Erasmus+

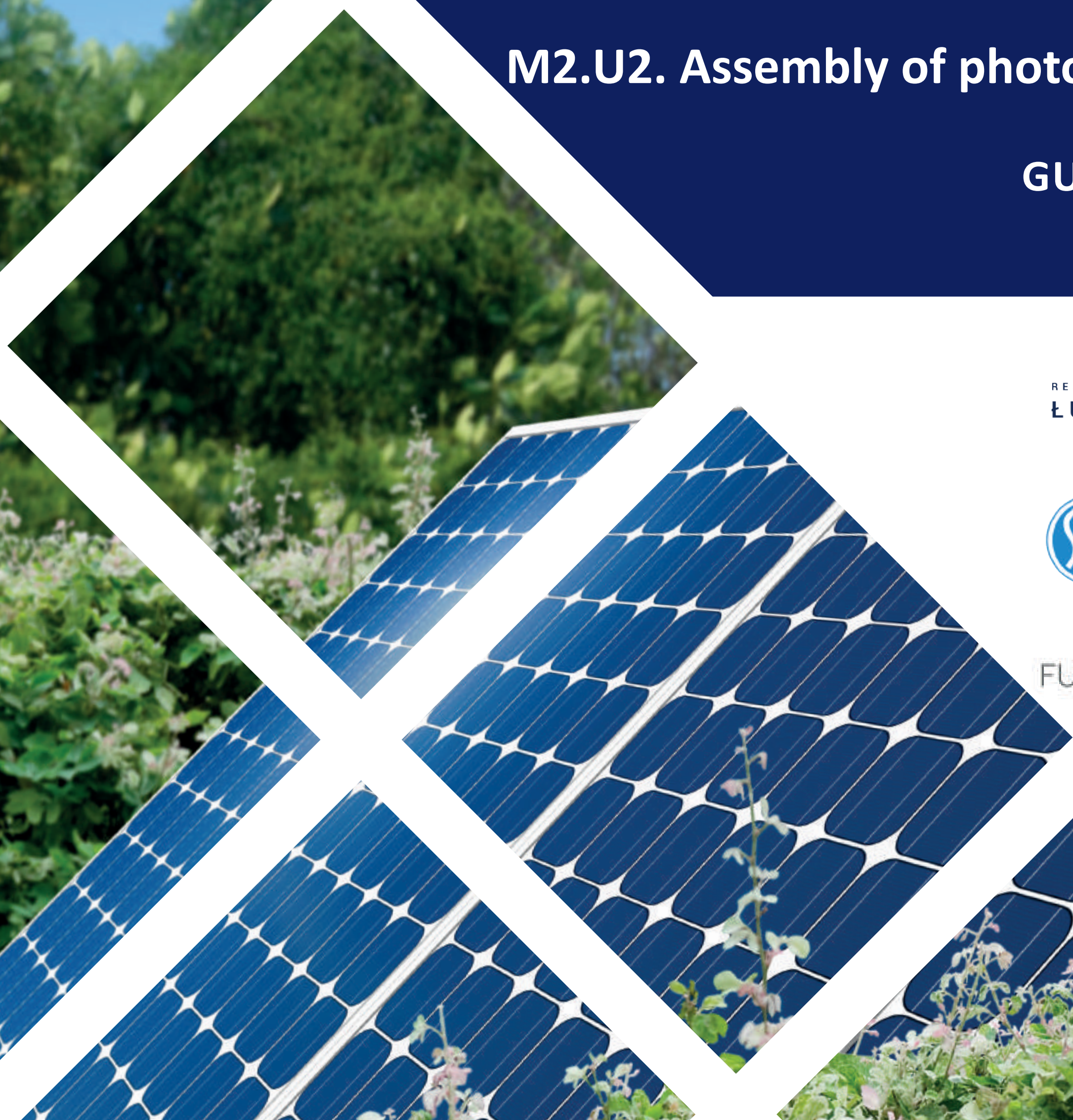
PV TRAINER

Project Erasmus+: Training and certification model for photovoltaic trainers with the use of ECVET system (EU-PV-Trainer). No 2016-1-PL01-KA202-026279

MODULE 2.
PLANNING, INSTALLATION, MODERNISATION AND MAINTENANCE OF PHOTOVOLTAIC INSTALLATIONS

M2.U2. Assembly of photovoltaic installations

GUIDE FOR THE TRAINEE AND THE TRAINER



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Bank of training modules for the photovoltaic trainer with regard to ECVET requirements (stationary learning)

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2018-2019

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GUIDE
FOR THE TRAINEE AND THE TRAINER

2018-2019

Course: Photovoltaics trainer

Module 2. PLANNING, INSTALLATION, MODERNISATION AND MAINTENANCE OF PHOTOVOLTAIC INSTALLATIONS

M2.U2. Assembly of photovoltaic installations

Guide for the trainee and the trainer

2018-2019

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The guide constitutes a didactic development for the modular unit **M2.U2. Assembly of photovoltaic installations** included in the module **M2. PLANNING, INSTALLATION, MODERNISATION AND MAINTENANCE OF PHOTOVOLTAIC INSTALLATIONS** contained in the modular curriculum for the course **Photovoltaics Trainer.**

2018-2019

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1. INTRODUCTION

While commencing performance of professional tasks assigned to the PV trainer in the modular education system, as a training participant you shall acquire necessary knowledge and professional skills included in two modules:

- M1. Planning, organisation, conducting and assessment of professional training,
- M2. Planning, installation, modernisation and maintenance of the photovoltaic installation.

Every module is divided into modular units composed of teaching material, checklist, exercises and progress test.

The study contains materials developed for the modular unit **M2.U2. Assembly of photovoltaic installations** included in the module **M2. Planning, installation, modernisation and maintenance of the photovoltaic installation**

Prior to the commencement of learning, as a training participant you should get familiar with initial requirements and detailed learning outcomes, i.e. knowledge, skills and attitudes that you shall acquire after the end of learning in a given modular unit.

While developing the teaching material, experience of the project partners within the scope of teaching classes on courses preparing future photovoltaic installation installers. Teaching material has been supplemented with e-learning training including e.g. instructional videos.

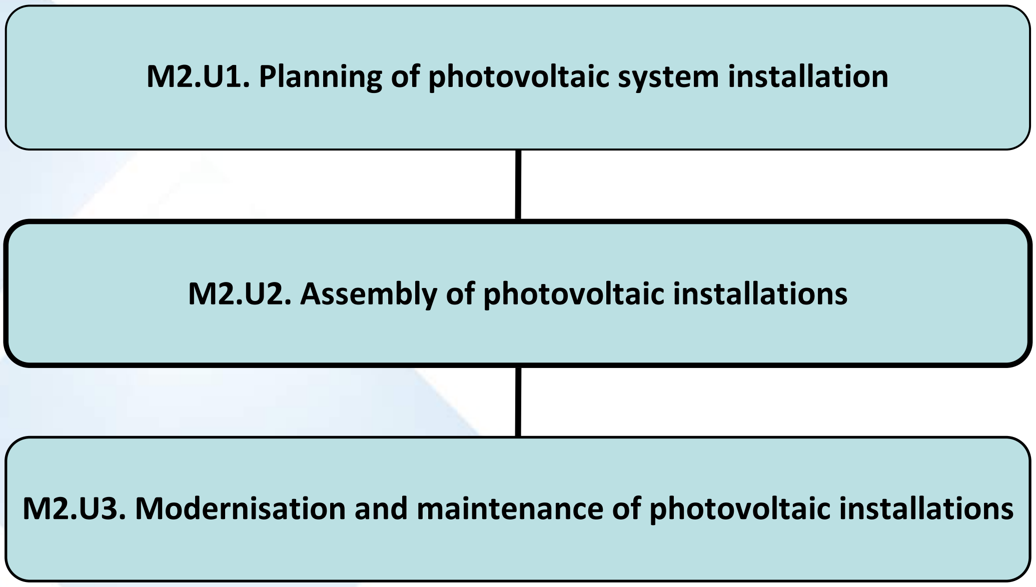
Prior to the performance of exercises, check if you are properly prepared. To this end, use checklists after each teaching material. Every subject is ended with a progress test that shall enable you to define the scope of acquired knowledge and skills. If your results are positive, you can go to the next subject. If not, you should repeat the content necessary for specific skills.

Passing the test in an e-learning version constitutes the basis for passing the modular unit.

Note: in case of teaching content including references to legal acts, it should be kept in mind that they are valid as at the date of study development and must be updated. The teaching content in the module is compliant with the legal status as of 15 August 2018.

The Guide has been developed under the project "**Training and certification model for photovoltaic trainers with use of the ECVET system (EU-PV-Trainer)**" co-funded by the European Union in the Erasmus+ programme *Cooperation for innovation and the exchange of good practices Strategic Partnership for vocational education and training*.

Materials included in the guide reflect only the position of their authors and the European Commission shall not be responsible for their content.



Scheme of the modular unit system in the module **M2. Planning, installation, modernisation and maintenance of photovoltaic installations**

List of modular units and approximate number of teaching hours

Name of module	**Name of modular unit**	**Planned number of teaching hours**
M2. Planning, installation, modernisation and maintenance of photovoltaic installations	M2.U1. Planning of photovoltaic system installation	28
	M2.U2. Assembly of photovoltaic installations	20
	M2.U3. Modernisation and maintenance of photovoltaic installations	16
	Total:	**64**

2. INITIAL REQUIREMENTS

While commencing implementation of the curriculum of the modular unit **M2.U2. Assembly of photovoltaic installations** included in the module **M2. Planning, installation, modernisation and maintenance of photovoltaic installations,** you should be able to:

- use various sources of information,
- determine your own rights and obligations,
- recognise basic legal acts,
- participate in discussion, presentation and defence of your own position,
- feel responsible for your and other's health (life),
- apply basic ethical principles (reliable work, punctuality, keeping one's word, honesty, responsibility for consequences, truthfulness),
- cooperate in a group with consideration of the division of tasks,
- use computer at a basic level.

