



Small Scale Grid-Connected Solar PV Systems

Additional Document on

Specific issue on the safety of PV systems

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1 INTRODUCTION

1.1 Scope

The present document outlines the main issues that have to be taken into account in terms of safety when evaluating a new solar photovoltaic (PV) system. The topics are mainly related to a low and medium voltage grid connection range and, mainly rooftop mounted.

There is a general agreement on the benefits that PV systems provide to the environment, but one should be also aware that when these systems are installed on buildings all the suitable installation criteria must be adopted. Installations made not in accordance with best practice might not work properly and, most important, may reveal to be a source of danger. In principle, rooftop PV systems might create electrical, fire, structural, and weather-related hazards and for this reason there are several codes, standards and guidance documents that address any specific aspects in order to prevent all the possible risks. In past years, significant progresses have been made in many countries where a large number of PV systems has been installed and nowadays we can assist to a general improvement in terms of R&D and standardization. Undoubtedly, a few aspects are still unsolved and there are still gaps that need to be pointed out.

The purpose of this document review is to compile information on a variety of hazards and damage potentially created by the installation and operation of PV systems on roof structures.

The report summarizes the basic performances associated with PV panel installation practice and identifies the key installation features that may impact on them. These include performance under structural loading, wind loads, seismic, hail, sand storms, and debris accumulation. Important features related to fire hazards include the performance of PV modules and the impact on roof fire rating, ignition hazards and electrical hazards.

The report reviews existing information in the literature related to best practices for installation to address the performance issues described above. A comprehensive reference section is provided.

Finally, the time shift of a PV system is presented with the different types of hazards that can apply at different stages of the plant life. The lifetime can be divided in the following time stages:

- Permitting – the stage of design and evaluation of risks linked to the new installation and the environment where it will be installed
- Constructing – the stage when workers with different skills and roles mount the PV system and connect it to the grid. It includes inspection activities
- Operating – the phase of generating electricity that include also the maintenance of the system
- Decommissioning – at the end of life, the plant and its components should be dismantled and all the parts have to be recycled or disposed, and the site correctly remediated

The issues that involve the safety are mainly related to permitting when the PV system is designed; constructing is mentioned with reference to aesthetical concerns, and decommissioning with particular attention to PV modules reaching their end of life.

Based on such analysis recommendations are provided to support Consultants and Contractors involved in PV installations.

1.2 Important notice

This document includes a number of safety measures that take into account the specific characteristics of PV systems and their components and equipment as well.

However, one should always consider these measures as additional to the existing ones; therefore, both the local Omani laws and these additional rules must be always applied. For sake of safety, in case of conflict the strictest measure shall prevail.

1.3 Definitions

The most relevant definitions for the present document are listed below.

AFDDs – Arc Fault Detection Devices: devices that protect specifically against arc faults. They automatically trip a circuit when they detect dangerous electric arcs. In US market are also known as arc fault circuit interrupters: AFCIs.

BIPV – Building integrated photovoltaics – photovoltaic materials that are used to replace conventional building materials in parts of the building envelope such as the roof, skylights, or facades.

BAPV – Building applied photovoltaics – photovoltaic materials that are used to substitute conventional building materials in parts of the building envelope such as the roof, skylights, or facades.

DMM – Digital Multi Meter, a tool which can measure voltage, amperage, and resistance used for testing PV systems

DISCO – Distribution Company. DISCOs operate the distribution network to bring electricity from the transmission network to Customers.

Application for Connection – It is filled by an Applicant for a new Solar PV Connection. This application shall be made in a format prescribed and shall contain the required information.

Connection Agreement – The agreement signed between the Customer and the local DISCO, by which the DISCO agrees to allow Customer to connect and operate their Generation Facilities in parallel with DISCO's electric system in accordance with the operating procedures and other conditions to be specified by the DISCO.

Grid Connection: The connection of a PV Plant to the electrical grid

Inverter – device which converts the direct current produced by the photovoltaic modules to alternating current in order to deliver the output power to the grid. The inverter is also capable of controlling the quality of this output power.

Low Voltage (LV) Network – is a Network with nominal voltage lower than 1kV.

Medium Voltage (MV) Network- a Network with nominal voltage included in the range from 1kV up to 33 kV. In Oman two voltage levels may be found on MV distribution network, namely 11 and 33 kV. The 11 kV voltage level is the most used and spread one.

Network – plant and apparatus connected together in order to transmit or distribute electrical power, and operated by the OETC and DISCOs

OETC – Oman Electricity Transmission Company

Overall duration: Total amount of time needed for project development until PV plant starts operating

Permission: A license to carry out an act that; without such licence would have been unlawful

Process: A Process is one of the functional procedures necessary to develop a PV system. A Process is described by a sequence of Process Steps (which may be either administrative or technical nature)

Producer: Any entity authorised by the Regulatory Authority to produce electricity connected to the network in the Sultanate of Oman. In other documents the term “Generator” may be used.

Photovoltaic (PV) Modules – also called Photovoltaic (or PV) panels. Set of elementary photovoltaic cells for the conversion of the solar radiation into electric current.

Photovoltaic Array – A frame containing different Photovoltaic Panels usually grouped in a “String” for the conversion of the solar radiation into electric current.

PV Plant – A plant that produces power from the conversion of the solar radiation into energy.

Surge Protective Device (SPD) – device intended to limit transient overvoltages and divert surge currents; contains at least one non-linear component.

WEEE – Waste Electrical and Electronic Equipment as defined in 2012/19/EU Directive

1.1 Reference documents

The following documents are here quoted as a reference:

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- [2] Commercial Roof-Mounted Photovoltaic System Installation Best Practices Review and All Hazard Assessment; Final Report; Dpt. Fire Protection Engineering; Univ. of Mariland, College Park, MD, USA (February 2014),
- [3] S-Energy, Company Introduction 2010, Korea (<http://www.acurus.co.kr/20100615.pdf>)
- [4] Wind Load Analysis for Commercial Roof-Mounted Arrays, O'Brien and Banks, 2012 (<http://solarprofessional.com/print-issue/june-july-2012>)
- [5] A. Asker, "Structural Design Statement and program analysis for buildings", Conference Sustainable Construction, 27-11-2013
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- [7] M. Alshakhs, "Challenges of Solar PV in Saudi Arabia" Submitted as coursework for PH240, Stanford University, (2013)
- [8] L. Sherwood, B. Backstorm, B. Brooks, A. Rosenthal, "Fire Classification, Rating Testing of Stand-Off Mounted Photovoltaic Modules and Systems", Solar America Board for Codes and Standards, (August 2013)
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- [16] HSE Management System, "Electrical Safety Rules Procedure", 2014
- [17] Oman Ministerial decree no 286/2008
- [18] ARWA – Omani Environmental Regulations. International Reference Documents. SEU Guidance Notes
- [19] I. El-Hussain, A. Deif, K. Al-Jabri, N. Toksoz, S. El-Hady, S. Al-Hashmi, K. Al-Toubi, Y. Al-Shijbi, M. Al-Saifi & S. Kuleli – Probabilistic seismic hazard maps for the sultanate of Oman – Journal of the International Society for the Prevention and Mitigation of Natural Hazards (ISSN 0921-030X Volume 64 Number 1)

2 GENERAL OVERVIEW

The installation of solar PV system can have an impact on the environment which shall be evaluated in advance in order to highlight any possible drawback, and adopt the suitable prevention measures. From a general point of view the installation of solar PV systems on rooftop of buildings may have an impact on such sites where people live, work and perform everyday activities. Hence, these sites where we are about to analyse the impact of the said systems will be addressed as the “built environment”. A preliminary concern is related to quite common environmental aspects such as noise, waste, air, and water, in order to assess how these may affect people’s health. On the other hand, it is assumed that the installation of a rooftop system does not impact geology or soils. Then the PV systems shall be analysed under a variety of aspects that may have an impact on the safety of the built environment, the severity of which shall be evaluated, so that the most relevant are managed by a proper design that can be optimized in the permit phase.

2.1 Solid waste

In principle, a solar PV system will produce solid waste during construction/installation and decommissioning. The Contractor will be required to clean up all waste material after the installation. With the implementation of best management practices in the handling of waste material from the site, there should be no impact to the environment from solid waste generated from construction/installation. In the decommissioning stage the Contractor that will dismantle the PV plant shall ensure that all kind of wastes such as electronic equipment are properly managed. However, to ensure proper management of any hazardous waste, there should be a procedure for recycling and disposal of solar PV modules at their end-of-life.

In fact, PV modules at end-of-life will be the main source of solid waste from the decommissioning of a solar PV plant. Particularly, PV modules shall be submitted to the waste treatment according to the type of module (e.g. silicon or thin film).

Waste PV modules may be expected also at installation (damage in transportation or mounting stages) and operation (modules which may need substitution).

The management of PV modules at end-of-life is analysed in Section 7.1 of the present report, that describes the state of the art in recycling of PV modules and illustrates the possible actions to manage this new kind of waste.

2.2 Hydrology and water quality

The PV panels would require periodic cleaning to maintain efficiency in power generation. This cleaning would likely be by a spray wash-down that might include a mild detergent biodegradable household cleaner and some fraction of that wash-down could also ultimately reach off site drainage. However, such a small amount of dust, debris and wash-down detergents would not be expected to impact water quality.

In all cases where the availability of clean water is a concern, cleaning operations must be planned and managed carefully, in order to avoid any waste of water.

Alternatively, cleaning may be performed by compressed air which will avoid using water and detergent.

Recommendation

The designer shall describe in the O&M Manual of the solar PV system the cleaning procedure most appropriate with reference to the actual layout of the PV system.

3 PERMITTING

Permitting is intended as the process prior to the construction and installation of the solar PV plant. Permitting process include the phase of design as well the risk evaluation for the solar PV plant in order to put in place, at design stage, all preventive and corrective action in order to prevent any hazardous action both in construction and operation.

At the stage of permitting the authority should give clear indication on what is allowed and what not and how to prevent any non-compliant action with the permission of installing a solar PV plant.

Consultants/Contractors have to provide a detailed project construction plan, providing any information suited to aid in this process. These practices ensure that any environmental and architectural impact is minimized.

Normally, the size of a PV system and its location are the factors that differentiate among the different paths of permitting process. Large (utility-scale) PV plants, usually ground mounted, have more environmental constraints to deal with like the use of land and the constraints linked to the construction in a wild site. On the other hand, the placement and position of the PV plant can be the driver of a deeper analysis of environmental impacts that could be introduced. For instance, a large PV plant near an airport might introduce impacts referring to potential sunlight reflection from PV modules, particularly from front glasses and frames, or a cleaning system that employs desalinated water would need a deeper evaluation on environmental impacts.

Hence, in the permitting stage, a prospected solar PV plant shall be analysed under any aspects that may have an impact on the safety of the built environment, and the severity of such impacts shall be evaluated and in case managed by a proper design. Before such issues are analysed some statistical data can highlight the relevance of the accurate design of a solar PV plant in terms of safety of the built environment.

In this chapter the main risks are listed and analysed except the Fire Hazard that is described in a separate chapter.

