sealing of roof penetrations as applicable for the installation. Tighten connections and repair/replace parts as needed.

Cleaning

If the array is in a location which naturally collects debris such as: leaves, bird droppings, films from airborne pollution, animal nests, etc. clean the array often. Manufactures' instructions should be followed.

DISCUSSION

General

While not covered in this guideline, ground mounted installations should not be installed in areas that are subject to flood. In areas subject to wildfires, installations should be installed at adequate distance from forests or other areas with high vegetation density. There should be no bushes or high grass inside or underneath the ground mounted panel that could contribute to fire spread. Preferably gravel or other non-combustible base should be used.

Firefighter Safety

When the fire department arrives at a fire scene, the electrical supply to the building is disconnected and there is no longer a hazard of electrical shock. This is different with PV systems; the panels will produce electricity as long as there is light. This can be over 1000 V. In the majority of existing and many new installations, there is no option of isolation the power to the inverters, which will only shutdown the AC side. This means that panels and wiring up to the inverter will be energized (“hot”) with DC current. If wiring or panels get damaged, there is the potential of electrical shock.

Other potential issues for firefighters can include: no longer able to cut holes in the roof to enter or to use them as smoke and heat vents, possibility of tripping over the conduits, the panels failing and energizing the metal roof, and panels coming loose from the roof and falling down. The use of outside hoses by firefighters to fight a roof fire might be hampered by the presence of PV panels on the roof.

In a number of countries, local fire departments and brigades may refuse to fight fires on roofs equipped with PV panels because of the fear of electrical shock. There is certainly justification to this fear. However, installations only present a shock hazard if a panel or energized cable gets damaged.

Even with damaged panels firefighting with spray nozzles is possible as long as recommend distances are maintained. The hazard is not different to any other life electrical hazard for which the fire service gets training on how to handle it.

A number of solutions have been proposed in the past to try to reduce the electrical hazards from panels and cables in case of emergency. These range from foams, to black ink, or covering the panels with tarpaulins. Some of these might work for small domestic systems but are not suited for larger industrial installations.

The second type of solutions that have emerged since 2010 are based on the principle of reducing the voltage to a level that is no longer considered a hazard (80-100V). Many of the proposed solutions have little track record, have again disappeared from the market, or are only suitable for small domestic systems.

A suitable system should:

- Be fail safe
- Have double redundancy
- Go to safe position also when one component fails
- Go to a safe position when a control or signal cable gets damaged
- Have possibility to test the system
- Provide personal safety for intervention teams and fire fighters

Building Construction

An analysis should be made to verify that the structural integrity of the building will not be affected by the additional loads introduced by the PV panels and related components.

Make sure that not only the roof structures, but also the PV panels, frames, and supports are adequate for the expected snow, ice and wind loads, in accordance with recognized standards.

Wind

Testing conducted at the Insurance Institute for Building and Home Safety (IBHS) has shown some ballasted arrays, even though secured with the manufacture’s recommended ballast weight, have slid and lifted up during a wind tests at wind speeds below the design speed. This sliding caused cuts in the roof covering and the uplifting of the panels could cause the conduit connection to fail and potentially start a fire.

Lightning

Based on current scientific knowledge, a PV installation does not increase the probability of a lightning strike on a building. The PV installation should be incorporated into an existing direct or indirect lightning protection system. Make also sure that PV components and cables are adequately separated from lightning protection system components and do not interfere with them.

Hail

Hail impact on rigid PV panels is tested as part of the overall tests of the PV modules. The tests vary between the various main standards being used IEC 61215, EN 61215, UL 1703, or ANSI/FM 4478.

Tests are either done with steel or ice balls. Important parameters are the steel or ice ball diameter and test velocity. The majority of the panels sold in Europe, use a standard 1 in. (25 mm) diameter ice ball and test velocity of 51 mph (23 m/s). The size used will be mentioned in the test certificate delivered with the PV module.

FM Global uses the “average number of hail days per year” to determine the hazard zone. A “hail day” is defined as “a day where minimum ¾ in. (19 mm) diameter hail occurred within 25 mile (40 km) of a location”. Internationally this is also called “large hail” in a number of regions.

The following 2 zones are being used:

- Moderate hazard: less than 3 hail days on average per year. FM Class 2 – 1 ½ in. (38 mm) ice balls at 60 mph (27 m/s).
- Sever hazard: more than 3 hail days on average per year. FM Class 3 – 1 ¾ in. (45 mm) ice balls or Class 4 – 2 in. (50 mm) at 72 mph (32 m/s) ice balls.

Presently very few FM listed panels are available on the market.

UL 1703 listed panels are tested with steel balls which have an equivalent impact rating of approx. 1 ½ in. (38 mm) ice balls.

If the photovoltaic system will be installed in an area that has more than a low hail hazard then look for panels that have been tested larger than 1 in. (25 mm) ice balls.

Fire

In the USA, roof coverings are tested for external fire exposure to ASTM E108 or ANSI/UL 790. There are 3 types of tests which give a final roof cover rating of Class A, B, or C. Two parts of the tests, spread of flame and burning brand, are also used for PV modules in UL 1703. Many roof types that are classified as non-combustible will have certain components that will contribute to fire under certain conditions. These tests were developed to allow the heat from the fire to escape freely. When a PV panel is installed over the covering, neat from a fire cannot freely escape and the energy will re-radiate back to the roofing system, causing the fire to spread. With a non-combustible layer between the roof covering and the roof insulation, the spread of fire is minimized.