3. DETAILED LEARNING OUTCOMES

M2.U2. Assembly of photovoltaic installations

After taking classes in the modular unit, the trainee shall achieve the following learning outcomes:

Knowledge (it knows and understands):	Skills (it can):
– Health and safety regulations for the installation. – Installation plan. – Tools and equipment for installation of photovoltaic systems. – Practical principles of module installation, selection and dimensioning of wires and cables. – Rules for configuring and running photovoltaic systems. – Cooperation of batteries with photovoltaic systems. – Surge protection in photovoltaic installations. – Lightning protection and earthing installation. – Installation rules for photovoltaic systems. – Typical assembly installation errors. – Collection conditions and technical documentation of the installation. – Estimate, offer, contract for the installation of photovoltaic devices and systems.	– Applies health and safety rules at the installation and is able to pass them on to participants of the training. – Performs the installation plan. – Uses tools and equipment for assembly. – Evaluates the quality of materials used and works performed. – Installs modules, selects wires and cables in accordance with the design documentation. – Configures and runs photovoltaic systems. – Selection and installation of surge voltage surge arresters in photovoltaic installations. – Selection and assembly of lightning protection and grounding elements. – Installation of photovoltaic systems. – Detection and analysis of typical installation assembly errors. – Development of as-built documentation of a photovoltaic installation. – Performs measurements and measurements of works related to the assembly of photovoltaic devices and systems. – Prepares cost estimates and prepares offers and agreements regarding the installation of photovoltaic devices and systems.

Social competence:

– Finish the work according to criteria of suitability, speed, economy and efficiency.
– Recognize the productive process of the organization.
– Comply with the production standards set by the organization.
– Maintain the work area with the degree of order and cleanliness required by the organization.
– Participate and collaborate actively in the work team.
– Interpret and execute working instructions.

4. TEACHING MATERIAL

4.1. Health and safety regulations for the installation

While discussing the occupational health and safety regulations during the installation of photovoltaic system, the following two main issues cannot be omitted:

– performance of live working and
– performance of works at height.

Particular attention should be paid to the possible occurrence of both risks at the same time.
Installers performing assembly works on buildings' roofs should have permissions allowing them to work at height, should be equipped with special equipment protecting them from fall from a height and electrocution.
Works should be performed carefully, with use of properly selected materials and assembly systems, in order to ensure long and failure-free operation of the photovoltaic system.

Basic activities prior to the work commencement

Prior to the work commencement, the following activities should be performed:

– reading the documentation and planning the sequence of particular work stages,
– preparation of necessary tools with insulated handles protecting from direct electrocution,
– preparation of necessary warning boards,
– Preparation of necessary measuring equipment and necessary insulation equipment, such as dielectric gloves, protecting from consequences of an accidental touching of two wires of different potential (controlled every 6 months), gumboots, carpets, insulating platforms and protective glasses.

Mechanical works

Proper establishment of the supporting structure constitutes the first operation while installing the photovoltaic module. The supporting structure must be selected for an installation type. Nevertheless, no matter if this installation takes place on the ground, on the roof or as BIPV on the facade, the structure must meet the specific technical standards.

Fig. 1. Installation of the mechanical structure for the ground-based PV system
Source: https://solarprofessional.com/articles/products-equipment/racking/ground-mount-pv-racking-systems#.W7uZynszapo, (access: 20 September 2018).

Then, photovoltaic modules should be fixed to the supporting structure in the planned order, with use of original attested assembly elements of a given producer and with use of tools and devices recommended in the manual. Excluding installation on the ground, other installation methods shall constitute the work at height. There is a series of provisions and recommendation of how to perform such works.

Fig. 2. PV system fitter working at a height at the module installation
Source: http://theconversation.com/why-rooftop-solar-is-disruptive-to-utilities-and-the-grid-39032, (access: 20 September 2018).

Works at height belong to the works particularly hazardous, as a fall from a height is very often a cause of accidents, usually serious or fatal.
It is estimated that the fall was the reason of over 30% of all accidents at work. Therefore, during assembly works often performed at a height, there must be ensured exceptional precautions due to the high level of risk to personnel life and health.
Work at height shall mean the work performed on the surface at least 1.0 m over the floor or ground level. Rails should be installed on surfaces above 1.0 m over the floor or ground level, where employees may stay due to the performed installation or to constitute passages.
If, due to the type and conditions for performance of works at height, application of this kind of rails is impossible, other effective measures to protect employees from the fall from height should be used, as appropriate to the type and conditions of work performance.
Works at height should be organised and performed in the way not forcing an employee to lean out of the rail or the outline of the device on which it is standing.
At works on ladders, braces, scaffolds and other platforms up to 2 m, it should be ensured that ladders, braces, scaffolds, platforms and other devices are stable and protected from an unexpected change in location and that they have appropriate resistance to expected load.

Fig. 3. PV system fitter working at a height
Source: https://easi-dec.co.uk/products/solar-access-system, (access: 20 September 2018).

At works performed on scaffolds higher than 2 m from the surrounding level of floor or outside area and on hanging portable platforms, one should in particular:

- ensure safety at vertical communication and workplace access,
- ensure stability of scaffolds and their appropriate resistance to expected load,
- prior to the commencement of scaffold use, its technical acceptance should be conducted pursuant to separate provisions.

While assembling mechanical parts, quality of performed operations should be controlled and verified on an ongoing basis.

Electrical works

After operations related to the structure fitting, performance of electrical connections should be commenced, including electrical connections between modules, performance of cable connections to the connection box, installation of protections and, if necessary, operations related to the lightning installation.

The electrical module is an electrically active tool that produces electricity.

Contact with electrically active module parts may result in blowing, sparking, burning or electrocution. The photovoltaic module produces voltage when solar radiation or other source lights its surface.

A good practice is that during the assembly the module must be covered with a tilt to isolate solar radiation for the time of installation.

Fig. 4. Protection of the PV module with the tilt
Source: http://securedsolar.com/why/, (access: 20 September 2018).

Electrical works that include works at the assembly of photovoltaic installations constitutes the works related to the performance of many electrical connections both in DC and AC circuits.
These works take place on an open ground (ground-based installations and module connections on the roof) and in buildings – guiding of the installation of an inverter and a switchboard and alternating current protections.
Electrical works should be performed by an employee – an adult who graduated from a vocational school as an electrician, has valid professional qualifications, confirmed with a proper certificated, is of good health and has been trained within the scope of OHS.
The photovoltaic system fitter hired for electrical works should be equipped with appropriate working clothes, protective gloves and necessary toolkit.
Prior to the assembly, it should be verified whether every currently installed module is not damaged. If damage is detected, a damaged element or part must be immediately replaced based on original parts or complained about.

Fig. 5. Properly packed PV module
Source: http://sinovoltaics.com/solar-basics/basics-of-solar-panel-packaging/, (access: 20 September 2018).

Assembly of direct current installation

Installation of photovoltaic modules on the roof should be conducted according to the recommendations of manufacturers of modules, electrical cables and connections.
These works should be performed with use of tools recommended by manufacturers of particular elements, while cable crimping should be executed with use of dedicated press tools.

Fig. 6. Exemplary set of DC cable press tools for PV installations
Source: http://www.solar-test-equipment.co.uk/knipex-mc4-tool-kit-24, (access: 20 September 2018).

While arranging cables, special attention should be paid to their protection from mechanical damages. While forging grooves and openings in building walls, protective glasses and gloves should be applied.
Every performed section of electrical installation should be verified with regard to technical fixture, mainly with regard to electrical correctness with use of gauges or meters.

Assembly of alternating current installation

In domestic installations and facade installations integrated with the building, the alternating current part is located inside the building. While for ground-based installations, there may occur alternating current installations on an open ground or in the building. In this case, one should take special care during the assembly due to the land formation and atmospheric conditions.
It is recommended that all outdoor works related to the guiding and connection of elements of the electrical installation should be conducted when it does not rain and there is small or limited humidity.
Assembly of the AC installation covers the installation of an inverter, main AC cable from the inverter to the switchboard, protections and connection to the electrical network in the switchboard. These activities should be conducted according to the recommendations of manufacturers of particular elements.

If damage to the installation is detected during its operation, power supply should be stopped and switched off (for the DC part the only effective solution means covering modules with the tile), while for the AC installation the PV circuit should be switched off with the main DC switch and the AC part – with the main AC switch in the switchboard.
In case of electrocution, every fitter should absolutely know and be able to apply in practice the basic rescue principles for electrocuted persons.
In such a case, the following activities should be performed:

– removal of an electrocuted person as soon as possible from the current operation,
– administration of artificial respiration (cannot be interrupted until the doctor arrives),
– administration of first aid,
– immediate calling of the doctor.

Main causes of fires

In the photovoltaic installation, the fire causes are usually located in the direct current circuit (particularly in those located on the building's roof) and in the AC part in the inverter or the main switchboard.
In the DC part, we usually have to do with ignition caused by damage to the solar wiring or the connection.
Then, an electric arc is established, open fire appears and roofing material catches fire.

Fig. 7. Fire of the PV generator

Source: http://www.greenworldinvestor.com/wp-content/uploads/2016/06/PV-on-fire.jpg, (access: 20 September 2018).

Another reason is constituted by micro-damages of PV modules during their operation or at the stage of production or transport – unnoticed by the fitter. In places of these damages, hot spots are established, where temperature is high enough to cause the appearance of open fire on the roof.

On the AC side, the most common causes of fires include an improper selection of the inverter and its damage during operation, improper selection and assembly of AC cables, as well as improper selection of protections.

This type of situations is usually caused by the lack of initial control of components applied for installation, incompetent performance of assembly works, accidental cutting through wires. It results mainly from improper performance of assembly works by fitters.

Fig. 8. AC switchboard fire in the PV installation

Source: https://www.researchgate.net/publication/254027370_Fault_analysis_in_solar_PV_arrays_under_ Low_irradiance_conditions_and_reverse_connections, (access: 20 September 2018).

4.2. Installation plan

Any works at the photovoltaic system assembly should be planned in detail. A good plan of works and verification of assembled devices shall allow to avoid an unnecessary confusion during the assembly, reduce the assembly time and the number of unexpected situations.
Some elements may demand the installation in casings resistant to atmospheric conditions. The fitter should estimate, at the initial planning stage, the size of space necessary for installing all required components.
Assembly begins from fixing the supporting structures and then photovoltaic modules together with cables and DC side protections. The next stage is constituted by the assembly of inverters, cables of the AC side and the AC side protections.
If it is necessary to perform the lightning installation, it must be installed.
After the performance of all installation works, the fitter conducts an initial system start, keeping in mind the sequence of circuit activation. Firstly, the DC circuit is started and then the AC circuit.
The photovoltaic installation should be shut off in the opposite order, i.e. firstly we switch off the AC circuit from the network and then DC.
During the system pre-commissioning, regulatory operations in inverters, voltage regulators or battery chargers are performed.
After the end of commissioning operations, the fitter should train the user within the scope of an ongoing service of the photovoltaic system.

Fig. 1. Stages during the PV system installation process
Source: own work

STAGE I – Pre-installation activities

A graph in Fig. 1 shows particular pre-installation activities.