3.1 Damages on PV installations: statistical data

Comprehensive statistical data describing the damages occurring to PV installations are rarely available in a very detailed form. To our knowledge one interesting exception comes from Germany where a private insurance organization, the German Insurance Association (GDV) which is the federation of private insurers in Germany, provided a very precise characterization of such damages in their status report 2010 on "Renewable energies – Overall survey of Engineering Insurers within the German Insurance Association (GDV) on the level of technological development and the technical hazard potential" issued in May 2010. The information provided by this survey is below summarized.

Statistical data are provided with reference to the number of the incidents recorded in the 4 years period 2004-2007, and the repartition of the costs of such events. According to these data the biggest number of incidents has no specific or clear origin, and the related cost is not the most relevant. Fire accounts about 2% of the total number of incidents that however represent 26% of the observed cost of damages. Overvoltage was recognized to be the source of 26% of incidents, while other relevant number of incidents is due to the weight of the snow and particularly to storms. Such 9% of incidents due to storms represented 25% of the costs of all damage events. Hence, in Germany fire and storms are the most significant source of damage costs in PV plants. It is worth noticing that the above data reflects the meteorological conditions typical of continental Europe with snow and storms affecting the land at such latitudes, while incidents of other types could arise in Oman due to the exposure to quite different and harsh weather conditions. Nevertheless, to prevent the consequences of fire incidents as

well as to avoid that some even occasional storms affect an installation, PV plants shall be carefully designed and installed. These activities shall be accomplished by putting very accurate attention to the local rules, the relevant standards and the best practice available from worldwide experience in the PV field, with the aim of increasing the overall safety of PV plants and particularly of rooftop installations.

3.2 Type of mounting PV panels on buildings

The installation of solar PV system, on a building has different implications, because it does not affect only the structural loading, but it is also related to additional effects such wind loads that can be particularly significant in case of storms. The two main categories of mounting solutions, BAPV and BIPV, are described hereafter. There are three different BAPV (Building Attached) methods of mounting PV systems on a roof plane structure:

1. Ballast only systems, that are weighed down by heavy materials such as concrete to keep them located in the same position (see Figure 1). These systems are not attached to the roof structure.
2. Attached roof-bearing systems that use friction clips to secure PV modules to the beams of the framing system. Supports are attached to the building by screws, clips, or adhesives (see Figure 2);
3. Structurally attached on flat roof. They are attached to the roof structure such that the load path is the same for both upward and downward forces (see Figure 3);
4. Structurally attached on tilted roof (see Figure 4).

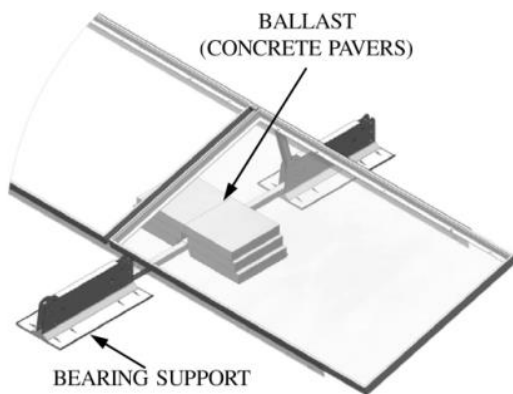


Figure 1 – Ballast only PV System

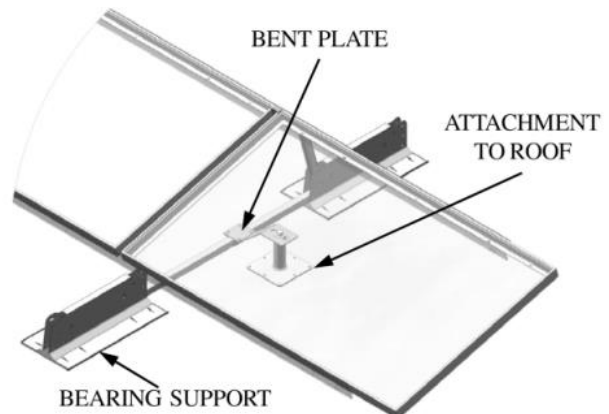


Figure 2 - Attached Roof-bearing PV System

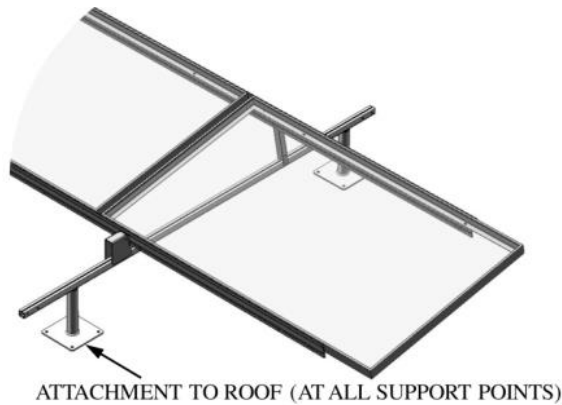


Figure 3 - Structurally attached on flat roof PV system



Figure 4 – Structurally attached on tilted roof

A further method for installing PV systems is the BIPV (Building Integrated), which is most similar to the attached roof bearing system. Building-integrated systems are integral with the roof or lay flat on the roof surface such that they do not affect the roof profile.

The differences between BIPV and BAPV are mainly the followings:

- Building-integrated photovoltaic - BIPV – Photovoltaic modules are considered to be building-integrated, if the PV modules form a building component providing a function as defined in the European Construction Product Directive CPD 89/106/EEC. Thus the BIPV module is a prerequisite for the integrity of the building's functionality (if the integrated module is dismantled it has to be replaced by an appropriate building component).
- Building attached photovoltaic - BAPV – Photovoltaic modules are considered to be building attached, if the PV modules are mounted on a building envelope and do not fulfil the above criteria for building integration.

As an example, Figure 5 shows the table with the mounting categories taken into account in the EN 50583-1/2 – Photovoltaics in buildings.

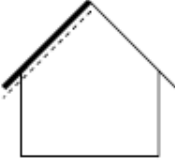

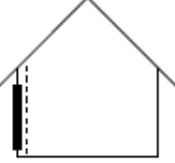
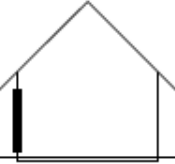
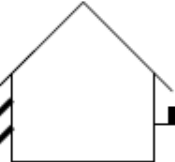
Category A:	Sloped, roof-integrated, not accessible from within the building	
	The PV modules are mounted in the building envelope at an angle of 0° - 75° with a barrier underneath preventing large pieces of glass falling onto accessible areas below	
Category B:	Sloped, roof-integrated, accessible from within the building	
	The PV modules are mounted in the building envelope at an angle of 0° - 75°	
Category C:	Non-sloped (vertically) mounted not accessible from within the building	
	The PV modules are mounted in the building envelope at an angle of 75° - 90° with a barrier behind preventing large pieces of glass or persons falling to an adjacent lower area	
Category D:	Non-sloped (vertically) mounted accessible from within the building	
	The PV modules are mounted in the building envelope at an angle of 75° - 90°	
Category E:	Externally integrated, accessible or not accessible from within the building	
	The PV modules are mounted onto the building and form an additional functional layer (as defined in 3.1) exterior to its envelope.	

Figure 5 - The table with the mounting categories taken into account in the EN 50583-1/2 – Photovoltaics in buildings

3.3 Structural Loading

Installing PV panels onto roofs might introduce overloads that can affect their structural integrity. Not only does the roof support the dead load of the PV system itself, but also external forces introduce additional structural loadings. Outside installations exposes the PV system and the whole roof assembly, to specific weather conditions such as wind, hail, debris, and the effects of the air temperature. These factors may determine stress conditions on PV modules and roof through wind up-lift, thermal expansion, and debris build-up. In some cases, excessive stress conditions can lead to damages or to the destruction of the rooftops with the PV systems. Therefore, this issue is seriously

considered in the literature, as it can be understood from the following extract: “Structural engineers must consider each of these loads separately and in combination to identify the worst-case loading situation”. There are guidelines on the installation, maintenance, and testing of PV systems that can help to prevent failure of the system due to extreme external forces.

Guidelines depend on what type of mounting is used to attach the PV System to the roof.

There are many codes for calculating structural loads and wind loads: for USA and Europe there are, respectively:

- A.S.C.E. Minimum design loads for buildings and other structures. ASCE Standard ASCE/SEI 7-05 American Society of Civil Engineers, Reston, Virginia, 2006.
- C.E.N. (European Committee for Standardization), Eurocode 1: Actions on structures - Part 1-4: General actions, EN 1991-1/2/3/4

3.4 Wind Loading

An additional complexity to having PV systems on rooftops is that the PV system will be exposed to wind forces and as a result will have to be capable of withstanding those forces. PV systems must withstand escalated weather scenarios such as windstorms. Uplifts from strong winds can create appreciable additional loads or load concentrations. The very presence of the building changes the aerodynamic load because “there is a complex interaction between building generated vortices and the flow induced by the array, which depends on building height, the setback of the array from the roof edge, and other building parameters”.

When installing a PV mounting structure on an existing building one should always take into account the following considerations:

- It is important to use data taken from a detailed and highly reliable wind map, and use a proper set of rules or model in order to estimate the maximum wind speed in the specific site.
- The mounting structure shall withstand the maximum wind considered in the project. Moreover it is important that also the building itself is able to withstand the forces and momenta added to the building structure in the points of mechanical connection.
- The points of mechanical connection in the building structure shall be chosen carefully because they must transfer the forces and momenta without breaking themselves and/or damaging the building.

3.5 Sand Storms

Oman is located in a region that has frequent dust storms and dusty conditions. Deposits of dust on the surface of PV module can prevent the solar irradiation from reaching cells through the glass cover. The density of deposited dust, its composition and particle distribution, will have an impact on the power output and current voltage and characteristics of PV modules. The effect of dust accumulation on the power output of solar PV has been the objective of a PV study based on field tests performed in Dhahran. Four mono-crystalline PV modules and two polycrystalline modules were tested at outdoor conditions for several months and power output was monitored daily.



Figure 6 - Effect of sand deposit after sandstorm

It has been observed that the atmospheric dust scatters the solar radiation, in addition to dust deposits on PV surface, which also blocks PV module from direct solar radiation. A long period of PV module exposure to outdoor conditions gradually decreases power output if no cleaning is performed to remove the dust.

More than 50% power output reduction has been observed over six months of no cleaning and furthermore a single dust storm in the month of March decreased the power output by 20% for all modules. The dust density was measured to be 0.0618 milligram/cm²/month. Another observation is that rainfall helps to clean the panels and restore its power output to higher levels. Rainfall, however, is not frequent in the region, so it can't be relied on for PV surface clean up. A study also showed that power output was sustained at high levels when it was cleaned up routinely once a week.

In addition to the reduction of performance of the panel it has to be considered that sand storm causes degradation of PV modules and, more in general, wires, structures, etc. Effects of abrasion can be in some way tested by means of the IEC 60068-2-68.

Nevertheless also sand deposit may affect safety because they may give origin to "hot-spot" on PV modules with unpredictable consequences.

