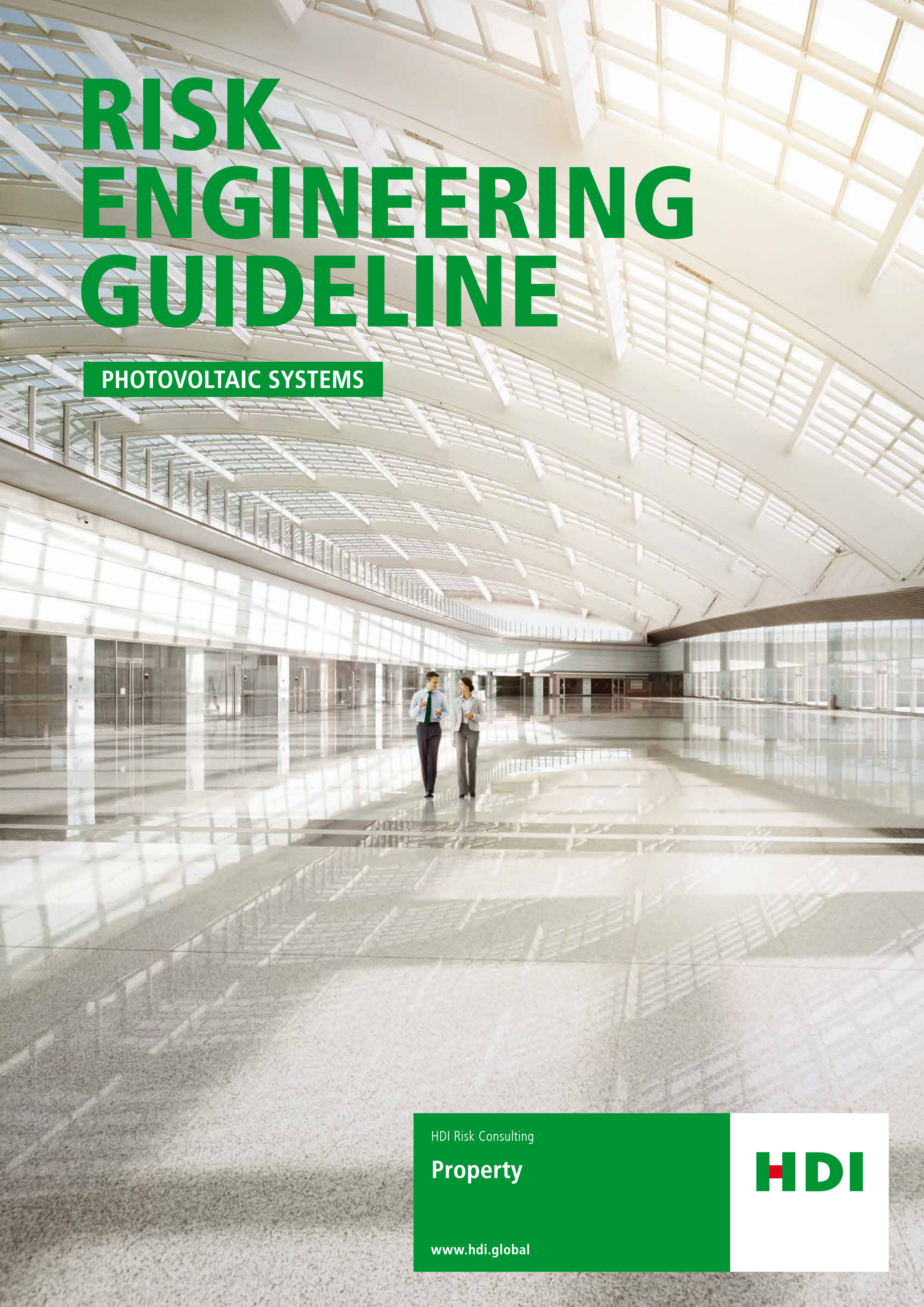
RISK ENGINEERING GUIDELINE

PHOTOVOLTAIC SYSTEMS



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Most damages of photovoltaic systems could be prevented by appropriate planning and assembly.

Photovoltaic systems are exposed to varying degrees of risk during an operating period of 25 years.

General.