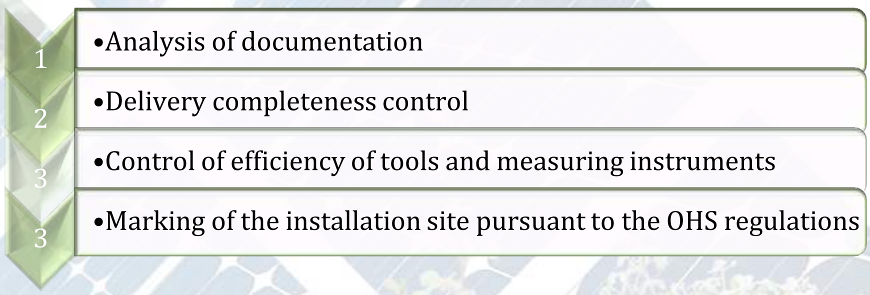


Fig. 2. Pre-installation activities
Source: own work

Analysis of documentation

Documentation delivered to the installation team should be verified with regard to formal aspects, i.e. whether it includes all the information necessary for installation works, whether it is prepared and approved by persons authorised.
Permissions to design electrical installations in the construction industry are granted in every EU country pursuant to the internal regulations.
Moreover, its completeness in an electrical and mechanical part should be verified. Only the correctly prepared documentation should allow for performance of the assembly system according to good building practice.

Delivery completeness control

Delivery completeness control constitutes the next step. Directly while making a purchase on one's own or immediately during delivery, all details must be verified qualitatively and quantitatively. This will enable to avoid future possible disputes with suppliers of particular elements. Special care should be applied to the quality of photovoltaic modules, as their quality conditions users' safety and system efficiency.

Control of efficiency of tools and measuring instruments

While performing electrical installation works, mostly also at height, special care should be applied to the completion of appropriate measuring instruments (meters of voltage, current, insulation, straight edge, etc.), ladders, personal protective equipment, working clothes.
All the above-mentioned details must be efficient, with relevant valid certificates ensuring the correctness of conducted works and necessary safety of fitters during works and of users after launching the entire system.

Marking of the installation site pursuant to the OHS regulations

As the majority of works conducted during the implementation of photovoltaic investments occurs in the field, outside, pursuant to the applicable provisions the installation site must be fenced and clearly and unambiguously marked. This will allow for the avoidance of appearance of third parties in a risk area and for the minimisation of a risk of these parties' participation in an accident.

STAGE II – Installation operations

The graph below shows particular operations during installation

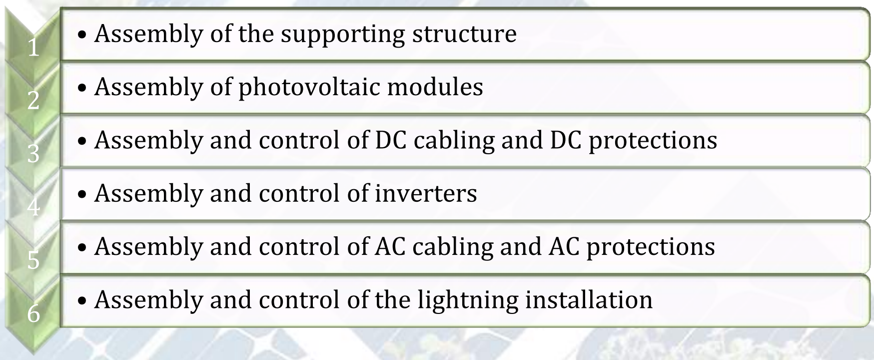


Fig. 3. Further installation steps
Source: own work

Assembly of the supporting structure

After performance of the above-mentioned initial activities, every installation must be started from the arrangement of the supporting structure. No matter if installation is conducted on the ground, on the roof or integrated with the building, the supporting structure must be performed according to the documentation.

One should proceed according to the recommendations of manufacturers of these systems, using recommended tools and measuring devices necessary for the performance of these works. After their completion, assembly correctness should be controlled.

Assembly of photovoltaic modules

Photovoltaic modules constitute a key element on which safety and efficiency of the photovoltaic generator depends. Prior to the commencement of assembly operations, visual inspection of each module should be absolutely performed to detect possible irregularities (frame tightness, glass smoothness, correct installation of the DC box and integrated wires and connectors). Assembly of each module should be verified with regard to its durability, whether wires are not accidentally crimped in the supporting structure, as well as critical distances should be checked (e.g. distance from the roof edge, height from the roof plane). It is important that these modules are assembled in one plane.

Assembly and control of DC cabling and DC protections

DC wires should be guided according to the basic principles. The DC wire delivered to the site should be verified on an ongoing basis with regard to quality. Whether there are not installation cuts, wire kinks. In addition, DC connectors and the DC connection box should be controlled with regard to quality.

Installation should be guided strictly according to the manufacturers' guidelines according to the established cable routes with use of dedicated tools and original wire crimpers. These activities, although seem to be simple, require great carefulness, as their improper performance certainly increases the risk of installation damage, and for sure constitutes the reason of reduced efficiency, as generated power losses on resistances of wires and connections of the entire DC circuit are adequately higher.

After the assembly of the entire PV generator, it is necessary to verify the mechanical assembly correctness and check it with regard to electricity.

Assembly and control of inverters

Assembly of the alternate current circuit shall be commenced from the installation of an inverter (inverters).

Standardly we check the delivery completeness and quality. Then, with use of tools dedicated by the manufacturer, we assemble it in an appropriate place as recommended by the manufacturer. The perfect place for inverter installation should be cool, dry, dust-free and located near PV modules, control box and batteries.

It may be located on the supporting structure, in the switchboard or on the wall. In each of these cases, installation must be safe and ensure proper device ventilation. After verification of the assembly correctness, next we perform necessary programming of the device, dedicated adjustments of electrical parameters necessary for proper operation of the entire installation.

Assembly and control of AC cabling and AC protections

After verification of the correct operation of the installation, we commence the AC cabling assembly. Just like in the case of the DC circuit, AC wires should be guided according to the basic principles of cable route guiding, while the AC wire delivered to the site should be verified on an ongoing basis with regard to quality. Assembly of the AC installation protections should be performed after previous quality control.

Assembly and control of the lightning installation

If necessary, due to the occurrence of the risk of installation damage resulting from lightning, we perform such an installation. As the majority of small installations is founded on roofs, assembly is conducted in the standard way. The lightning installation is assembled with use of traditional spacers. Their number shall significantly exceed the number required at the tension method. In walls and on flat roofs, mainly handles driven and with rawlplugs are applied. In addition, handles pasted with pitch or silicone adhesive (in the case of flat roofs covered with tar paper or coated sheet). If the roof is sheer, usually it is necessary to apply demijohn-like brackets assembled to the surface with use of grapples or tacked to battens. There are also handles pasted to ceramic roof tiles with use of water- and freeze-proof glues.

STAGE III – Post-installation operations

Particular final works in the photovoltaic system installation process are presented on the scheme below.

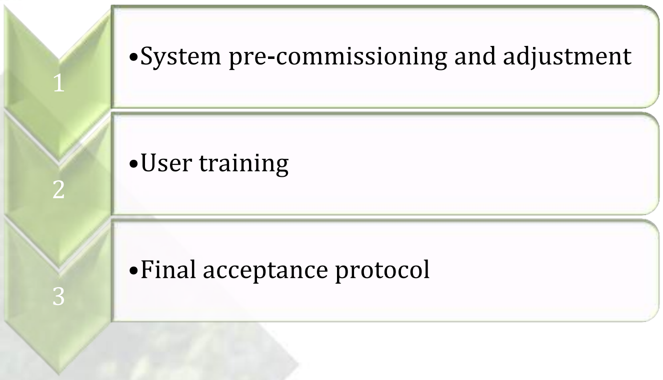


Fig. 4. Final operations in the PV system installation process
Source: own work

System pre-commissioning and adjustment

After construction of the entire installation, pre-commissioning is conducted and then necessary adjustment takes place in order to achieve the assumed system efficiency. Due to the nature of these works, they should be conducted both on the sunny and cloudy day, thus verifying the system operation in various atmospheric conditions.

User training and acceptance protocol

At the end of installation, user training is conducted within the scope of system service (it refers in particular to the user interface and an application associated with it, if any). It is a very important part of the entire process, as thanks to the proper training the user not only becomes acquainted with key principles of operation, but also confirms trust to the installation company and may be recommends it to another interested party.

In addition, we show possible alarms that may appear during the system operation and steps that should be taken when they appear.
The final stage of our work is constituted by the preparation and signature of the installation acceptance protocol with the investor.

4.3. Tools and equipment for installation of photovoltaic systems

During the photovoltaic system assembly, the fitter should have at its disposal dedicated tools facilitating the assembly of the supporting structure and photovoltaic modules. Special attention should also be drawn to tools and preparation of materials required for the DC cabling performance. DC electrical circuits are exposed to the impact of atmospheric conditions throughout the entire installation use period. Any connections, arrangement and fixing of wires and cables, tightening DC connectors should be performed carefully and thoroughly. No chemicals should be introduced to the DC connectors, as they may cause quicker corrosion of materials from which connector joints are made.
Depending on an installation type and distribution of its particular elements, the AC side can be made outdoor or indoor. In each case, the provisions concerning the AC installation assembly should be absolutely applied, while in the case of outdoor installations, materials resistant to atmospheric conditions should be applied. After the performance of cabling-related works, the fitter should conduct measurements verifying the condition of the entire photovoltaic installation.

Tools for the assembly of the supporting structure

The supporting structure constitutes a load-bearing element for the entire installation. From the mechanical point of view, it constitutes an intermediary element between the ground (which is constituted by the ground, roof surface or building facade) and photovoltaic modules. On both sides the safe, durable and mechanically secure connection of all cooperating elements should be ensured. This structure shall be constructed with use of machines and devices for ground works – small excavator, piling device (pile driver), sometimes crawler dozer to level the ground unevenness. For unstable grounds, it is necessary to have devices to pour foundations on which supporting poles shall be arranged.

Fig. 1. Pile driver to drive ground structures
Source: https://solarprofessional.com/articles/design-installation/utility-scale-pv-ground-mount-racking-solutions/page/0/1#.W7z-P3szapo, (access: 20 September 2018).

Moreover, for all types of supporting structures, there shall be necessary the spanners to screw modules, scaffold ladders, level set and very important personal protective equipment.

Tools and instrumentation for the assembly of photovoltaic modules

Due to the simple construction of photovoltaic modules and various assembly elements dedicated by various manufacturers and adjusted to them, a set of tools for their foundation is reduced to minimum.

The set of simple spanners (sometime one is enough), screw gun, metre measure, pencil. It results also from the necessary minimisation of the quantity of tools mandatory for the performance of these works, as they are conducted at a height and often on a slope roof surface.