"Hot spot" is typically produced by a partially shaded cell (or by dust): the shaded part absorbs power from the unshaded one, reaching locally very high temperature. This effect is dangerous in case of very high irradiance: when "Hot spots" produce very high temperature on cells and back-sheet (up to 180°C), so it could be a cause of ignition of fire.

Recommendation

A well designed PV plant suited to Oman climate peculiarities should take into account the effects of sand storms and sand deposit on PV modules. The periodically removal of sand, and debris too, should be taken into account by the owner of the plant as a common practice. Both at design stage and during operation, thus, it has to be pointed out how it will solve the problem of sand removal. When designing the PV plant, horizontal and very low inclinations of PV modules shall be avoided. At design

verification by the Applicant or the Producer should be verified that the PV system has a dust removal system in the project or that there are procedures for dust and sand removal periodically.

In the case of utility scale PV plant, for the biggest facilities installed in the rural areas or in places with heavy sand storms this recommendation is more compulsory, particularly if the removal system is of wet type.

The removal system, if wet type, should indicate the amount of water needed for cleaning and the system of supply. A comparison among different cleaning system should be set in order to rank the effectiveness of the system itself (i.e. monthly amount of desalt water per square meter of PV panel).

3.6 Hail Phenomena

Even if hail phenomena are seldom in Omani weather, the PV modules shall be tested and certified against hail damage according to the standard IEC 61215 series or IEC 61646, nevertheless the economic value of the PV installation can be protected also with an insurance that refund the damages caused by hail.



Figure 7 – Examples of hail damage on PV modules

Recommendation

The best way to prevent a PV system failure from hail is to have the system tested and approved through a standard testing procedure. Normally the solar panel are already made and tested against hail IEC 61215 series or IEC 61646, depending on PV technology, assure the quality of the PV modules and give also a resistance to hail classification.

3.7 Debris and Dust accumulation

Debris accumulation is another major hazard applicable to both roofs and PV systems. Partial shading is a problem that can arise from dirt build up on module surface. Partial shading can decrease the

effectiveness of the PV panels, which may dissuade consumers from accepting the new energy source. Having to periodically clean roof-mounted PV panels to eliminate cell shading may subject workers to increased incidence of fall and shock injuries.

Debris build up can be a result of undrained water floating on top of roofs or being the mere deposit last by wind. Not only does debris affect the efficiency of the panel, debris can also quickly turn into a fire hazard. Underwriters Laboratory (UL) created a study to determine how well screens would prevent ignition of debris accumulation between mounted PV systems, also providing a significant amount of information on how fire spreads between PV panels and roof tops. In order to respect these concerns the IEC 60068-2-68 standard becomes important specifically in environment with sand and dust deposits.

In Europe debris and dust are mainly composed by leaves and other vegetal residues as well as bird excrements, all combustible. In Oman debris are mainly represented by sand deposits which hardly ignites but there could be the case of ignition of the roof membrane or other material improperly left on the roof caused by the effect of an "hot spot" on the panel; also bird's leftover and nests could be common in Oman.

The main point is that a class A rated roof with a 5" mounted PV panel resists to ignition when exposed to hot embers. But when there is debris accumulated between the PV panels and the roof, even when protected by 1/8" and 1/16" screens, and it is exposed to hot embers, the debris can ignite spreading the fire across the roof.

In particular cases, the drop in solar energy efficiency over 3 months without cleaning may reach up to **30-45%**. The decrease in solar energy efficiency due to dust storms was measured to be **60%**.



Figure 8 – Example of cleaning of PV modules

Debris deposit is composed by dust from pollution, sand and other debris that accumulated on the surface of the cells during operations; debris can affect the performance of the system and should be removed with a cleaning system. This can be done manually by an operator in case of rooftop mounted PV modules (Figure 8). For ground mounted (utility-scale) PV plants of large capacity also mechanized systems might be used.

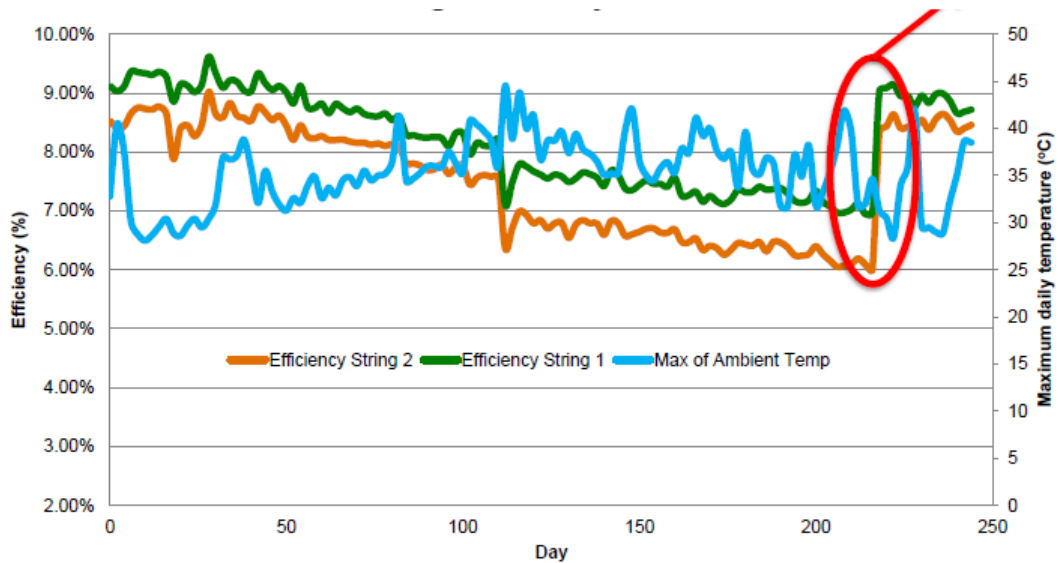


Figure 9 - Efficiency increase after cleaning [9]

In the design stage of O&M a cleaning system and a cleaning procedure should be defined: the cleaning systems applicable are:

- Compressed air;
- Water based;
- Passive with pre-treatment of the surface;

Environmental issue is mainly linked to water consumption during O&M operations of cleaning.

The Figure 10 shows the different possibilities that might be used when facing the problem of the solid depositions on PV modules. Some of them are viable, while others need further development or refinement. Therefore the following comments may be done:

- Ideal coating would have mechanical and optical characteristics
- Coating life is at best 3 to 5 years and it is site specific
- Multiple re-application of coatings can degrade performance
- Suitable standards are needed for coatings on PV panels

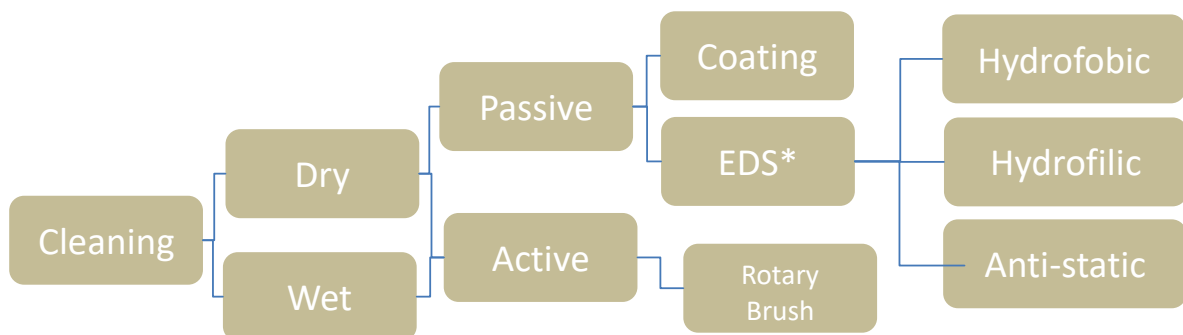


Figure 10 - Classification of cleaning systems of PV panels (* Electro Static Systems: ionization of dust particles)

Recommendation

The designer shall include a description of the O&M procedure for modules cleaning and dust removal that will be annexed to the documentation for approval at the Design Approval stage. Proposal and identification of suitable cleaning method shall be the responsibility of the Applicant and also the choice of the Owner of the plant to avoid a decrease of performances of the PV plant, but also preserve the safety of the PV plant itself.

3.8 Sunlight reflection from PV panel surface

In general, light is specularly reflected from any smooth surface where the index of refraction is different from that of air. The intensity of the reflection will be dependent on the angle between the sun and the solar panel, and the index of refraction of the panel.

Multiple reflections from the front and back surface of the glass are not apparent in solar panels since they are designed to absorb light and convert it into clean, usable energy. At a normal incident solar panels reflect about 4% of incoming light, when, in comparison, a car window reflects about 8%.

An anti-reflective coating or glass can reduce the sunlight that is reflected and increase the amount of sunlight that is absorbed. Most solar panels are now designed with at least one anti-reflective layer and some panels have multiple layers.

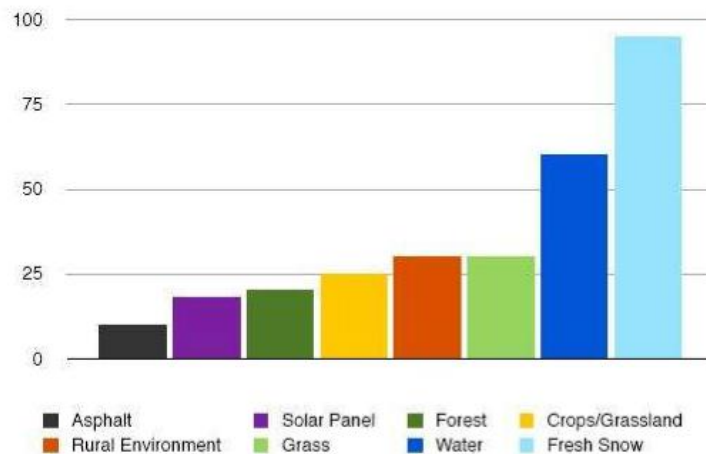


Figure 11 - Comparative reflection analysis [10]

Even if reflection should not be an issue in cities and populated areas, the case of reflections can be presented that irk the buildings around inhabitants. In order to prevent any disturbance to inhabitants in taller buildings around the PV system an assessment of reflections should be required, particularly for installation sites that are close to airport areas.

Recommendation

As a general measure, check the presence of anti-glare on panels especially when the location could affect visual interaction. In addition consider:

- That some PV systems installations might interact with airport activity. In this case a permit or no objection letter shall be issued from the responsible authority.
- That a PV system on a roof may hit the taller buildings near to the installation.