Photovoltaic systems (PV systems) become more and more important in the private sector but in the industrial sector as well. These systems are usually installed on roofs of residential and public buildings, on commercial, industrial or agricultural buildings and also on unoccupied spaces.

The principle of the photovoltaic effect was discovered in 1839 by the French physicist Alexandre Edmond Becquerel and scientifically explained by Albert Einstein in 1905. The direct conversion of energy radiated by the sun in photovoltaic systems supplements conventional power generation in power stations which prevails today.

There are different versions of PV modules. As well as the familiar framed PV modules – frameless modules, modules on flexible films or modules shaped like roof tiles are now also available.

Modules made of thick-film cells (mono- or polycrystalline silicon) are the best known type. However, enormous potential is also attributed to modules comprising thin-film cells made of cadmium telluride (CdTe) or copper indium diselenide (CIS).

A PV system essentially comprises PV modules (these being made from single PV cells), power inverter, switching points, safety equipment (fuses, lightning and surge arresters), measuring units as well as DC and AC circuit cables (Fig. 1).

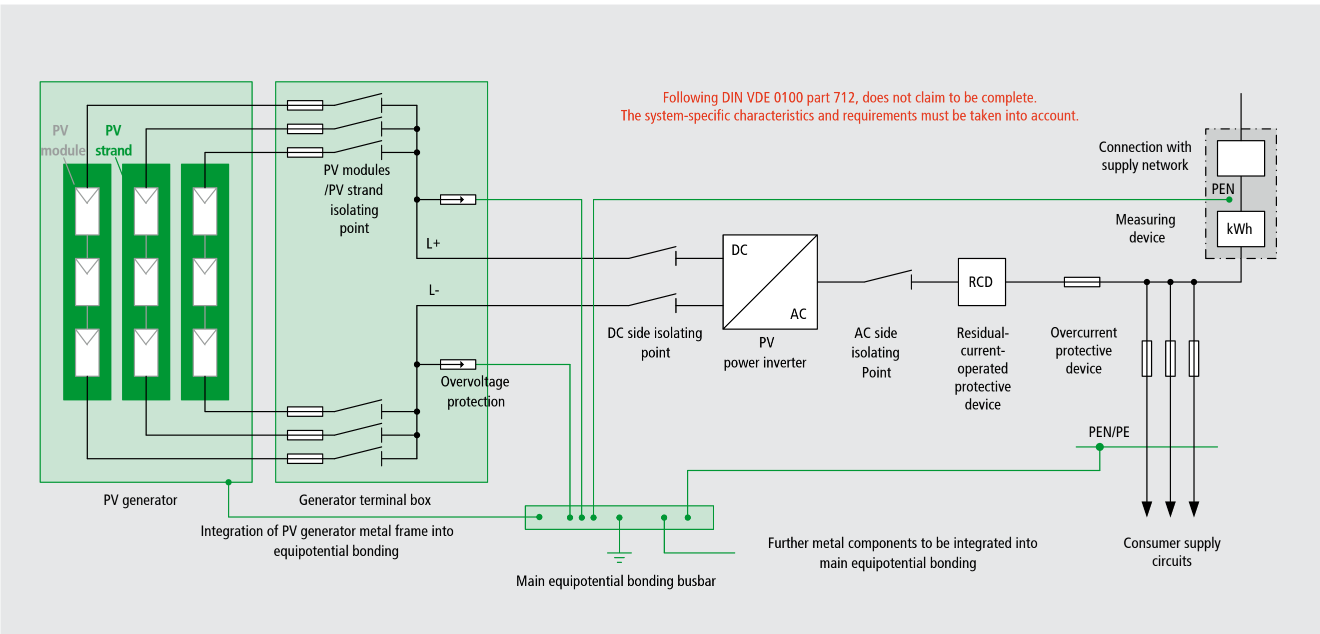

Fig. 1: Basic structure of a PV system

Several PV modules can be combined into PV generators in order to generate larger amounts of power. The output of PV generators is measured in kilowatt peak (kWp). The unit kWp is the maximum possible output of a PV generator under standard test conditions (IEC 60904). In this context, optimum insolation of 1000 watt per square meter is assumed.