Fig. 2. Exemplary assembly set
Source: https://www.solaris-shop.com/blog/essential-tools-for-solar-installations/, (access: 20 September 2018).

Tools for the assembly of the DC cabling of the photovoltaic installation

It is necessary to have a metre measure, pencil to determine dimensions and the handle and cable route site, proper tool for insulation removal and cable stripping.

The majority of manufacturers of photovoltaic connectors from the DC side offers to fitters the professional tool sets allowing for the performance of connections with minimal resistance and ensuring tightness even at the level of IP68. It is very important, as these wires are operating throughout the entire year outdoors in various atmospheric conditions, often in humid or wet environment.

Fig. 3. Tool set for photovoltaic connectors
Source: http://www.lensunsolar.com/Lensun-MC3-MC4-Solar-Crimping-Tools-Solar-PV-Tool-Kits,Crimper-Stripper-cutter-spanners, (access: 20 September 2018).

Tools for the assembly of photovoltaic inverters

Photovoltaic inverters, depending on processed maximal power, constitute heavy tools. Moreover, despite their high efficiency, losses generated during their operation require effective heat dissipation through the radiator system. Each manufacturer encloses a relevant template to mark out wall holes to its manual.

Moreover, the **drill** with appropriate drill bits and the **spanner set** (maybe the **screw gun**) to screw handles to hang the inverter. In order to connect the electrical part, measuring devices (voltage, current, resistance) shall be necessary.

Tools for the assembly of the AC cabling of the photovoltaic installation

The AC installation may be conducted with use of measuring devices applied for the inverter assembly, while guiding cable routes, wire stripping for connection shall require the **drill**, **screw gun** and sometimes the **spanner set**.

Fig. 4. Exemplary sets of tools for work at the AC installation
Source: https://www.wihatools.com/insulated-slimline-blade-19pc-set, http://www.imtechie.in/best-drilling-machine-reviews/, (access: 20 September 2018).

There shall be necessary the devices to determine the cable length, mark possible points for countersinking for the purposes of cable route fixing.

Measuring devices to control the photovoltaic installation

After the end of the photovoltaic installation construction and performance of the system configuration and adjustment process, final measurements of the entire installation should be performed.

Electrical measurements should be conducted with use of **legalised measuring devices for the measurement of voltage, current and resistance**. A device to control the earth resistance shall be necessary.

Fig. 5. Set of devices to measure the photovoltaic installation
Source: https://www.benning.de/products-en/testing-measuring-and-safety-equipment/measuring-devices-for-photovoltaic/photovoltaic-tester-benning-pv-1-1.html, (access: 20 September 2018).

If it is necessary to accurately determine the entire system capacity, determination of solar irradiation shall be necessary. This measurement requires the use of pyranometer – an instrument to measure total irradiation from the semi-sphere, produced by reflection and diffusion, usually within the entire scope of solar spectrum.

Fig. 6. Pyranometer
Source: https://www.test-therm.pl/katalog-produktow/meteorologia/pyranometry-promieniowanie-calkowite-rozproszone-i-odbite/lp-pyra-12, (access: 20 September 2018).

Selective measurement of selected radiation ranges is possible through the application of relevant filters.

4.4. Practical principles of module installation, selection and dimensioning of wires and cables

Installation of the photovoltaic module should proceed according to the module manufacturer's recommendations. However, there are some general guidelines concerning the majority of photovoltaic modules available on the European market.

Guidelines and recommendations of the photovoltaic modules' manufacturer

Every manufacturer of photovoltaic modules specifies the set of necessary recommendations, guidelines necessary for proper assembly of this element in the catalogue card and in the assembly manual. In addition, it defines a series of reservations concerning the operations that should not be done during the assembly and operation. Meeting the above conditions shall allow for proper operation of the module throughout its entire life cycle.

Inspection of the photovoltaic module, detection of mechanical damages

Inspection of the photovoltaic module should be conducted in order to detect mechanical damages. The fitter should not install a damaged module. This would cause a defective operation of the entire photovoltaic chain in which it is included. The framework should be thoroughly controlled, whether it is not damaged, as well as tightness of the front and rear part of the module, quality of fixing the connection box, cables and DC plugs should be checked.

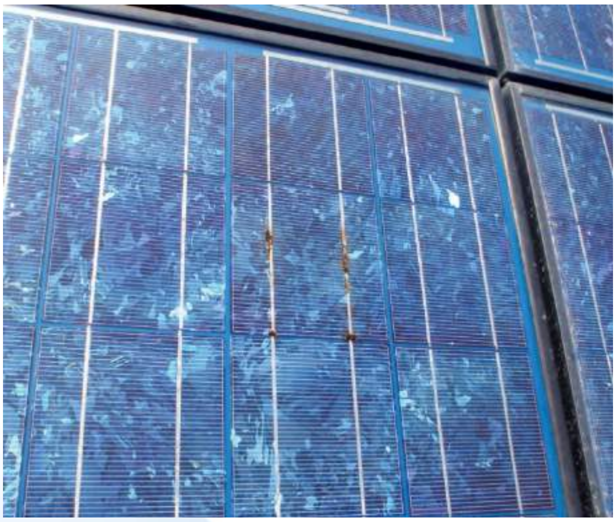


Fig. 1. Example of failed photovoltaic module
Source: https://www.homepower.com/articles/solar-electricity/design-installation/potential-pv-problems, (access: 20 September 2018).

The fitter, while commencing works, specifies based on the design the installation site for photovoltaic modules and verifies the design assumptions with regard to possible shading.

Verification of field conditions with regard to possible shading of the photovoltaic installation

Field obstacles such as trees, preceding buildings, chimneys, etc. They constitute natural elements causing shading of photovoltaic modules. The fitter should foresee how the shade from the above element shall reduce effective electricity production in the specific case. It may use software tools for this purpose, in which it may simulate capacity of the entire installation after proper mapping of the whole installation together with field and urban obstacles.

Vertical and horizontal arrangement of photovoltaic modules

This visualisation may cover both vertical and horizontal arrangement of modules. The best effect may be obtained when a part of modules operates vertically and the other part - horizontally. This situation shall occur in the case of east-west type of installation and in both directions various field and building obstacles occur.

Exposure to solar radiation of modules being in the same photovoltaic chain or collector

In order to maximise the yield in the electricity generation process, one should strive for such an arrangement of modules in the same PV chain so that radiation exposure is the same for every module. While applying this principle to every chain, we may expect the receipt of maximum output currents for every one of them.

Verification of selection of wire cross-section

Due to the specific nature of the direct current installation in the photovoltaic installation, it is necessary to properly select the wire cross-section. While knowing output currents from every string, we may verify the correct selection of wires in collectors and the entire generator.

During the wire cross-section selection and verification, the following significant factors should be considered:

- rated voltage of wires,
- rated current of wires,
- minimisation of transmission losses.

Wire cross-sections should be selected in such a way that they constitute low resistance for flowing electrical current, while the size of losses on the route photovoltaic modules → inverter → power supply connection should not exceed 1% (for the DC and AC side).

Specific resistance of copper wires for:

2.5 mm² – 0.0074 Ω/m,	10.0 mm² – 0.0018 Ω/m,
4.0 mm² – 0.0046 Ω/m,	25.0 mm² – 0.00073 Ω/m,
6.0 mm² – 0.0031 Ω/m,	35.0 mm² – 0.00049 Ω/m,

Requirements for photovoltaic cables

Wires should be fitted with a double layer of insulation: basic and additional, which in the case of damage to one insulation protects from electrocution and fire. Wire bend radius should be large enough to facilitate the assembly and protect from internal damage. Conductor flexibility should belong to the fifth or sixth class, which means that the wire is very flexible and resistant to any movement.

A material from which external insulation is performed must be resistant to any type of oils and chemical factors that will affect it for a long time. Operating temperature should exceed 100 degrees Celsius while the conductor at the short circuit must withstand the temperature exceeding 200 degrees Celsius for a couple of seconds. The higher the thermal resistance of the conductor, the better. In addition, wire resistance to temperatures below zero is very important, as wires in PV installations must operate through the entire year, also in winter. Here, resistance to 40 degrees below zero is the standard, however some manufacturers offer wires with resistance up to minus 50 degrees. Wire durability should come to at least so many years as the failure-free period for the photovoltaic installation lasts, i.e. approx. 20 years. Now, many manufacturers offer wires which resistance is defined as 30 years. The PV installation wires should also be described with insensitivity to UV radiation.

Fig. 3. Structure of the photovoltaic cable, where: 1. Multi-stranded flexible copper conductor (Conductor), 2. First insulation layer, halogen-free rubber, white LSZH (Insulation), 3. Second insulation layer, halogen-free rubber, preventing flame propagation, smoke-free. Black or red (outer sheath).

Source: https://voltaconsolar.com/solar-products/pv-cables/solar-cables/red-solar-cable-100m-drum-6mm.html, (access: 20 September 2018).

Exemplary operating parameters

1. Operating temperature:
   - maximum operating temperature: 120°C,
   - maximum conductor temperature during short circuit: 250ºC (max. 5 s),
   - minimum operating temperature: -40°C.
2. Fire properties:
   - low emission of corrosive gases according to UNE-EN 60754-2 and IEC 60754-2,
   - low emission of density of smokes emitted during combustion according to UNE-EN 61034 and IEC 61034,
   - transparent gradient > 60%,
   - resistance to flame propagation: UNE-EN 60332-1 and IEC 60332-1 (test on single wire/cable),
   - halogen-free properties according to UNE-EN 60754-1 and IEC 60754-1.
3. Water resistance:
   - flooding protection AD8.
4. Mechanical properties:
   - minimal bend radius: 3x cable diameter,
   - impact strength: AG2 – average strength.
5. Electrical properties:
   - DC rated voltage: 1.8 kV.
6. Chemical resistance:
   - resistance to oils and chemical factors: Excellent,
   - resistance to lubricants and mineral oils: Excellent,
   - UV resistance according to EN 50618, TÜV 2Pfg 1169-08 and UL 2556.

Cable route should be as short as possible from one side, but also it should consider minimisation of risks related to lightning.