3.9 Seismic loads

A study named “Probabilistic seismic hazard maps for the sultanate of Oman” was published in 2012 by the Earthquake Monitoring Center, Sultan Qaboos University of Muscat, with the collaboration of other research centres and Universities. The study presents the results of the first probabilistic seismic hazard assessment (PSHA) in the framework of logic tree for Oman. The earthquake catalogue was homogenized, declustered, and used to define seismotectonic source model that characterizes the seismicity of Oman. Two seismic source models were used in the current study; the first consists of 26 seismic source zones, while the second is expressing the alternative view that seismicity is uniform along the entire Makran and Zagros zones. The recurrence parameters for all the seismogenic zones were determined using the doubly bounded exponential distribution except the zones of Makran, which were modelled using the characteristic distribution. Maximum earthquakes were determined and the horizontal ground accelerations in terms of geometric mean were calculated using ground-motion prediction relationships developed based upon seismic data obtained from active tectonic environments similar to those surrounding Oman. The alternative seismotectonic source models, maximum magnitude, and ground-motion prediction relationships were weighted and used to account for the epistemic uncertainty. Hazard maps at rock sites were produced for 5 % damped spectral acceleration (SA) values at 0.1, 0.2, 0.3, 1.0 and 2.0 s spectral periods as well as peak ground acceleration (PGA) for return periods of 475 and 2,475 years. The highest hazard is found in Khasab City with maximum SA at 0.2 s spectral period reaching 243 and 397 cm/s² for return periods 475 and 2,475 years, respectively. The sensitivity analysis reveals that the choice of seismic source model and the ground-motion prediction equation influences the results most.

The Figure 12 shows the peak ground acceleration on rock sites as a mean (a and b) and a 84 percentile (c and d) with 10% and 2% probability of being exceeded in 50 years (475 and 2,475 years return periods).

The maps delineate the northeastern region of relatively higher seismic hazard from the rest of the country which is characterized by its relatively lower hazard levels.

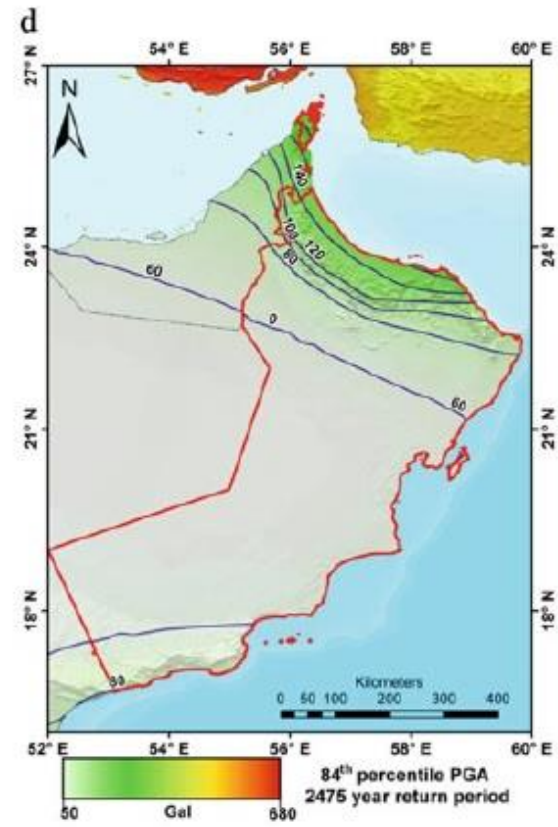
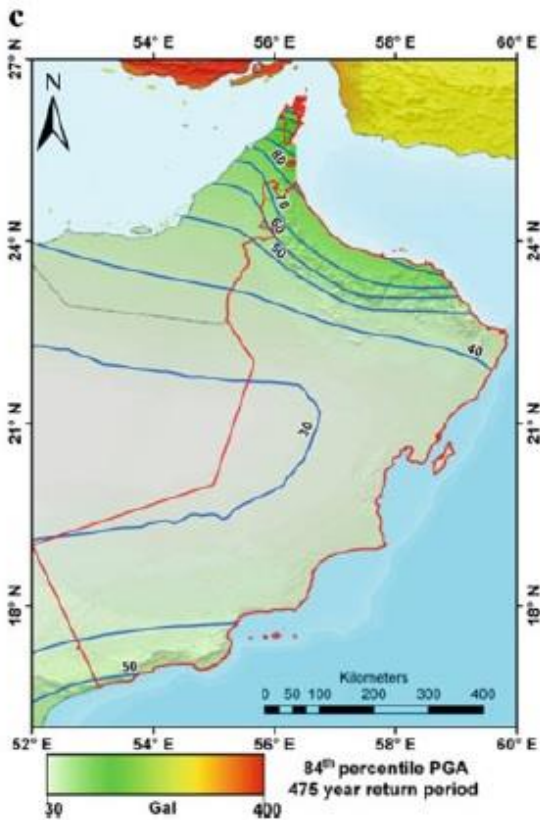
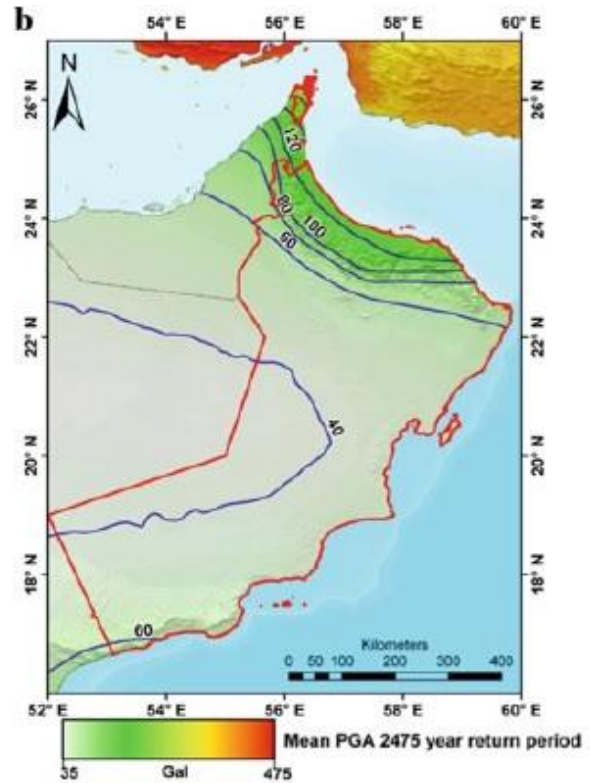
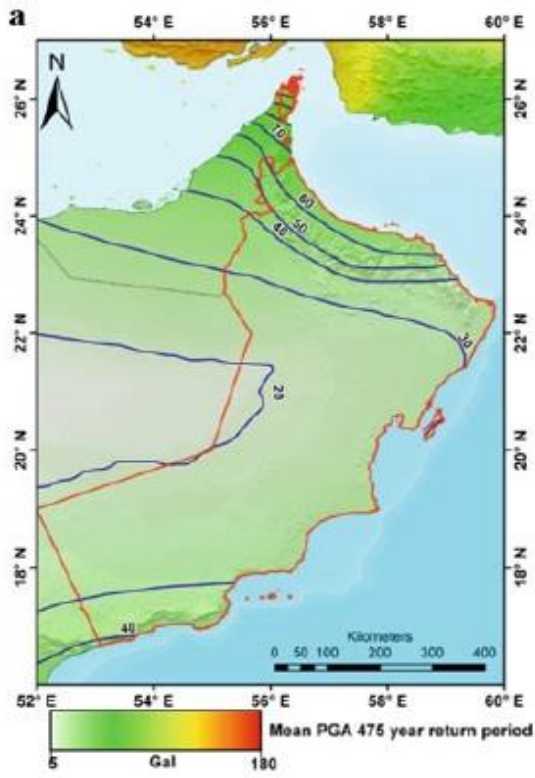


Figure 12 – Mean (a and b) and 84 percentile (c and d) peak ground acceleration (cm/s²) on rock sites with 10 and 2 % probability of being exceeded in 50 years (475 and 2,475 years return periods)

In the case of seismic load, the project of a PV system should show the types of mounting. It must distinguish between roof and ground mounted.

SEAO (Structural Engineers Association of California) “developed a draft document that addresses the seismic hazards associated with rooftop PV systems “Structural Seismic Requirements and Commentary for Rooftop Solar Photovoltaic Arrays” (SEAO Report PV1-2012). The seismic requirements document is applied to all the three types of PV systems: ballast-only, attached roof-bearing systems, fully framed (or structurally attached) systems” (the BAPV types of mounting PV modules on flat roofs). Extracts of such report are mentioned in the document “Commercial Roof-Mounted Photovoltaic System Installation Best Practices Review and All Hazard Assessment” [2], as “for each of the three attachment methods there are separate requirements”: for example, in case of fully framed systems, PV support systems that are attached to the roof structure shall be designed to resist the lateral seismic force F_p specified in ASCE 7-05 Chapter 13 (for reference see also EN 1998 - EUROCODE 8 - Design of structures for earthquake resistance).

In case of PV plant installed on roofs, the seismic load has to be treated as a structural load, in some cases a seismic risk assessment could be required for instance when the total weight of panels and mounting structures exceeds the 10% of the total load acceptable on the roof structure.

3.10 Performance of components

Specific requirements are described below with reference to the performance of selected components of the PV system.

3.10.1 Photovoltaic modules

The standards of the series IEC 61215 are fundamental for PV modules in terms of safety and performance. Characteristics shall be compliant to IEC 61215-1/2/3/4 or to the previous standards IEC 61215 and IEC 61646. Tests shall be made according to the IEC 61215-2 or according to the previous standards IEC 61215 and IEC 61646.

Safety standards IEC 61730-1/2 are used as prescriptions and test criteria as regards:

- *Electrical hazards:* Dielectric withstands, Ground continuity, Accessibility, Cut susceptibility, Impulse voltage, Reverse current, Partial discharge.
- *Mechanical hazards: Module breakage.*
- *Thermal hazards: Temperature test.*
- *Fire hazard: Fire resistance.*

It can be useful to mention the revision made in 2013 of the standard UL 1703 on the system fire class rating of module and panel with mounting systems in combination with roof coverings.

Although the actual application of this part in the UL 1703 standard is still debated and one should consider that it will be effective in 2016, further fire test have been introduced:

- Spread of Flame at roof and Module or Panel interface over representative steep sloped roof
- Spread of Flame at roof and Module or Panel interface over representative low sloped roof
- Burning Brand on surface over representative steep sloped roof
- Burning Brand between Module or Panel and representative steep sloped roof

PV modules installed in coastal regions shall comply with IEC 61701 and PV modules installed on stables or where ammonia can be present shall comply with IEC 62716.

Compliance to IEC 60068-2-68 is highly recommended, because the effects of sandstorms shall be always taken into account.

The compliance to the standard IEC TS 61853-1 is also recommended in order to prevent the effect of PID in crystalline PV modules and it is also preferable that the manufacturing process be compliant with IEC TS 62941 in order to guarantee an effective quality system.

3.10.2 Inverters

In consideration of safety requirements, inverters shall comply with IEC 62109-1/2.

3.10.3 Combiner boxes

The combiner boxes represent one of the most frequent source of hazard in PV system because if not properly made and maintained they may release fires.

The design of a combiner box shall always be done according to IEC 62548 and the certification of at least one of the following standards shall be present: IEC 62447-1, IEC 50178, IEC 62093.

3.10.4 Wirings

Usually PV cables comply with National standards, i.e. 2 PfG 1169/08.07 (Germany), UTE C 32-502 (France), EA 0038 (Spain), CEI 20-91 (Italy), JCS 4517:2010 (Japan) UL 854 Use 2 or Subject 4703 PV-wire (USA), C22.2 No. 271-10 (Canada).