Depending on the orientation of the PV system, different insolation levels can be achieved. In Central Europe (Germany), the optimum is achieved when the system is oriented towards the South, with a 30 % inclination. Based on an average insolation, a 1 kWp generator set up in Central Europe produces around 900 kWh per year.

As regards design – a distinction can be made between fixed PV generators and tracking systems. Tracking systems are generators which track the sun by means of electric motors. Twin-axle tracking systems achieve up to 30 % more output than fixed systems.

A further distinction is also made between island systems (mains-independent PV systems) and PV systems connected with the mains network. The first category has additional batteries allowing storage of the electric energy and plays a relatively minor role (examples of island systems: parking meters, mountain huts, emergency telephones etc.).

The dividing line between small and large PV systems is at an output of 100 kWp. Systems with an output of up to 10 kWp are mostly installed on roofs of private houses. Roofs and façades of commercial buildings (e. g. halls, DIY superstores) usually accommodate systems with an output from 10 to 100 kWp. Large PV systems have an output of more than 100 kWp up to several megawatt peak. They are mostly set up on unoccupied areas and on industrial buildings.

Isolating points on PV power inverters and on the PV modules/strands enable safe shut-down in case of danger.

As PV modules always generate electricity when light is present, isolating points are required on the PV power inverter (DC and AC side). Additional isolating points on the PV modules and PV strands (Fig. 1) enable safe shutdown of the PV system in case of danger or fire.

Sloping and flat roofs as well as façades of buildings are suited for installing PV generators. Retrofitting on existing roofs is by installation on base frames, with the roof covering remaining completely intact (which in fact is a must). PV modules can also be installed as part of the building shell. In this case, they substitute roof tiles and façade elements. Their task is therefore multifunctional, i. e. they generate electricity and also protect the building against the weather.

In a similar way as on flat roofs, PV systems set up on unoccupied spaces consist of modules installed on supporting structures that are mostly made of metal or (glass-fibre reinforced) plastic or timber in exceptional cases, and inclined above the ground. The supporting structures are weighed down with concrete sleepers or gravel-filled flat containers and must withstand the mechanical loads caused by snow, ice and wind.

1 Risk situation.

Photovoltaic systems are designed for a service life of 25 years or more and are considered to be particularly reliable and robust.

Photovoltaic systems are exposed to different various influences during their entire service life:

- Effects of natural events such as storm, hailstorm, lightning, snow pressure, frost and fire
- Loss/failure by improper planning and execution
- Theft from remote or hidden sites
- Vandalism
- Cables and lines damaged by rodents
- Additional hazards also arise as a result fire in the PV system itself or in buildings on which PV systems are installed. Especially emergency services might be exposed to the following hazards:
  - Electrocution due to constant electric voltage, generated on the DC side during light generation
  - Toxic gases/respiratory poisons
  - Parts falling down

As a consequence of this potential hazard, intervention or fire-fighting may be delayed, with the possibility of having to leave a fire to burn – permitting a "controlled combustion" without any intervention, dependant on the conditions concerned. Closed PV generator areas are fixed to the building and cannot be opened without a hazard during a fire. This leads to difficult manual fire fighting actions in the roof section.

Further, if there is a failure to follow appropriate building (fire etc.) regulations during the installation of the equipment, a fire may also spread across fire compartments during the early stages of a fire outbreak. This is the case in particular when combustible materials (e. g. cable runs) extend accross or through fire walls or when fire wall penetrations required by cable routes are not properly closed.

2 Typical reasons of losses.

The reasons for a loss can frequently be identified only after commissioning or after extended service life.

The use of insufficient number or in-correct dimensioning of load-carrying fastenings of the PV generator is often the origin of losses. The static conditions of the building are frequently not considered to a sufficient extent either or not considered at all. In combination with snow, ice and wind loads, such shortcomings also lead to losses on the PV system itself or on the building. Failure to take possible snow and ice loads into account may additionally cause broken glazing of the PV modules (Fig. 2 to 4).
In the field of cabling – especially underground cabling – losses can be caused by rodents (rats, martens etc.) unless suitable precautions (metal cable conduit) are made (Fig. 5).