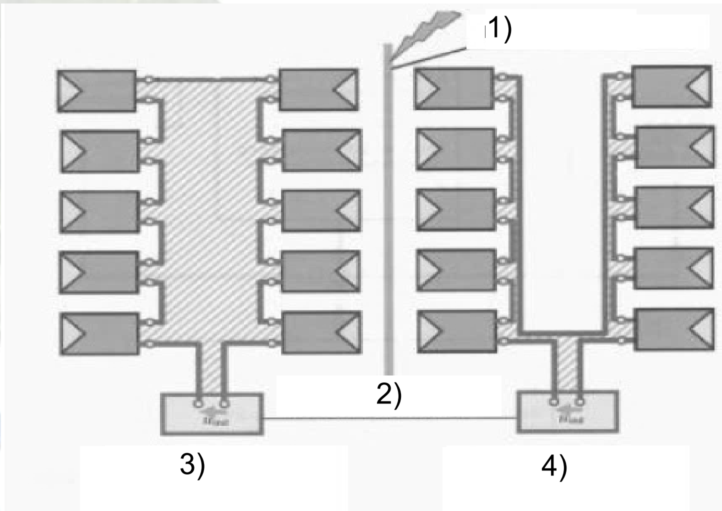


Fig. 4. Proper and improper arrangement of DC wires, where: 1) Lightning rod, 2) Panel junction box, 3) False: Large area for inductive coupling, 4) Correct: A minimized area for inductive coupling Minimal area for inductive coupling.

Source: http://www.tec-institut.com/construction-of-a-100-kwp-solar-power-system-on-top-of-carports-built-for-a-parking-lot-with-60-parking-spaces-on-company-premises/, (access: 20 September 2018).

Cables for parts of the AC low voltage installation.

Cables for the AC circuit should be flexible, oil-resistant and self-extinguishing. It may be arranged directly in the ground and installed on channels, cable ladders and in cable channels. Cable should be resistant to UV radiation and prepared for installation outside the premises without application of additional protection also for application in humid conditions, including total short-term immersion in water.

Multi-stranded flexible conductors should belong to the flexibility class 5 according to IEC 60228 and are made from electrolytic copper. High flexibility and small bend radius (5 x cable diameter) significantly facilitate the installation process, allowing for quicker cable arrangement even in particularly demanding conditions and places with limited access. Conductor insulation should be made from cross-linked polyethylene XLPE. Thanks to this, it is possible to obtain better cable electrical parameters (higher long-term load capacity, lower lossiness, higher electrical resistance) than in the case of cables with PVC conductor insulation. A broader range of operating temperatures of the cable (from -40°C to 90°C), while at the short circuit the maximum acceptable temperature comes to 250°C (up to 5 s).

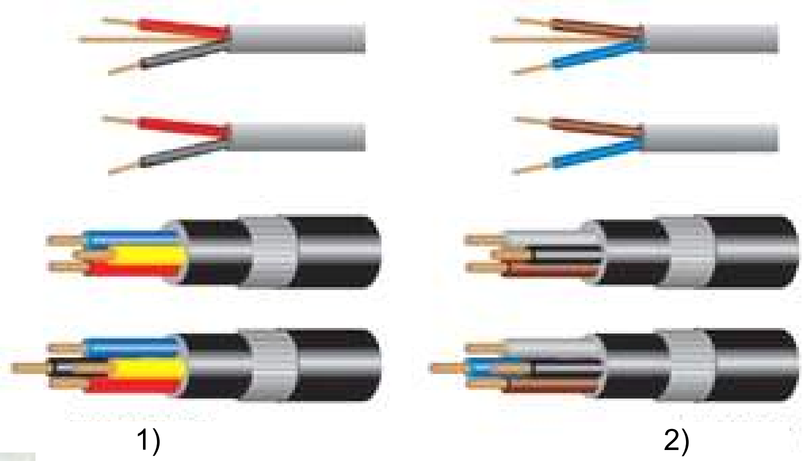


Fig. 5. Structure of the AC cable, where: 1) Existing colour, 2) New colour
Source: https://www.emsd.gov.hk/minisites/New_Cable_Colour_Code/en/tech1.html, (access: 20 September 2018).

If the photovoltaic installation is performed in public utility buildings or higher parameters concerning fire safety are required for the AC part, application of halogen-free cables is recommended.

If there is fire, they do not emit poisonous halogenic compounds, such as chlorine, fluorine, bromine and iodine. They are characterised with a low level of emission of toxic gases and aggressive corrosive gases. Quantity and density of emitted smoke are low, while its transparency gradient exceeds 60%. They have self-extinguishing properties and in case of fire they do not propagate flame, both on an individual cable and in a wiring harness. They may be arranged directly in the ground, as well as inside and outside the premises, without the necessity of additional protection against the external environmental impact. The cables' external coating is made from halogen-free plastics, highly resistant to UV radiation and well resistant to oils. Cross-linked polyethylene applied on the conductor insulation allows for the operation within the range of temperatures from -40˚C to +90˚C, while the highest acceptable temperature of the conductor in the short circuit conditions comes to 250˚C. In both cases, for DC and AC cables versions with anti-rodent protection are available. All types include labelling of one-metre sections, significantly facilitating the fitters' work.

DC connectors in photovoltaic installations

The PV connector is composed of the pair plug-socket. Switches, tightened on wires entering the connector, are located inside insulators. Wire entries are protected with seals and cap. Thanks to the maintenance of dependence between connection polarity and a connector part assembled on the wire (PLUG "minus" and SOCKET "plus"), the fitter's work is significantly facilitated. It allows to avoid mistakes related to connection polarity if there is a need to disconnect and reconnect the PV module installation wires.

Fig. 6. Socket (+) and plug (-) of the photovoltaic connector
Source: https://www.fabian.com.mt/en/products/webshop/14928/solar-----power-connector-mc4-plug-and-socket-kitf.htm, (access: 20 September 2018).

The connector's underbelly is constituted by switches, i.e. conducting elements tightened on wires entering connectors and then they ensure contact inside the connector. Their correct tightening and quality of the contact itself is crucial if it is about durability of this element and losses that it may introduce as a result of resistance, which may cause failure. Connector resistance is a very important parameter due to the efficiency loss they it may cause in the photovoltaic system. In the module cabling section, this value is multiplied due to the occurrence of more connectors (modules, aggregate boxes), thus making the low (and stable in a multi-year period) resistance of properly tightened connectors important.

(a) (b)

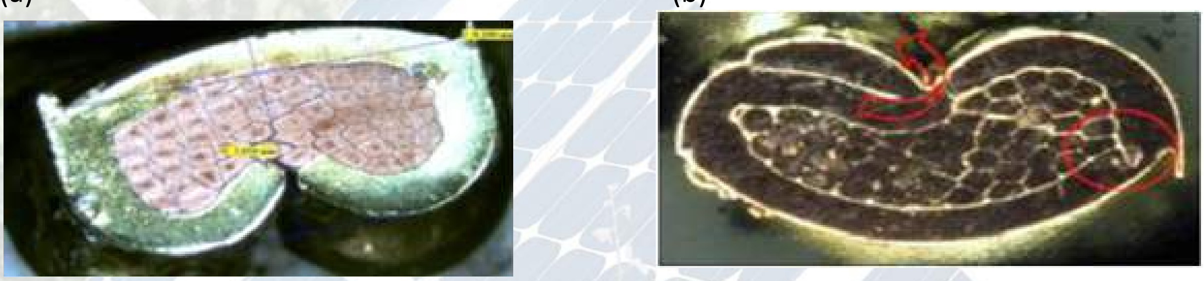


Fig. 7. Correctly (a) and incorrectly (b) tightened wires on the photovoltaic connector
Source: kabelforum.de, (access: 20 September 2018).

Failure reasons may be various:
- low quality of the connector,
- loosened connection resulting from continuous changes in temperature, vibrations, material fatigue or incorrect installation,
- mechanical damage to insulation as a result of scrape or direct impact of external forces (wind, ice formation, temperature and solar radiation),
- insulation degradation due to environmental factors (UV radiation, moisture, chemicals, heat),
- insulation damage by rodents and insects,
- surge insulation damage.

Apart from the resistance to failure, it is also important that wires do not cause losses of the system efficiency.

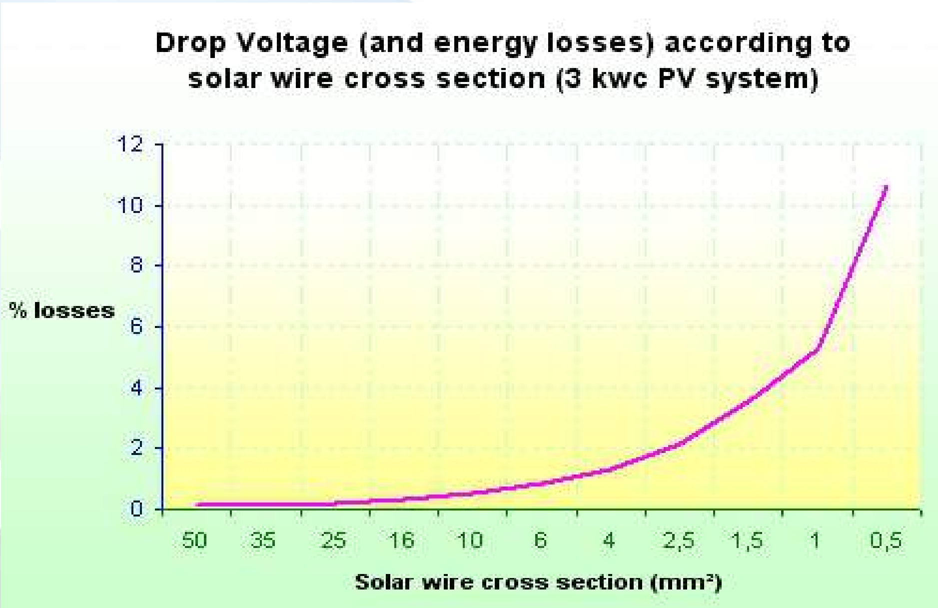


Fig. 8. Losses in the DC cabling, where: –Drop Voltage (and Energy losses) according to solar wire cross-section (3 kwc PV system), – % losses, – Solar wire cross section (mm^2)

Source: https://photovoltaic-software.com/solar-tools/dc-ac-drop-voltage-calculator, (access: 20 September 2018).

Operations related to the connection and disconnection of elements of the photovoltaic generator

The generator's connection must be processed in the strictly specified sequence:
- assembly of the supporting structure,
- installation of modules in the sequence consistent with the design,
- DC cable connections in particular collectors with emphasis put on safe and durable fixing of cabling to the supporting structure or roof elements,
- assembly of the DC junction box and protections,
- connection of particular collectors to the junction box,
- if lightning installation occurs in the installation, it should be connected,
- verification of everything with regard to electricity and technicality.

Arrangement of wiring harnesses and cables of the photovoltaic installation

Principles of the assembly of photovoltaic wires in roof systems

Wires cannot dangle loosely, "swing" or lay loosely on the roof surface, especially in circulation areas. Wires should be protected e.g. with use of band clips or put into cable routes, boards, ducts, etc.