Typical characteristics such as UV resistance, working temperature ≥ 90 °C, proper voltage insulation and sheath are basically required for DC circuits in photovoltaic applications.

The European standard EN 50618 – Electric cables for photovoltaic systems (December 2014) encompass the basic features for PV cables and applies to low smoke halogen-free, flexible, single-core power cables with crosslinked insulation and sheath. In particular for use at the direct current side of photovoltaic systems, with a nominal DC voltage of 1,5 kV between conductors and between conductor and earth.

The EN 50618 describes also the test to be made on PV cables (electrical and non electrical) and the code designation “H1Z2Z2-K”.

3.11 Weather-related Maintenance Considerations

The high summer temperature in Oman is very often associated with very high humidity along the coast. Humidity affects solar PV in ways comparable to dust accumulation. Water vapour particles might reduce the irradiance level of sunlight that is required for PV panels to reach high efficiency.

The humidity associated with salty particles coming from the sea could reduce the lifetime of some parts of the PV plant: wiring materials, panels, array's frames, mounting anchor. The designer shall assess that the PV modules envisaged for installation are certified according to the relevant International Standards, as also reported in the Connection Standards. Modules certification will guarantee the performance of the modules as well as of their components including cables and connectors.

Recommendations

The designer shall address maintenance of PV modules especially in the presence of severe weather conditions and particularly in case of high humidity should be addressed. Designers shall take care about the products selected to build the PV plants.

3.12 Lightning

Lightning protection measures are required by design and the standards to be followed are listed in the “Standards for the Solar PV systems connected to the Distribution Network – Electrical Installations”. Particularly, SPDs and surge arresters are normally provided by design as overvoltage protections in a PV plant. Also earthing of PV support structures and frames PV shall be required by design as a general protection measure.

3.13 Earthing

Earthing is a further issue for the safety of a PV plant installation. It is addressed by the IEC 60364-5-54: Low-voltage electrical installations. Part 5-54: Selection and erection of electrical equipment. Earthing arrangements and protective conductors. Designers shall be responsible to design PV system earthing arrangements according to standards and site conditions (e.g. rooftop PV system in an existing building with earthing system available, or PV system to be designed as a part of a brand new building). According to each specific PV system installation the designer shall: measure the resistance of the existing earthing system, or assess its performance from available test reports / certifications, investigate the resistivity of the soil (in principle feasible for new buildings on green sites). Should a building be not equipped with an earthing system the designer shall include design and installation of earthing system in the scope of work for a new PV system installation.

4 SAFETY AND FIRE HAZARD

4.1 Foreword

This section contains special considerations and prescriptions against fire hazard to be used when PV plants are to be mounted on buildings.

Fire hazard prevention is considered under the following points of view:

- PV plants and their components shall not be a source of fire.
- Should a fire originate from a PV plant it shall not propagate into the building.
- The PV plant shall not interfere with the fire safety system of the building whatever the origin of the fire.

Different types of buildings are considered as regards the fire hazard and PV plants are basically divided into externally-mounted (BAPV) and building-integrated (BIPV).

In this section, the prescriptions adopted in countries with a high PV penetration have been taken into account. Particularly useful were the following: VDE-AR-E 2100-712 (Germany), Guida CEI 82-25 (Italy), UL 1699B (US).

4.2 Ignition hazards

There are many causes of possibly ignition in a PV system; the causes for the fire are not associated with the PV panels directly, but are actually linked to fault problems in the wiring and in the construction and maintenance. Mainly it has to be take care of:

- The presence of debris under the panels or a surface of the roof with high index of flammability can cause ignition as long as the temperature under the panel can be around 90°C or more depending on environmental conditions;
- Short circuit current or improper mounting of electricity boxes can cause ignition;
- Joule effect in the connection cables because improperly sized at design stage or in construction phase;
- Possible damages to cables caused by rodents, that can be avoided by adopting the cable protections suited to the purpose;

Although the fire classification of PV modules according to IEC 61730-2 (Classes A, B or C) is undoubtedly important, there are several further aspects to consider when PV modules are used in buildings. Characteristics as thermal behaviour, noise isolation and overall transparency may play a fundamental role under both a functional and a safety point of view.

Furthermore, the same PV module might be classified differently as regards the set of standards adopted (e.g. ANSI/UL or CEN). If one considers that, each building component usually must comply with several standards in order to be eligible for a given application the proper use of PV modules in buildings may become a real concern.

The standards on fire prevention must be taken into account at design level and during construction; it is also recommended that both the installer and the Owner check at every stage the correctness of the installation.

Control checks shall involve:

- Check the readiness of the wiring connections and the general cleanliness and order;
- Check the presence of any debris accumulation under the panels and check the fire ignition risks of the mounting surface. Dust and sand on the panels only cause a decrease in performance of the PV system. Electrical hazards are associated with Fire Fighters Operations.

The PV modules add to the complexity of the traditional firefighter tactics for suppression, ventilation and overhaul more complex. However, the electrical and fire hazards associated with electrical generation and distribution systems are well known, PV systems present unique safety considerations. The increased operating temperatures allowed by newest panels mean that PV modules are not placed flush against a roof, but may now be placed four to seven inches above a roof deck. This air gap can cause any fire between the PV panel and the roof to be much more intense than a traditional roof fire. The 2014 edition of NEC (NFPA 70) code states in 690.13(A) "Location. The PV disconnecting means shall be installed at a readily accessible location either on the outside of a building or structure or inside nearest the point of entrance of the system conductors."

It applies also to O&M operations when disconnection is requested:

- i) Readily accessible - Capable of being reached quickly for operation, renewal, or inspections without requiring those to whom ready access is requisite to climb over or remove obstacles or to resort to portable ladders, and so forth.
- ii) Readily accessible provision is primarily for emergency operation. If the disconnect is not mounted in close proximity of the service entrance disconnect (usually within 1 m. of the meter location or service disconnect switch), then a diagram or directory must be provided to clearly identify where the disconnect device is located.
- iii) A rooftop disconnect on a residential roof will normally not qualify as a readily accessible disconnect.

4.3 FIRE RESISTANT PV MODULES

The standard IEC 61730-2 includes the fire test (MST 23) for PV modules. The requirements assessed in the fire test establish the fundamental fire resistance of PV modules serving either as roof covering materials or mounted onto a building over an existing roof. These modules may be exposed to fire conditions, and therefore need to indicate their fire-resistance characteristics when exposed to a fire source originating from outside the building on which they are installed.

The fire resistance classes range from Class C (fundamental fire resistance), to Class B to Class A (highest fire resistance). A minimum fire resistance rating Class C is necessary for any building-mounted module (BAPV). Certification to a higher level may be considered in order to satisfy specific application requirements.

Depending on the building characteristics or class, design criteria and other relevant aspects, PV modules integrated in buildings (BIPV) may require specific characteristics as regards fire hazard further than those tested by means IEC 61730-2. As a rule, a minimum fire resistance rating Class A or Class B is needed.

A PV module used in place of classified roofing material or mounted to or above an existing classified roofing material needs to comply with the following:

- Spread-of-flame test
- Burning brand test

These are based on ANSI/UL 790. Sufficient samples shall be provided to create a single test assembly for a single spread of flame and a single burning brand test.

Products that comply with these tests are not readily flammable, afford the measurable degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands.

4.3.1 Spread-of-flame test

A test sample is to be mounted, and luminous gas flame applied, as described in 6.1 of ANSI/UL 790. The test is to be conducted with the module or panel oriented with respect to the test flame, so that the flame impinges only on the top surface of the module or panel.

The sample area of the test material should be not less than 1 m in width for all classes, 1.82 m minimum length for the fire safety Class A, 2.4 m minimum length for the fire safety Class B, or 3.9 m minimum length for the fire safety Class C, as measured from the leading edge of the sample.

For the safety Class A or B test, the gas flame is to be applied continuously for 10 min or until the spread flame (flaming of the material being tested) permanently recedes from a point of maximum spread, whichever is the shorter duration. For a safety Class C test, the gas flame is to be applied for 4 min and then removed.

During and after the application of the test flame, the test sample is to be observed for the distance to which flaming of the material has spread, production of flaming or glowing brands, and displacement of portions of the test sample. The observation is to continue until the flame has permanently receded from a point of maximum spread.



Figure 13 – Spread-of-flame test (LAPI laboratory)

4.4 Burning-Brand test

A test deck is to be mounted as described in 6.1 of ANSI/UL 790, with a few differences as specified in the standard IEC 61730-2.

The fire safety Class A brand is to consist of a grid, 300 mm square and approximately 57 mm thick, made of kiln-dried Douglas fir pine lumber that is free of knots and pitch pockets. The dry weight of the finished brand is to be 2000 ± 150 g.

The fire safety Class B brand is to consist of a grid, 150 mm square and approximately 57 mm thick, made of kiln-dried Douglas fir pine lumber that is free of knots and pitch pockets. The dry weight of the finished brand is to be 500 ± 50 g.

The fire safety Class C brand is to consist of a piece of kiln-dried non-resinous white pine lumber that is free of knots and pitch pockets. The dry weight of the finished brand is to be 9.25 ± 1.25 g.

Before application to the test deck, the brands are to be ignited so as they burn freely in still air (times and other details depending on safety class).

Each individual tests, whether fire safety Class A, B or C, is to be continued until the brand is consumed and until all evidence of flame, glow or smoke are disappeared from both the exposed surface of the material being tested and the underside of the test deck.