UV radiation and thermal cycling also cause premature ageing of sealing materials, which can lead to moisture issues and ingress of rain water into the closed PV modules. In addition, failures of the PV power inverter caused by wear lead to standstill of PV system components. As experience indicates, the service life of power inverters is the same as the usual service life of electric/electronic devices.

Incorrect planning and installation often cause losses on PV modules, system components (e. g. PV power inverters) and the roof covering of buildings.

The simple disassembly in combination with high concentration of values leads to an increased theft risk of PV modules, especially in systems installed on unoccupied areas.
PV systems set up on remote areas are difficult to protect efficiently against theft and vandalism.

PV systems installed at exposed spots (e. g. roofs, unoccupied spaces etc.) are exposed to a lightning discharge hazard due to their position and arrangement.

The PV system itself usually does not contribute to an increased lightning strike rate on buildings unless the PV generator is installed on a supporting structure on a flat roof. Overvoltage caused by lightning may cause losses on the electric equipment of the PV system (e. g. PV modules, PV-power inverter etc.).

Faulty electric installation of PV systems may cause not only system losses, but also substantial building losses, especially in case of fire.

Possible reasons include:

- Insufficient conductor cross-sections
- Incorrect or loose terminals/connectors
- Improper laying of lines, e. g. accross sharp edges
- Improperly installed cable penetrations into buildings (moisture ingress leads to damage where there is insufficient sealing of roof covering)

Fig.2: Snow load

Fig. 3: Broken glass

Fig. 4: Broken tiles

Fig. 5: Rat bites

3 Loss prevention.

Proper system planning, installation and maintenance are critical factors for loss prevention.

3.1 Planning phase

The following aspects must be considered in the planning phase:

- Contractual agreement regarding the relevant quality assurance rules when ordering, designing and installing PV systems.
- Proof of sufficient strength to support the structure (building roof structure, installation system of PV system and/or supporting structure of systems set up on unoccupied spaces). The relevant snow and wind loads must also be observed.
- Where the roof covering or the outer building shell is affected by the installation, roofers installation standards should apply. It is recommended that a roofer and/or a technical planning specialist be involved in the installation work on the roof.
- In case of systems set up on open land, proof of sufficient soil-bearing capacity should be provided (e. g. expert soil report).
- The electrical installation must follow relevant national codes/rules (e. g. IEC 60364-7-712: Low-voltage electrical installations – part 7-712: Requirements for special installations or locations – photovoltaic (PV) power systems). If the PV system is connected with the electric building infrastructure, generally recognised rules must also be observed.

Lightning and overvoltage protection must be planned properly and provide adequate risk protection.

Attention must also be paid to the need for installing suitable lightning arresters and surge arresters both on the DC and on the AC side (special protectors for the DC side). As a supplement, reference is made to the relevant technical standards (e. g. NFPA 780: Standard for the installation of lightning protection systems, IEC 60364-7-712: Low-voltage electrical installations – part 7-712: Requirements for special installations or locations – photovoltaic (PV) power systems).

- When designing the electric equipment, especially the lines and switching devices, a simultaneity factor of 1 shall be used. The reason for this is that the PV system modules generate the most power at maximum insolation. It must also be observed that at maximum insolation, the equipment will be subject to the highest temperatures.
- To avoid possible hazards to persons in case of fire, suitable switching points must be provided both on the AC and on the DC side of the power inverter. It is also recommended to provide switches that can be controlled by a telecontrol system for limiting the voltage amount on the DC side in order to ensure that the applied voltage is limited to the amount of the module voltage. The maximum module voltage should be selected so that physiologic effects on men and animals will not occur. Reference is made to IEC 60479.

3.2 Delivery and installation

The following loss prevention measures must be observed during delivery and installation:

- Modules must be properly transported, stored, fastened and installed. The manufacturer’s instructions given in the installation manual must be complied with.
- When a system is installed on the ground, the premises must be surrounded by a fence prior to delivery of the PV modules (steel trellis fence, minimum height 2 m). Instead of setting up temporary hoarding, the fence required for the operation phase should be set up prior to commencing system installation.
- PV systems/PV modules must be installed properly, observing the following aspects:
  - Structural statics, wind/snow loads, type of fastening.
  - When fixing the modules at their narrow sides, the allowed maximum deflection may be exceeded. An approval from the module manufacturers must be obtained (caution in areas with high snow and wind loads).
  - When installing a system on a roof, a sufficient clearance (5 cm min.) from the roof covering must be ensured so that good ventilation of the PV modules is guaranteed (heat dissipation).
  - Tightness of roof (exclusion of broken roof tiles, if necessary cutting-to-size of milling out of roof tiles, cable penetrations must be properly and reliably sealed).
  - The requirements of an expert soil report must be met (consideration of possible settlement, especially in case of made-up ground, open-pit mining areas).
  - When using inserted sections, it must be ensured that water and dirt accumulations as well as moss formation is restricted or excluded altogether if possible.
  - When installing frameless modules, anti-slip safeguards must be provided in addition to lateral fixing with special clamps (with glass protection inserts).
  - Electrolytic corrosion (metal combinations within the installation system and at the roof joints). It is important that only corrosion-resistant metals/metal combinations are used.

Structural fire protection measures must not be affected or neutralised by the installation of PV systems.

- Execution of lightning and overvoltage protection as well as earthing and equipotential bonding (observe eloxal coating of module frame) must be made properly (e. g. according to NFPA 780).
- Structural fire protection measures must not be affected or neutralised by the installation of PV systems.(crossing of fire walls by PV modules and cables is not permitted, cable penetrations in fire walls must be closed using systems approved by the construction supervision).
- Cabling must be effectively protected against weather conditions and damage caused by small animals (rats etc.) (e. g. by laying cables in metal cable ducts or cable conduits).
- DC cable strands between the generator and the power inverter must be laid outside of the building shell if possible.
- Setting-up/installation of power inverters as specified by the manufacturer and protection of electric connections and data cables against accidental disconnection.
- The system installation company must confirm the proper installation of the PV system in an acceptance protocol or commissioning statement.

3.3 Operation and maintenance

The following loss prevention measures must be ensured during system operation:

- Systems installed on remote areas should be protected against theft and vandalism as follows:
  - Protection of facility with a steel trellis fence including an anti-climbing protection (minimum height 2 m).
  - Monitoring of a PV system installed on an un-occupied area by an approved burglar alarm system with alarm transmission to a security company which can be reached round-the-clock.
  - Fixing of PV modules with permanent bolts/ connectors.
  - Installation of a video monitoring system.
  - Connection of module frames with "alarm cables" triggering acoustic and optical alarms, and alarm transmission to a permanently manned office.

The safeguarding measures must consider a reasonable ratio between investment and income.

- Servicing and maintenance of electric PV equipment/ systems by a recognized specialist electric company or a PV systems installation company.
- As a minimum an annual inspection of the lightning protection system surge arresters and replacement if necessary.
- Regular cutting back of green areas (i. e. plants, shrubs, trees) of systems installed on unoccupied spaces.
- Regular checks of the duty to safeguard traffic. It must be ensured that the PV system does not cause any hazard to third parties.
- Introduction of operating company into the technical and operational procedures of the system and documentation of introduction prior to handing-over the PV system.
- Marking of non-interruptible current-conducting cables between the PV generator and the power inverter (e. g. by means of a cable routing diagram provided at the isolating point) as guidance for fire-fighters in case of fire.

4 References.

Local standards should be complied with.

Internationally recognised standards:

IEC 60364-7-712	Low-voltage electrical installations – part 7-712: Requirements for special installations or locations – photovoltaic (PV) power systems
NFPA 780	Standard for the installation of lightning protection systems
IEC 60479	Effects of current on human beings and livestock
IEC 60904	Photovoltaic devices

5 Comment.

The sheet does not claim to be complete and does not relieve from obligation to comply with legal or authority regulations and conditions.

The current version in force of the codes, standards and regulations mentioned above shall be applied.

About HDI Risk Consulting.

HDI Risk Consulting GmbH supports major corporations, industrial and mid-size companies with loss prevention and in establishing risk management systems.

HDI Risk Consulting offers its' customers access to some 180 engineers and experts from a wide range of technical disciplines. We aim to support companies with the management of risks and the development of individual risk-based concepts for insurance cover.

HDI Risk Consulting operates globally in the Property, Motor, Engineering and Marine markets, with particular focus on the identification and assessment of risks and the development of appropriate, individual protection concepts.

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