In addition, wires cannot be tight, excessively bent or cannot touch elements of the PV system or the building. It threatens with insulation damage. Wires must be guided to the aggregate box. Appropriate seal must be ensured to avoid leaking to the inside of the box, which may result in short circuits and possible occurrence of electric arc.

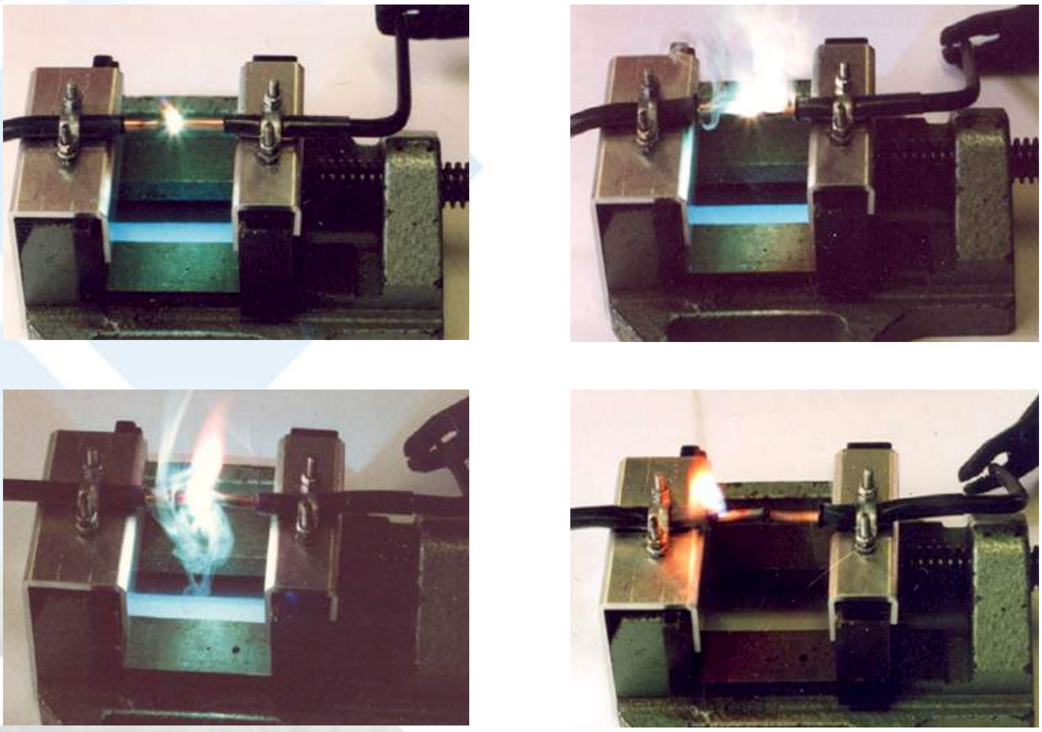


Fig. 9. Electric arc in the DC circuit
Source: ALTENER Projekt Soltrain 2004 Fraunhofer ISE, (access: 20 September 2018).

Principles of the assembly of photovoltaic wires in ground-based systems

Wires in ground-based systems are placed in ducts.

Ducts should protect wires from atmospheric conditions, direct sunlight and mechanical damage. Cable ducts prevent also from unauthorised access. Ducts should be placed on the ground or on the supporting structure behind PV modules and they should lead to the aggregate box located near module rows. Wires in ducts should not be arranged loosely, but also they cannot be fixed too tight (thermal expansion, tensions).

Wires must be guided to the aggregate box and glands should be adequately sealed to avoid leaking to the inside of the box. If possible, wire entries should be placed on the bottom side of the box. For better protection of the installation from the risk of sparks or short circuit, positive and negative wires may be guided separately, with use of cable channels with a compartment or in separate channels. If insulation is damaged, wires are physically split.

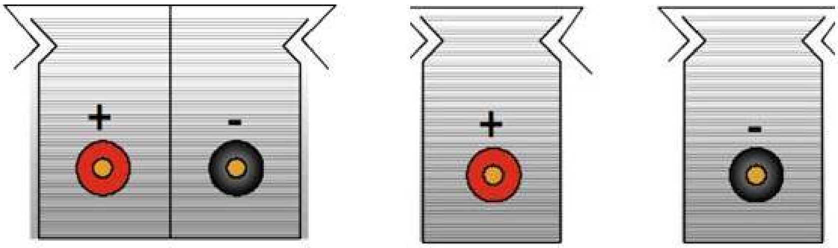


Fig. 10. Wire splitting through their provision in channels
Source: Polskie Towarzystwo Fotowoltaiki. Elementy instalacyjne: kable, złącza i puszki przyłączeniowe.

4.5. Setting up and start-up of photovoltaic system

Launch of the photovoltaic system

When everything is finally assembled, there comes the time of the first launch of the installation. The photovoltaic installation is composed of AC and DC circuits, so its start-up should be conducted sequentially, verifying and starting up every circuit separately. Verification must include control of the mechanical fixing and efficient operation with regard to electricity.

Sequence of switching on and off particular elements in the photovoltaic installation

The basic element of every photovoltaic installation is constituted by the device reached by energy produced in photovoltaic modules that flows further to output circuits. Depending on an installation type, this shall be the charging regulator or photovoltaic inverter.
However, before we configure these devices, control actions should be performed with regard to other installation elements.

– In the DC installation, electrical control and control of assembly generators for all elements of the photovoltaic generator should be performed.

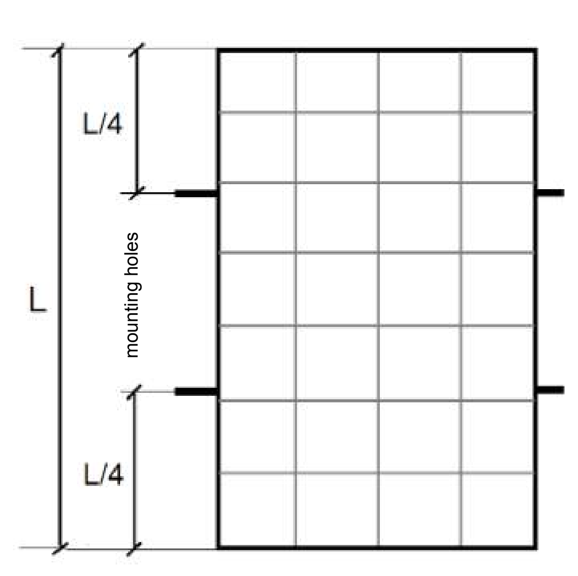


Fig. 1. Proper mounting distances for modules operating vertically (mounting holes)
Source: http://www.suntrans.pl/produkty/moduly/instrukcja_montazu_i_uzytkowania_modulu_pv_05_08.pdf, (access: 20 September 2018).

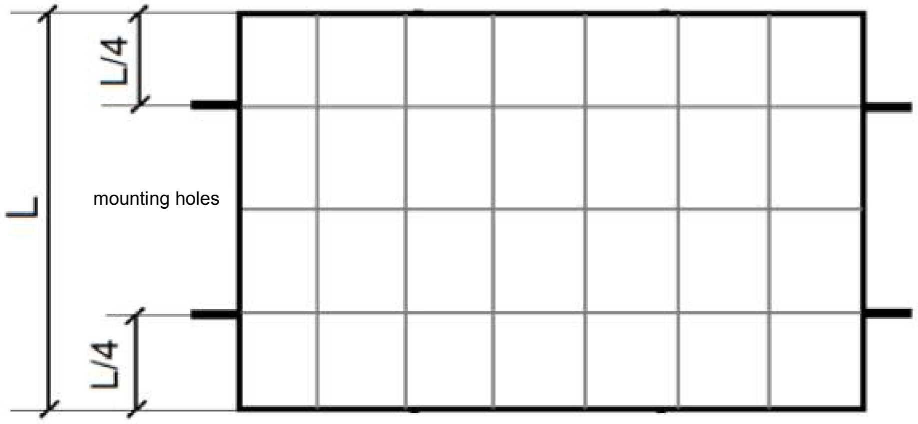


Fig. 2. Proper mounting distances for modules operating horizontally (mounting holes)
Source: http://www.suntrans.pl/produkty/moduly/instrukcja_montazu_i_uzytkowania_modulu_pv_05_08.pdf, (access: 20 September 2018).

- We verify whether modules are assembled according to the manufacturer's recommendations.
- We check the assembly box location in every module.
- We control the correctness of electrical connections and fixing of cables connecting particular modules, putting a special emphasis on polarity.
- We verify the output voltage from the collector (in the case of larger amount of collectors this action should be repeated for all collectors) before the connection box.
- We control the correctness of assembly of the connection box and devices located there – DC fuses, SPD protections and DC main switch.
- We check the assembly of the main DC cable from the connection box to the DC entries in the inverter.
- We measure the DC output voltage from modules being also the DC input voltage for the inverter.
- If lightning installation is present in our installation, we also check the correctness of its performance, as in this situation it constitutes an integral part of the DC installation.

Connection and configuration of the charging regulator

The voltage regulator constitutes the device applied in off-grid photovoltaic systems, so it is not connected to the power supply network. Such installations constitute autonomous installations from the user's point of view, as they ensure electricity supplies to receivers.
As the owned off-grid installation may constitute the only source of energy in the given location, the regulator should be installed with due diligence, guaranteeing the user the correctness of its operation. The sequence of actions is as follows:

- Assemble the regulator in a vertical position in order to ensure free flow of cooling air from the bottom to the top by the radiator.
- Check whether acceptable output current from the PV generator and input current of the receiver do not exceed data of the installed model.
- Firstly, the battery should be connected and then receivers.
- The battery charge status should be considered – according to the regulator's type it shall be visible on the LCD screen or on the LED indicator.

- Select a battery type to be connected.
- Set correctly rated voltage of the battery (12V, 24V, 48V or other available in the regulator).
- Depending on the charge status, further actions indicated in the assembly instruction should be performed.
- Connect the PV photovoltaic generator to the regulator.
- Switch on the PV regulator with the ON/OFF button.
- If the regulator has the self-test function, it should be conducted.
- If there is no such a function, proceed according to the manufacturer's guidelines.
- If connecting actions are performed correctly, the system should operate and in solar radiation conditions, depending on the battery charge status, we should observe an appropriate mode of operation (battery charging or energy transmitting to receivers).

Connection and configuration of the network inverter

There are many types of photovoltaic inverters and many manufacturers. Commissioning of each of them proceeds differently and is described in detail in the installation and use manual of each of them. Below you may find the discussed basic issues, and where a particular action is necessary, one should refer to the specific model and manufacturer's instruction to conduct the process correctly.

As the inverter constitutes the device of relatively high power and voltage and currents on the DC and AC side pose a risk to the fitter's and user's health and life, the OHS principles and warnings provided by manufacturers should be absolutely followed (the basic ones are described below.