Traditionally roof systems and PV modules were tested completely independently. Between 2009 and 2013 several tests were conducted with standoff panels on roofs to see if these have an influence on the external fire rating of the underlying roof. Parameters that influence the behavior are the roof slope, the panel slope in relation to roof slope, distance between roof and panel, and the setback of the panel versus roof edge.

This led to a revision of UL 1703 in 2013 which came effective January 1, 2015. This includes now a complete new fire classification test which tests the PV module, mounting system and underlying roof as a complete system. At present there few to none Class A rated systems available on the market.

Outside the USA the situation is more complicated. IEC 61730 refers in test MST 23 to ANSI/UL 790. So if a test is done then one will get a rating of Class A, B, or C. Unfortunately, there are basically no Class A or B panels on the market available. The European counterpart, EN 61730 has no specific requirement on fire testing of the PV panel.

However, testing might be required to fulfill local building regulations. This can be:

- EN 13501-1 – Fire Classification of Construction Products: Ratings can range from A (non-combustible) to F. The majority of the panels currently on the market will only get E rating. Try to obtain better than Class E, if available.
- EN 13501-5 – External Fire Exposure to Roofs and ENV 1187: Classification should be Broof (tx).

In Europe there is no testing standard that evaluates offset panels together with the underlying roof system.

The potential of debris accumulation at and underneath PV panels will largely depend on the angle to the roof, distance between the panels and the roof, and physical location of the installation. The removal of debris should be part of the preventive maintenance program. In certain type of installations, it might be beneficial to install a wire screen to prevent accumulation underneath the panels in the first place.

Panels should be installed in such a way that they do not conflict with the operation and required maintenance of smoke and heat vents. Maintain minimum 4 ft (1.2 m) separation from roof vents, skylights, roof hatches, etc.

Electrical

Cabling

At this time there is no official IEC or EN standard for photovoltaic cables.

Electric cables that are used in photovoltaic systems may not have received the required importance in the past as other installation parts such as panels and inverters. Cables were “just” considered a commodity item.

An average of approximately 31 miles (50 km) of cable is used per MW installed capacity. Cables need to be UV and ozone resistant, weather and moisture resistant, temperature and temperature cycle resistant, acid and alkaline resistant, flame retardant, and does not contain halogen. Special rodent resistant cables might be needed for ground mounted installations.

There is indication that “less suitable cables” used in some existing installations will need to be replaced before the end of lifetime of the PV installation. This is a point that needs specific attention during inspection and maintenance of affected installations.

Inverters

It is not recommended to install the inverters decentralized.

Burglary and Malicious Act

During installation, provide security around the PV panel storage area, preferably with around-the-clock surveillance (either human or electronic) and fencing of the storage zone with access control. Confirm that roof access will be prohibited and restricted by physical barriers (doors or gates), only accessible by authorized personnel.

Ground mounted and installations in more remote locations or sites that are not constantly occupied are more prone to theft or vandalism as others. Ground mounted installations should be protected by fences and electronic systems.

Panels can be marked by non-removable identification markings.

Commissioning and Maintenance

Monitoring and supervision of the proper running of the installation is an important factor that can help in detecting emerging issues before the lead to failures. Responsibilities and expectations should be clearly defined especially with third party ownership.

PV installations require regular maintenance and inspections by a qualified electrician as any other electrical installation. This applies also to installations that are owned and operated by third parties.

In general, modules mounted at a pitch of greater than 10° to the horizontal will self-clean under the action of rainfall. Regular cleaning may have a small beneficial effect on yield.

Disposal of end of life or damaged panels

Many countries treat PV panels as hazardous waste and they need to be disposed of in accordance with legal local requirements.

Installation Standards

Due to the multitude of various engineering disciplines involved, there are few all including installation guidelines and standards. Below is a list of some of some reference documents:

- FM DS 1-15 – Roof Mounted Photovoltaic Panels
- FM DS 7-106 – Ground-Mounted Solar Photovoltaic Power
- VDS 3145 - Photovoltaikanlagen – Technischer Leitfaden (German) http://vds.de/fileadmin/vds_publikationen/vds_3145_web.pdf
- http://www.ralsolar.de/download/RAL-GZ_966_Juni_2011.pdf (German)

REFERENCES

1 ASCE 7 - *Minimum Design Loads for Buildings and Structures*, American Society of Civil Engineers, Reston, VA.

AS/NZS 1170.2 – *Structural Design Actions* Part 2: *Wind Actions*, Standards Australia, Sydney, Australia

EN 1991-1-4 - Eurocode 1: *Actions On Structures* - Part 1-4: *Wind Actions*, European Committee For Standardization, Brussels, Belgium

NBCC - *National Building Code of Canada*, National Research Council of Canada, Ottawa, Canada

GB50009 - *China National Standard*, China Architecture and Building Press, Baiwanzhuang, Beijing, China

CP-2004 - *Code of Practice of Wind Effects*, Building Department Hong Kong

IS875 (Part 3) - *Indian Standard Code of Practice*, Bureau of Indian Standards, New Delhi, India

SNI-03-1727 - *Standard National Indonesia*, Indonesia

AIJ-RLB - *Recommendations For Loads On Buildings*, Architectural Institute of Japan, Tokyo, Japan

KGG – KBC 2005 -*Korean Government Guidelines of Korean Building Code*, Korea

MS1553 -*Code of Practice of Wind Loading*, Malaysia Standard, Malaysia

NSCP - *National Structural Code of the Philippines*, Association of Structural Engineers of the Philippines, Manila, Philippines

EIT-1018-46 *Wind Loading Code for Building Design*, Engineering Institute of Thailand,

TCVN2737 – *Loads and Actions Norn for Design*, Vietnam