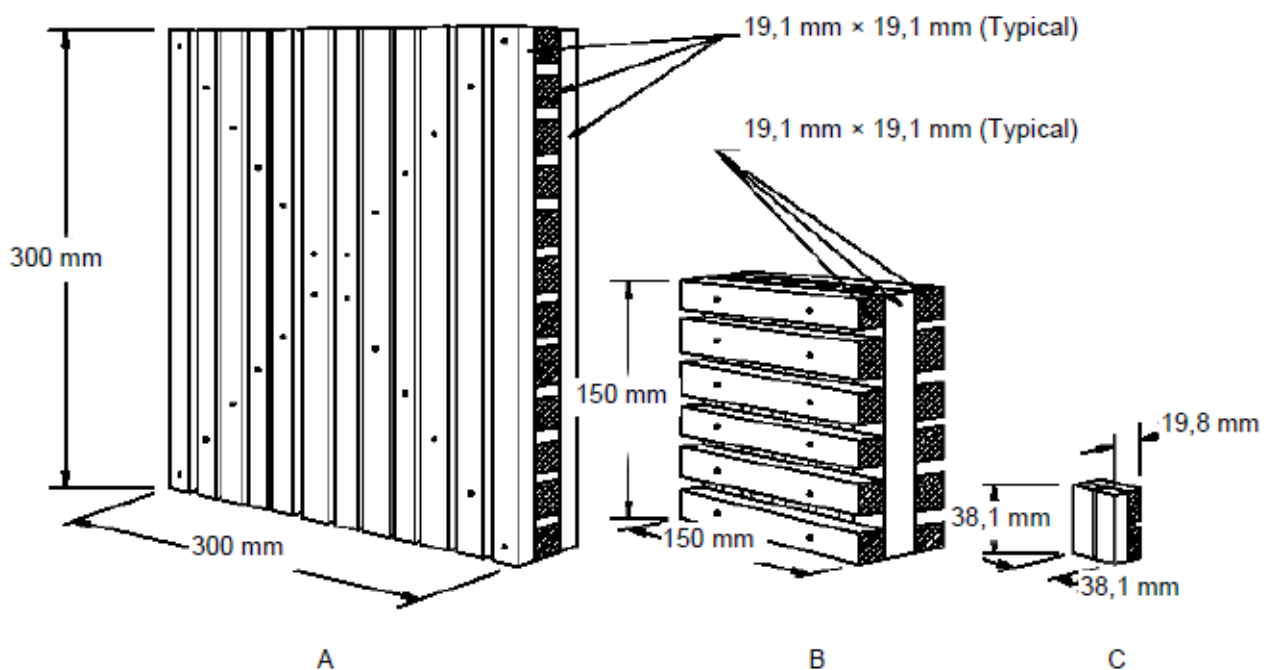


Figure 14 – Burning brand construction

4.4.1 Conditions of acceptance

At no time during the spread-of-flame or burning-brand tests shall:

- Any portion of the module or panel be blown off or fall off the test deck in the form of flaming or glowing brands.
- Portions of the roof deck, or portions of a module or panel intended for installation integral with or forming a part of the building roof structure, fall away in the form of glowing particles.
- The flame spread beyond 1.82 m for fire safety Class A, 2.4 m for fire safety Class B, or 3.9 m for the fire safety class C rating. The flame spread is to be measured from the leading edge of the sample.

- d) There be significant lateral spread-of-flame from the path directly exposed to the test flame. Spread-of-flame includes flaming on both of the top surface (the surface to which the external flame is applied) and in any intermediate channel, such as the space between stand-off and integral modules and the roof.

As an example, in Figure 15 is visible the result of a Class A burning-brand test on a PV module that can be certified only for a Class C fire test. The PV module fails the test.

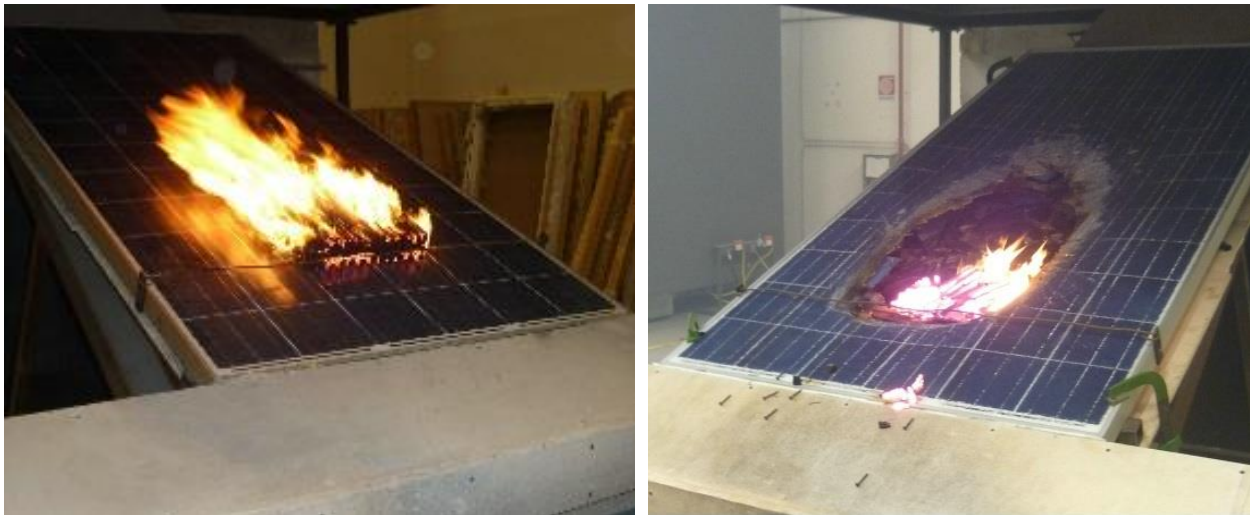


Figure 15 – Example of a Class A burning-brand test – the PV module fails the test (LAPI laboratory)

4.4.2 Further criteria

The adoption of further criteria for PV module assessment is valid, in particular, in case of BIPV, where the fire characteristics of PV modules shall fully meet the design safety criteria adopted in the building's design. As a reference the following international and national standards give information for tests, which could be used:

- ISO 834-1, Fire-resistance tests – Elements of building construction – Part 1: General requirements
- ISO 834-3, Fire-resistance tests – Elements of building construction – Part 3: Commentary on test method and test data application
- ISO 5657, Reaction to fire tests – Ignitability of building products using a radiant heat source
- ISO 13501-5:2005, Fire classification of construction products and building elements – Part 5: Classification using data from external fire exposure to roofs tests
- ENV 1187-1/4: Test methods for roof coverings under the influence of a thermal attack of burning brands and radiant heat
- ANSI/UL 790: Standard Test Methods for Fire Tests of Roof Coverings
- ANSI/UL 1703-2013, Standard for Safety for Flat-Plate Photovoltaic Modules and Panels

Here below the EU approach (ENV 1187) and the US approach (UL 1703-2013) are described briefly.

ENV 1187

The ENV 1187 fire test methods, parts 1 to 4, differ in terms of radiant heat, the used brands, additional air flow (wind simulation), tilt angles, amount and size of the demanded test specimen. The pass criteria for each test method are described in EN 13501-5.

In general building, integrated PV systems shall be tested in conjunction with a defined mounting system following the installation instruction of the module manufacturer. When testing PV modules, the mounting material and the joints between modules as well as sealing materials have to be considered and included in the test set-up.

UL 1703-2013

After the changes to ANSI/UL 1703 (2013 edition), the fire classification rating approach takes into account the module or panel in combination with the mounting system and the roof covering products over which it is installed.

Research tests demonstrated that fire class rating of the PV module alone determined according to ANSI/UL 1703-2012 may not predict the fire performance of the PV module, mounting system, and roof assembly as a system. From a safety perspective, the objective of the work turned towards promoting stand-off-mounted PV systems with improved performance and developing a system-based test that would differentiate high performing from low performing designs. Thus, it was decided to pursue the development of a new fire classification test for the PV modules, the mounting components, and the roof assembly as a system.

The new fire classification rating tests in ANSI/UL 1703-2013 involve the combination of the module or panel, the mounting system, and the roof covering system. Because each of these three components has many products in the marketplace, testing every possible combination of the three components could mean thousands of required tests. This is not practical and could stifle market innovation. In response, a number of considerations and provisions were written into the new standard to reduce the number of required tests.

4.5 DESIGN AND INSTALLATION CRITERIA

Basically, the installation of a PV plant on an existing building, in consideration of the components used and their location, may increase the fire risk of that building. This may consist of:

- Interferences with smoke ventilation systems (e.g. partial or total obstruction of skylights, impediments to the opening of smoke extraction systems).
- Obstacle to cooling and fire extinguishing of combustible roofs.
- Risk of flame propagation to external or to internal of the building (presence of wiring on the rooftop of a building divided into several compartments, modification of the rapidity of fire development in a single compartment building).

Furthermore, a possible exposition of firefighters to electric-shock risk has to be considered, given the voltage present in the daylight.

4.5.1 Basic requirements

PV plants shall be designed, built and maintained in a workmanlike. Components and equipment shall be properly made, tested and certificated. For this purpose the following documents, where applicable, shall be considered:

1. IEC and CENELEC standards
2. Rules, Standards and Guidelines issued by OES
3. Codes issued by the Government of Oman, Local Municipalities and other local competent bodies

4.5.2 Prevention of fire propagation from PV plant to inside the building

Unless differently indicated in the Risk Assessment of the given building or required by the Civil Defense Law or other Law in force, at least one of the following measures shall be adopted when installing a PV plant on a rooftop:

- PV modules and their interconnections placed on a roof made of non-combustible material according to ASTM E 136 or EN 13501-3 (class A1)
- Interposition of a non-combustible layer between PV modules with their interconnections and the roof. The non-combustible layer shall be at least one-half-hour fire-rated.
- Preparation of a new risk assessment which take into account the presence of the PV plant to be approved by an Omani competent body

4.5.3 Minimum distance from rooftop openings

PV modules, wirings, switchboard assemblies and other equipment shall not cover any possible ventilation systems on roof, e.g. skylights, smoke extraction systems or chimneys.

In order to allow the correct operation of the smoke extraction systems, PV components and wirings shall be placed at a minimum distance of 1 m (top view) from their perimeter and in any case their position and installation shall be in accordance with the manufacturer's prescriptions.

In order to avoid a sudden propagation of fire to external, PV components and wirings shall be placed at a minimum distance of 0.5 m (top view) from the perimeter of skylights, chimneys or other openings.

Components and equipment installed internally or externally shall not obstruct in any way the existing means of egress.

Minimum elevation of the PV modules above the roof shall be 50 mm.

4.5.4 Emergency disconnection and wiring of PV plants

A manual emergency system for the disconnection of the PV modules from the internal electric plant of the building shall be present. Electrical disconnection may be made on DC side (typically when inverters are placed inside the building) as in Figure 16 or on AC side (typically when inverters are placed outside the building or in an outer cabinet or shelter) as in Figure 17 (disconnection on DC side is possible as an alternative but it is not recommended). A proper fire-compartmented area can be used instead of an external placement of the disconnecter (DC or AC).

The Figure 18 summarizes these possible cases (the manual call point is not necessary in case of One-and-Two-Family Dwelling).

The passage of cables from PV modules inside the building before the disconnecter is allowed provided that inside the building they are placed in a channel with a fire-rated protection of at least one-half-hour.

In all above mentioned buildings, except for One-and-Two-Family Dwelling, electrical disconnection shall be operated by means of a manual call point installed at the height of 1.1 – 1.4 m above floor level and in a plain, accessible, well lit and free-hindrance place. The manual call point shall be close to an external access in order to be easily operated by personnel or firefighters.

The manual call point shall be in accordance with NFPA 72 and a proper label shall indicate that it actuates the disconnection of the PV plant.

In case of High Hazard buildings a detailed design including safety measures and new "risk assessment" shall be submitted to the Omani competent Body for approval.

In case of BIPV not installed in fire compartmented areas it is necessary to adopt one of the following further measures:

- The manual call point also disconnects or short-circuits separately each module or groups of modules each of them having an open circuit voltage at STC not greater than 120 VDC.
- Installation of an Arc Fault Circuit Interrupter (AFCI) to protect the DC side from series arcs in accordance with NEC Section 690.11 and UL 1699B. When AFCI detects a failure it disconnects the DC side of the PV plant and generates an audible signal.