- On clamps and in wires of the inverter, there may appear voltages dangerous for life also after its switching off and disconnection.
- The inverter must be closed during its operation.
- Wires or clamps should not be touched while switching on and off.
- No changes in the inverter should be done.
- Operational safety should be ensured through proper earthling, selection of wires and appropriate protection from short circuit.
- Prior to the commencement of inspection or maintenance works, all voltage sources should be switched off and protected from unintended activation.
- Unauthorised persons should stay far away from the inverter and the photovoltaic installation.
- In particular, the standard PN-EN-60364-7-712 "Requirements for work establishment, premises and installations of a special type – photovoltaic supply systems" should be followed.

During the live performance of measurements in the inverter, the following principles should be complied with:

- Take jewellery off from fingers and wrists.
- Do not touch electrical connections.
- Use safe and legalised measuring instruments.
- Stand on the insulated ground during work at the PV inverter.

Operational safety of inverters is ensured through:
- Lightning protectors/varistors protecting input circuits from power surges of high energy charge on the side of the network and the generator.
- Cooling element temperature monitoring.
- EMC filter protecting the inverter from high frequency interference.
- Varistors on the AC network side, protecting inverters from power surges and power surge series.

Draw attention to the conditions in which the inverter should operate (inverter's use instruction):
- In every case, removal of heat excess from the inverter should be ensured.
- Ensure undisturbed air circulation.
- Guarantee the good access to further service and maintenance of the inverter.
- Protect from excessive humidity and solar radiation.
- If the inverter has a display, it should be installed in the way allowing for an easy reading of parameters from the display.

Position:
- Stand-alone or wall-mounted assembly.
- Sufficient load-bearing capacity of walls on which it is assembled.
- Walls made from the material resistant to high temperatures, flame resistant.
- Minimum clearance and easy access for the maintenance engineer should be ensured.

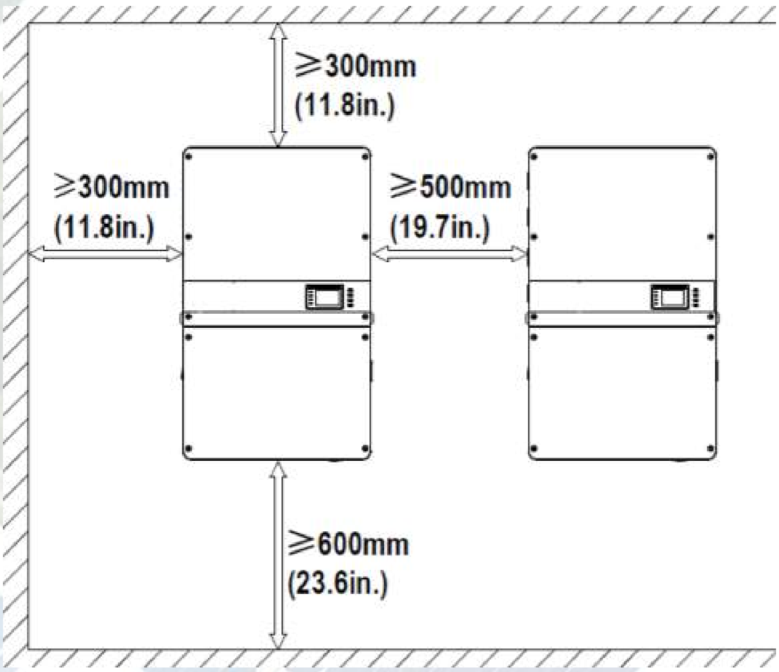


Fig. 3. Exemplary distances during the assembly of a group of inverters (sizes provided in inches)
Source: https://www.solectria.com//site/assets/files/2265/docr-070645-f_manual_installation_and_operation_pvi_50-60tl.pdf, (access: 20 September 2018).

Connection to the power supply network:

- The inverter can be opened and installed only by a qualified electrician.
- Prior to the connection to the electrical installation, it should be checked whether the inverter is properly mounted.
- Disconnect the AC and DC side from voltage and protect them from re-activation.
- Attach connecting wires to the network in the dedicated connection box.
- Prior to the introduction of a network wire to the device, check once again whether the inverter is entirely disconnected from voltage on the AC and DC side.

In the case of high resistance of wires, i.e. at very long wires on the network side, voltage on network clamps of the inverter is increased during operation in the supply mode. The inverter monitors this voltage. If it exceeds the limit value for the given network, the inverter shall disconnect. Therefore, attention should be paid to sufficiently large wire cross-sections and to their small distances to minimise wire resistance.
In installations with many inverters, attention should be paid to activation of inverters in various phases in order to avoid asymmetry in the network.

Activation of the inverter

- Check if the inverter is mounted and connected to the electrical installation.
- Check whether the connection box cover is earthed and closed.
- Check whether the photovoltaic generator provides voltage larger than the minimum DC input voltage in the inverter.
- Connect the photovoltaic generator through the DC disconnector.
- Connect network voltage through external fuses.
- The inverter should start operation.
- The first activation is described in use instructions for specific inverters.

Remote communication with the device (charging regulator or inverter)

- Communication with use of the RS 485 bus system occurs with use of two signal wires Data "plus" and Data "minus". In order to eliminate interference, the shielded twisted pair should be used as the communication wire.
- Connect screen to PE only from the one side.
- Attention should be paid to proper connection of conductors Data "plus" and Data "minus".
- In the case of change of conductor places, communication is impossible.
- During the connection DATA+ and DATA-, attention should be paid to proper conductor pairing.
- Do not arrange wires of the RS485 bus system near DC/AC electrically conductive wires.
- Devices should be connected in parallel and every bus system subscriber (inverter, sensor) should be assigned with a unique address.
- The communication circuit should be ended with the end device, so-called terminator.

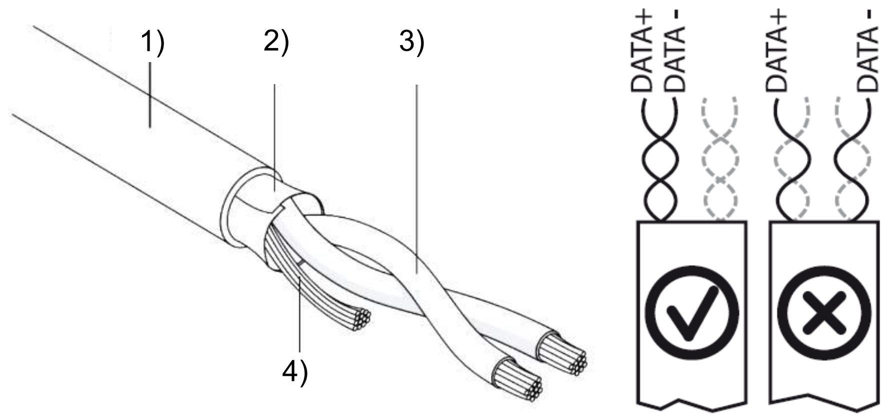


Fig. 4. Communication twisted pair for RS 485, where: *1) Sheath – First insulation layer, 2) Shield (foil-type) – Foil-type insulation, 3) Twisted pair – pair of wires, 4) Earning of shield – earthing, 5) Data+, 6) Data-*
Source: https://electrical-engineering-portal.com/correct-cabling-modbus-rs485, (access: 20 September 2018).

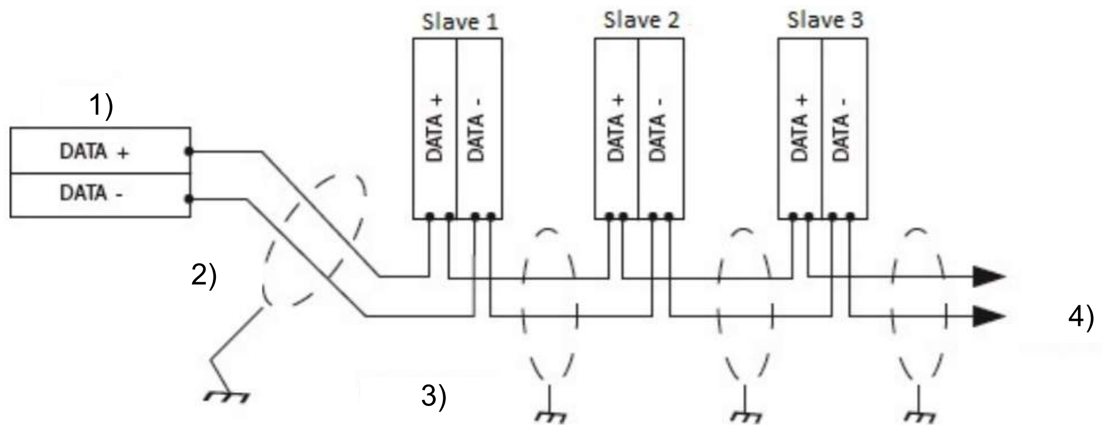


Fig. 5. Parallel connections of several inverters in the case of communication with the RS 485 protocol, where: 1) Master, 2) Shield, 3) One twisted pair, 4) Onto remaining RS-485 devices
Source: https://www.solectria.com//site/assets/files/1611/commercial_inverters_communication_manual.pdf, (access: 20 September 2018).

4.6. Cooperation of batteries with photovoltaic systems

Need for energy storage

Electrical energy storage occurs with use of batteries. There are available many battery types, starting from acid, gel, through nickelic, to lithium batteries. Every technology is characterised with its lifetime counted in years, number of charge and discharge cycles, discharging depth, maximum output current, etc.
Selection of a good battery should be preceded with an analysis of parameters in reference to the planned battery purpose.

General requirements concerning batteries:

a) large number of cycles > 5,000,
b) low self-discharge,

c) possible communication with the photovoltaic systems, in particular with the inverter,
d) large current capacity both at charging and discharging,
e) broad range of operating temperature,
f) long lifetime > 15 years,
g) scalability (modular construction),
h) maintenance-free,
i) high safety level,
j) access to key warehouse parameters – online.