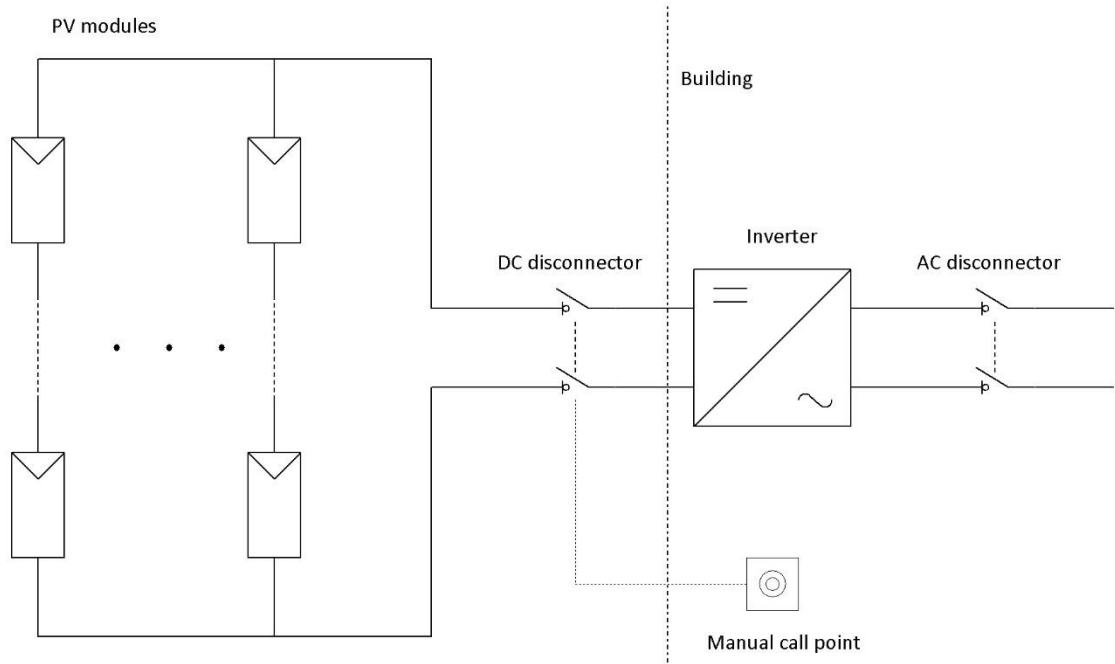


Figure 16 – Disconnection from a manual call point in case of inverter inside the building

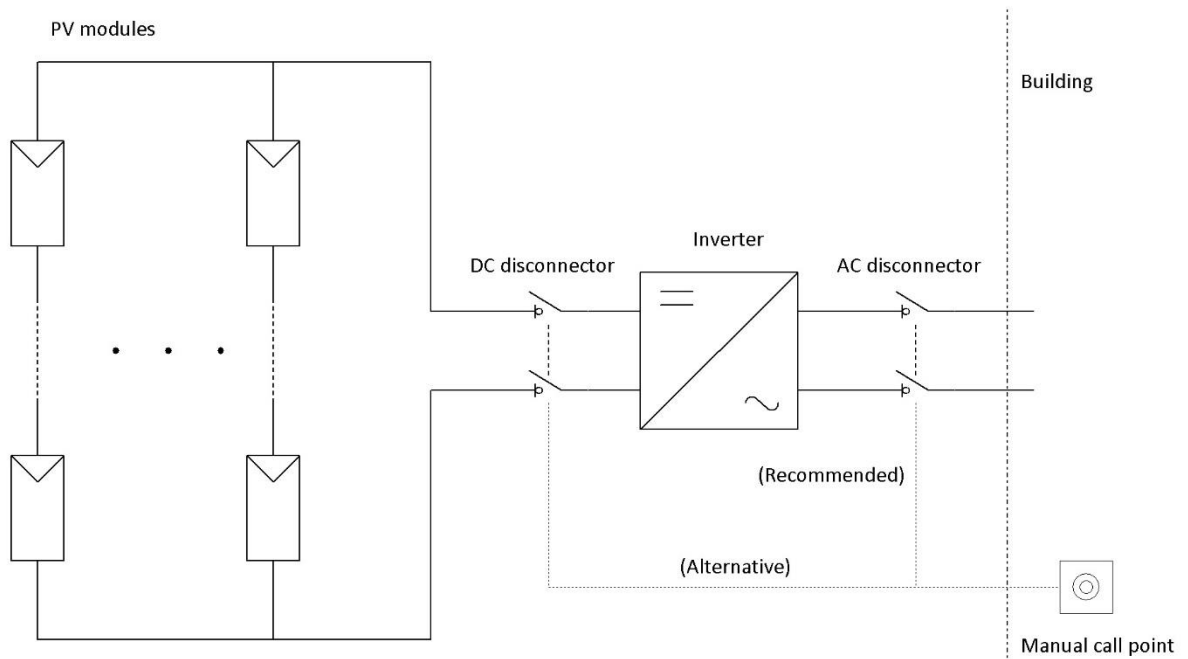


Figure 17 – Disconnection from a manual call point in case of inverter outside the building

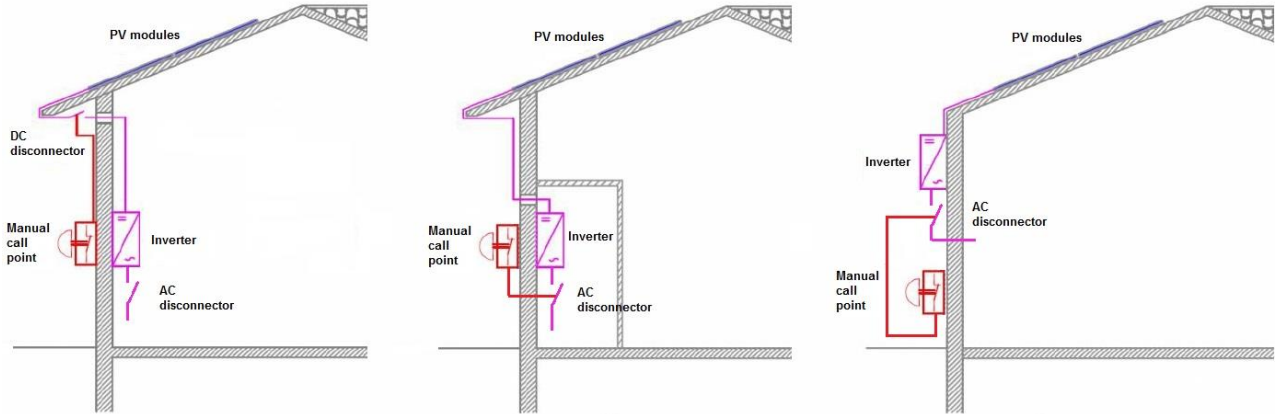


Figure 18 – Possible placement of the inverter and disconnecter with the manual call point (when required)

4.5.5 Labelling and marking

A simplified site plan with the position of PV modules, cables and disconnectors as in the example of Figure 19 shall be exposed close to the main energy meter. If a manual call point is present in the building a further copy of the simplified site plan shall be exposed on the side.

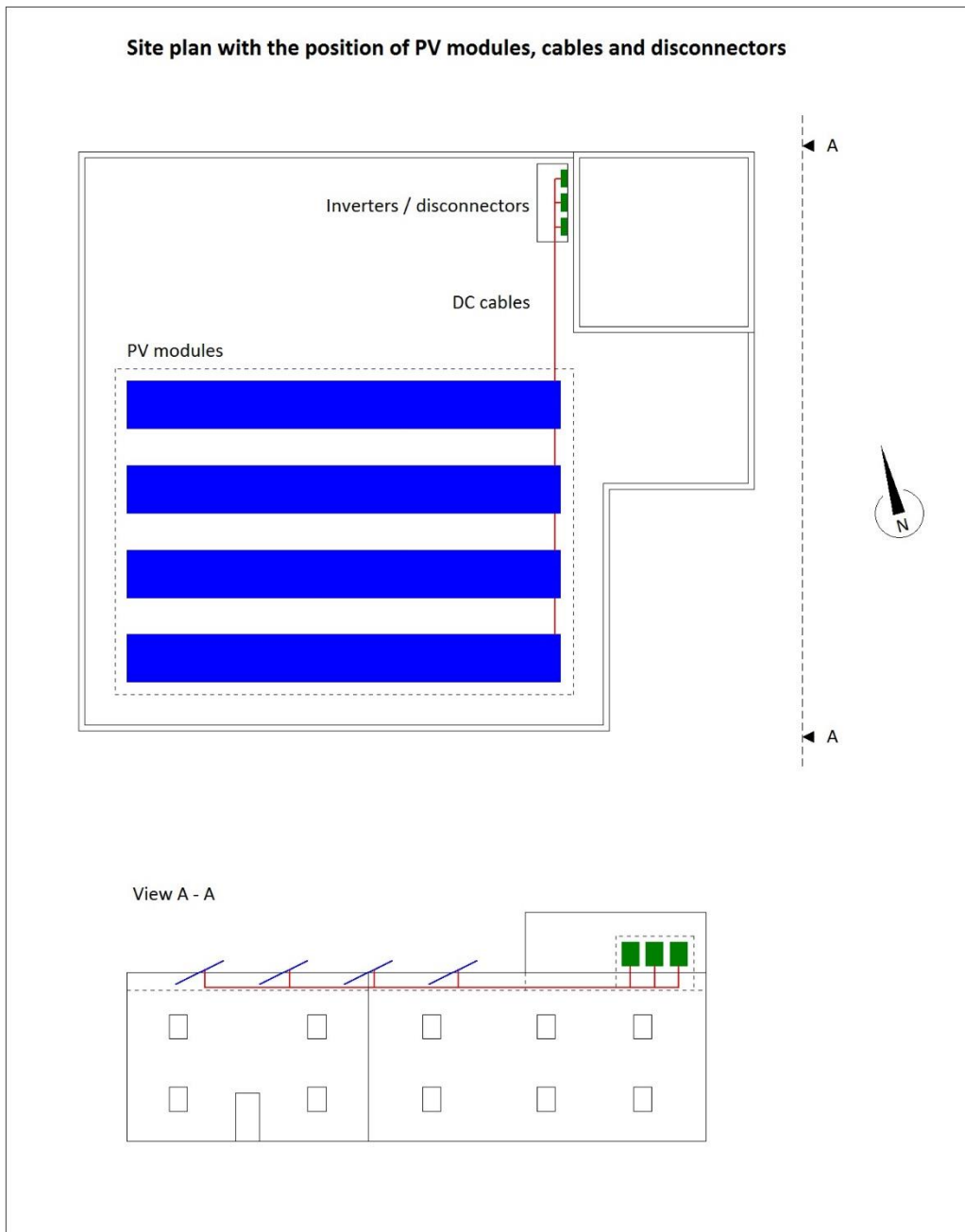


Figure 19 – Example of simplified site plan to be exposed in the building

The area where PV modules, cables and other equipment are located, if accessible, shall be marked by proper signs as that reported in Figure 20. They shall also be placed in correspondence of each access door to the PV plant. The same signs shall be used to indicate cables before disconnectors and shall be placed every 5 meters along the cable.

These signs shall be UV resistant, and shall indicate the DC voltage as the Open Circuit Voltage at STC of the PV array. Their minimum size is 200 × 200 mm (w × h).



Figure 20 – Sign to be used to indicate the presence of a PV plant

4.5.6 Summary of design and installation criteria

The following Table 1 summarizes the design and installation criteria mentioned in the previous paragraphs.

Table 1 – Summary of prescriptions with reference to design and installation criteria

Criteria	Descriptions	Notes
1 Basic requirements	<p>A. Fulfilment of applicable standards, rules and codes:</p> <p>A.1. IEC and CENELEC standards</p> <p>A.1.1. IEC 61730-2 Fire Class C (BAPV)</p> <p>A.1.2. IEC 61730-2 Fire Class A or B (BIPV)</p> <p>A.2. Rules, Standards and Guidelines issued by AER</p> <p>A.3. Codes issued by Omani Government and Local Municipalities</p> <p>A.N. Any other local competent bodies</p>	Applicable standards as specified in document "Connection Guidelines"
2 Prevention of fire propagation from PV plant to inside the building	<p>A. Apply one of the following:</p> <p>A.1. Roof made of non-combustible material according to ASTM E 136 or EN 13501-3 (class A1)</p> <p>A.2. Roof segregated from PV modules / interconnections by interposing a non-combustible layer (minimum fire-rating: 30 min)</p> <p>A.3. Submit "risk assessment" document to Civil Defence for approval</p> <p>B. High Hazard buildings:</p> <p>B.1. Submit detail design including safety measures and new "risk assessment" document to the Omani competent Body</p>	
3 Minimum distance from smoke extraction systems and openings on rooftop	<p>A. Smoke extraction systems, PV modules, components and wirings:</p> <p>A.1. minimum 1 m (top view) from the perimeter of the systems</p> <p>A.2. placed and installed according to manufacturer's prescriptions</p> <p>B. Skylights, chimneys, any openings, PV modules, components and wirings:</p> <p>B.1. minimum 0.5 m (top view) from the perimeter of the openings</p> <p>C. Means of egress, PV modules, components and wirings:</p> <p>D. forbidden in obstructing positions</p>	

Criteria	Descriptions	Notes
4 Emergency disconnection and wiring penetrations of PV plants	<p>A. Manual disconnecter on side:</p> <p>A.1. DC when inverters are inside building</p> <p>A.2. AC when inverters are outside building (outdoor or in cabinet/ shelter)</p> <p><u>Manual call point not necessary in case of One-and-Two-Family Dwelling</u></p> <p>B. Cables penetration inside building without manual disconnecter: provided cables inside building are in conduits with fire-rating protection of minimum 30 min</p> <p>C. Position of the manual call point: at 1.1 – 1.4 m above floor level and in plain, accessible, well lit and free-hindrance place, close to an external access for an easier emergency operation</p> <p>D. Standard reference for manual call point: in accordance with NFPA 72 and with label showing it actuates PV plant disconnection</p> <p>E. BIPV not installed in fire compartmented areas: adopt one of the following measures:</p> <p>E.1. Install manual call point disconnects or short-circuits separately each module or groups of modules with $V_{oc@STC} < 120$ VDC</p> <p>E.2. Install Arc Fault Circuit Interrupter (AFCI) to protect DC side from series arcs in accordance with NEC Section 690.11 and UL 1699B</p>	
5 Labeling and marking	<p>A. Install warning signs in any area where accessible PV modules, components and wirings are located:</p> <p>A.1. in correspondence of each access door to the PV plant</p> <p>A.2. to indicate cables before disconnectors every 5 m</p> <p>A.3. signs shall indicate DC voltage as the $V_{oc@STC}$ of PV array</p> <p>B. Size and characteristics of warning signs:</p> <p>B.1. signs minimum size 200 (w) x 200 (h) mm</p> <p>B.2. UV resistant</p> <p>C. Site plan with the position of PV modules, cables and disconnectors to be placed near:</p> <p>C.1. the main energy meter</p> <p>C.2. each manual call point, if any</p>	

5 CONSTRUCTION AND CONNECTION

Roof characteristics and PV modules position: when it is not a BAPV or a BIPV the modules and arrays have to be mounted on the roof with a proper structure.

Basically like any other structure to be placed on the roof there are rule of good practice to follow and rules for better performance of environment and plant in relation to the shape of the roof and other artefacts already in place on the roof.

Good practices are intended rules of good design of the generator both from efficiency point of view and environmental compliance. A PV panel installation identifies key points to be respected in order not to impact its performance. These include shadow presence on the panel surface under certain conditions (a time in the day or in the season when a portion of the roof or an artefact can affect part of the installation).

There are no doubts that the example of Figure 21, apart from any considerations of aesthetic order, represents a poor practice were a few technical errors are clearly visible:

- In spite of the little power of the systems, PV modules have several different orientations and inclinations. Unless the power conversion is made by using AC modules or DC optimizers, the system turns to be rather inefficient.
- The use of long support structures to anchor the PV modules on the roof decreases the wind resistance of the whole structure and may jeopardize the stability of the rooftop.

On the contrary, even if one has a reduced surface a proper design may lead to an excellent result as shown in Figure 22.



Figure 21 – Example of a poor installation on a rooftop



Figure 22 – Example of an excellent installation with PV modules integrated in the rooftop

Electrically, the DC section of the PV system shall comply with the standard IEC 62548 and, considering also the AC part, one should also reference the IEC 60364-7-712.

Recommendation

The recommendations are from an aesthetic and architectural point of view and can be addressed at design level. In order to have PV systems well integrated with building and landscape environment, a suitable set of rules and best practices for installation in different environments should be issued by competent authorities.

6 INSPECTION AND O&M

6.1 Inspection

A PV system is required to adhere to a range of guidelines, regulations and safety standards. The inspection shall verify that the design and installation of the plant has been carried out according to specifications and international standards.

The standard IEC 62446-1 is recommended for testing, documentation, commissioning test and inspection. The PV system performances may be assessed by means of IEC 61724-2 for power capacity and IEC 61724-3 for energy.

During inspection also many plant details that are related to safety and fire prevention issues shall be assessed:

- Visual inspection of the generator field, including support structure, modules, mounting, cabling and shadowing;
- Visual inspection of the inverter and connecting boxes, including location and mounting;
- Visual inspection of the safety system and labelling, including lightning and overvoltage protection (presence of signal indicating the risk of electroshock);
- Wiring layout and order of cables in the site;
- Correct earthing of arrays;
- Correct placement and position of cables and electrical distribution boxes (including visual inspection of cabling to the inverter);
- Correct isolation of batteries (if any), inverters and parallel connection to the network;
- Compliance with the standards of electrical equipment used in the plant;
- General cleaning of the site (debris can be a cause of ignition of fire);
- Documentation inspection: readiness with local legislation on documentation.

To support these tasks, the project envisages many other processes such as:

- Accreditation of Consultants/Contractors. Companies need to have Solar PV certified professionals on their team;
- Guidelines for assessing the compliance of a PV system according to standard and design;
- Guidelines for assessing the operation and performance of PV system;
- Check list for exploitation of above said guidelines.

6.2 Operation and Maintenance

Operation and maintenance issues are most treated in the “Safety of People” report particularly from the installer side. As to the environmental safety issues, they shall include:

- Maintenance and cleaning recommendations, especially for rooftop PV systems;
- Use of water and compressed air generation for cleaning;

The identification of suitable cleaning method is a choice of the designer and a responsibility of the Owner as long as they want to avoid a decrease of the performance and of the safety level of the PV system.

A proper monitoring system is highly recommended in order to facilitate the O&M activities. This system should comply with the requirements of IEC 61724-1. A periodic assessment of the PV system performances according to IEC 61724-2/3 is also recommended.

Recommendation

The designer shall issue a description of the O&M procedure for modules cleaning and dust removal that will integrate the documentation, for evaluation and/or getting approval at the Design Approval stage.

7 DECOMMISSIONING

During the decommissioning phase, there are some main safety issues to be taken into account. The main operations are:

- Correct disconnection of the plant;
- Correct dismantling;
- Separation of recyclable parts;
- Correct disposal or separated materials;
- Final remediation of the site.

It is known that the main issue in this process is the disposal of PV modules. In order to get a proper decommissioning project an economic scheme for financing the operations should be prepared in advance. In addition, the decommissioning plan has to be consistent with the design and construction, particularly in case a PV system was designed as a temporary installation.

Decommissioning issues include:

- Dismantling process, actions to be put in place previously or previewed: “disposal actions” or recycling of PV panels and other part and materials (i.e. inverter and wires, cables).
- Dismantling of metering devices.
- In case of replacement or substitution of PV modules, update of modules database. In case of disposal of PV modules, update of modules database and also of database of modules definitely treated as a waste.
- Bring back the installation site to its original configuration.

Recommendations

A disconnection and decommissioning phase shall be designed. The most important task however shall be the disposal and recycling of PV modules at end of life.

7.1 Solar Panel Recycling and end-of-life issues

The widespread technology of solar photovoltaic has installed tons of panel that, in the future, will stop working due to age, thus will need to be disposed or recycled. The life duration of a solar panel is between 20 and 30 years. In order to be prepared to correctly remove this electric waste both European Union and USA set strategies.

The Waste Electrical and Electronic Equipment Directive (WEEE Directive) is the law of the European Union regulating the treatment of electrical and electronic waste at the end of their life cycle. Since 2012, WEEE has set up the rules for the collection and recycling of photovoltaic panels. The Producers are now responsible for financing the taking back and disposing of the modules. The main goal of the directive is to reduce waste volumes and foster innovation by making Producers of electronic and electric products more responsible.

The European Union has decided to promote the practice of “Extended Producers Responsibility” for PV panels. This means that it would be up to the Producers of the modules to collect and dispose them of at the end of their life-cycle. End-users will not have to pay any additional cost to dispose of the PV modules and will have to be instructed from the Producers on how to proceed with the take-back of the modules.

According to WEEE, there are four categories of Producers: manufacturers, distributors or resellers, importers and internet or distance sellers. When first putting panels on a or multiple markets of the EU

Member States, they must all comply with national WEEE regulations of these markets by carrying out a series of requirements, including a number of administrative and financial duties with the designated authorities. Producers are a key figure in the disposal and recycling of photovoltaic modules because they are ultimately responsible for the panels they sell in the European Union.

In the United States there is no federal directive on recycling electronic equipment and only 17 states ban disposal of electronics in landfills. In fact, among the 50 states, there are 50 different sets of waste reduction rules, much like there are for the solar energy permitting process. But a number of individual cities and counties have started programs to support the recycling of electronic equipment – including PVs – based on the work of several independent organizations.

Recycling PV materials, especially the aluminium, silver, and rare earth materials, presents unique challenges since they require multiple technologies and variations within specific types of recycling technologies to separate the PV module components. The recycling rates are interesting (100 percent recovery of aluminium, 95 percent of glass, and 30 percent of rare metals) and there are already companies in this growing business.

Recommendations

It is recommended to follow the regulations in force in Oman for the disposal of Waste Electrical Electronic Equipment including specific regulations for recycling and disposal of solar panel at their end-of-life.