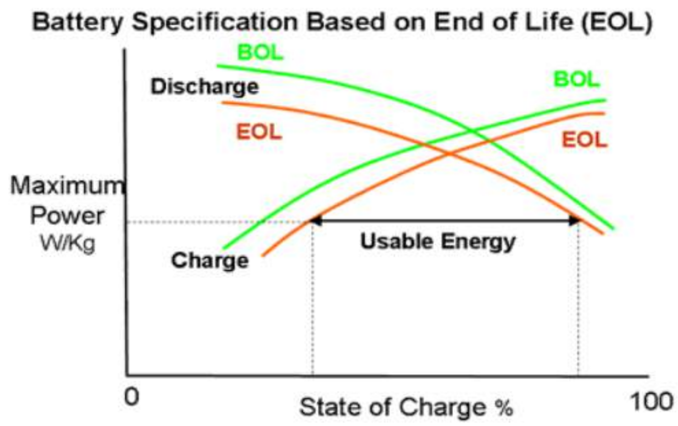


Fig. 1. Maximum power density according to the charging status in the entire lifecycle of batteries, where: – Battery Specification Based on End of Life (EOL) – Maximum power density according to the charging status in the entire lifecycle of batteries (EOL); – Maximum Power; – State of Charge; – Discharge; Charge; Usable Energy

Source: https://www.mpoweruk.com/traction.html (access: 20 September 2018).

General data of batteries

Sulphuric and lead batteries

1) Composed of cells connected in series
2) Nominal voltage of a single cell: 1.8-2.1V
3) Lead constitutes the basic component.
4) Electrodes are made from lead discs – frames – with (II) lead monoxide (PbO) pressed into them. After disc placement in a dish that is constituted by the battery case, 20% water solution of sulphuric acid (VI) is introduced with density of 1.15 g/cm^3 in the temperature of 25^{o}C.

VRLA (valve regulated lead acid) batteries

1) Type of acid and lead battery, with gel electrolyte. Sulphuric acid, after mixing with silica, creates the gel mass

AGM (absorptive glass mat) batteries

1) A technology in which electrolyte is absorbed in the separator made of glass mat.
2) Large capacity related to very high weight.
3) Obtained voltage depending on a number of connected cells: 6, 12, 24 => 12 V, 24 V, 48 V.
4) Stationary (battery rooms, UPS) applications, coupled with solar installations, but the limited number of cycles.

NiCd batteries

1) Low rated voltage 1.2 V/cell.
2) High voltage constancy during discharge.
3) Low dependence of capacity on discharge current.
4) Good parameters in low temperatures during discharge.
5) High cyclical durability.
6) Memory effect.
7) Cyclicality up to 1,200 cycles.

NiMH batteries

1) Rated voltage 1.2 V/cell.
2) Low dependence of capacity on discharge speed.
3) Good parameters in low temperatures for low.
4) Good acceptability from the point of view of environmental protection.
5) Resistance 500-1,000 (1,500*) cycles.

Lithium-ion batteries

1) Energy density 130-200 Wh/k, 300 Wh/L.
2) Charge/discharge efficiency: 99.8%.
3) Self-discharge: 2% / month.
4) Durability > 5,000 cycles.

Lithium-ferrous batteries

1) Energy density 130-200 Wh/kg; 300 Wh/L.
2) Charge/discharge efficiency: 99.8%.
3) Self-discharge: 3% / month.
4) Durability > 5,000 cycles.

There are other energy storage technologies:

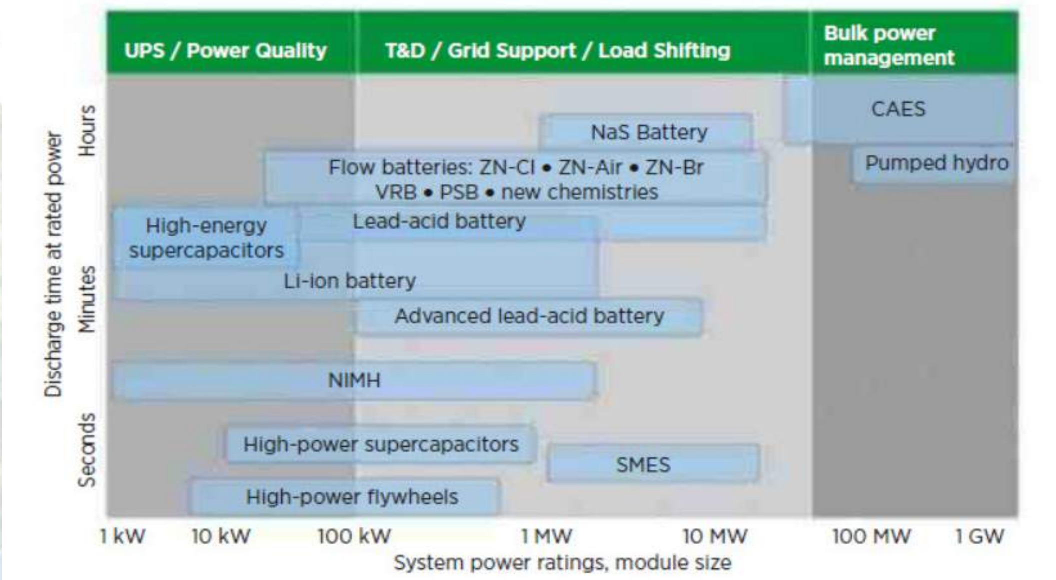


Fig. 2. Time availability of various energy storage technologies for various powers, where:
Source: https://hub.globalccsinstitute.com/publications/electricity-storage-and-renewables-island-power-guide-decision-makers/2a-understanding-storage-performance, (access: 20 September 2018).

1) Flywheels

Energy is stored in the form of kinetic energy of the whirling mass. Value of the stored energy increases with every square of angular velocity of whirling, which is limited with resistance of the material applied to construct the wheel. By applying light materials, it is possible to achieve higher speeds of whirling as compared with heavier materials of the same resistance to stretch, thus it is possible to store more energy.

2) Pumping power stations

Hydro storage power plants are intended for the storage of collected electrical energy and then its return to the network. When the power demand is low, the surplus of electrical energy in the system is used for pumping water to the upper container. In the period of increased demand, water flows from the upper to the bottom container through the turbine, generating electrical power. So reversible turbine sets operate alternately as engine-pump or turbine-generator. While considering the decrement of evaporated water and losses in the turbine set, when producing electricity, only 70-75% of energy collected for water forcing to the upper container is recovered.

3) Compressed air

The technology abbreviated as CAES (Compressed Air Energy Storage) constitutes the modification of a traditional cycle of pumping power stations based on gas turbines. This technology applies cheap, off-peak electrical energy to store compressed air, which then is applied to drive the gas turbine in the peak time

4) SMES (Superconducting magnetic energy storage)

SMES store energy in the magnetic field of the coil made from special alloys. Thanks to cooling wires to minus 269^{o}C, the material's resistance to current flow declines, allowing for conduction of very high current values without energy losses. From the point of view of the entire system, it is necessary to consider power consumption through the cooling system. Current flow through elements not having properties of superconductivity and power electronic connectors, where short circuit losses occur, is also necessary. Despite this, general efficiency in commercial applications is very high. Storage capacity (energy capacity) of SMES in commercial applications comes now only to approx. 1 kWh, while maximum output power to 1 MW and is limited by the capacity of power electronic elements.

5) Super-condensers

Super-condensers store energy in the electrical field created between two electrodes. Their basic structures and electrical properties are close to conventional condensers. The electrode structure and electrolyte selection allow for the receipt of high charge density on the surface of electrodes, but the limit voltage comes to approx. 2.7V per cell. Despite low voltage, the amount of stored energy is much larger than in conventional condensers and may reach the level of several Wh for the biggest condensers available commercially. Super-condensers are connected to obtain larger modules with energy capacity up to 1 kWh and further set to create larger energy storage units.

Fig. 2 presents time availability of various energy storage technologies for various powers.

Technologies and costs – today and tomorrow

As continuous cyclical work is necessary in photovoltaic systems, we may apply the accumulators that are able to perform several thousands of cycles in a broad range of temperatures (Fig. 3).

Necessity of permanent communication with the system and required small dimensions lead to the conclusion that only modern lithium-ion and lithium-iron technologies may be commonly applied in PV systems. A rapid increase of interest in energy storage has led recently to the significant price reduction. From the level of more than EUR 1,000/kWh to EUR 400/kWh for a complete energy storage system. It is foreseen that these prices shall decrease to the level of EUR 250-300/kWh in the nearest years, while the biggest optimists say that to EUR 150/kWh.

Basic electrical parameters of batteries:

1) Rated capacity in Q [Ah].
2) Internal resistance Rw [mω].
3) Maximum charging voltage U_{max} [V].
4) Rated voltage Un[V].
5) Minimum discharging voltage U_{min} [V].

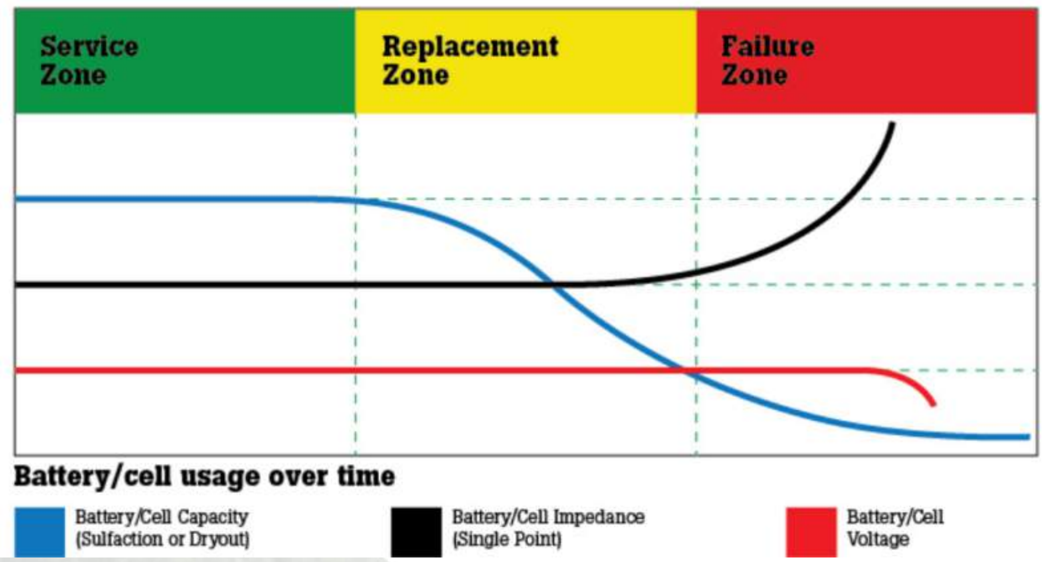


Fig. 3. Battery lifetime zones, where:
Source: https://www.fluke.com/en-us/learn/best-practices/measurement-basics/stationary-batteries/measuring-battery-state-of-health-over-time-to-ensure-optimal-uptime, (access: 20 September 2018).

Parameters specifying battery operating levels in time:

1) SOH [%] – state of health – capacity level against capacity of a new cell.
2) SOC [%] – state of charge – battery charging level
3) DOD [%] – depth of discharge – battery discharging level (Fig. 4)

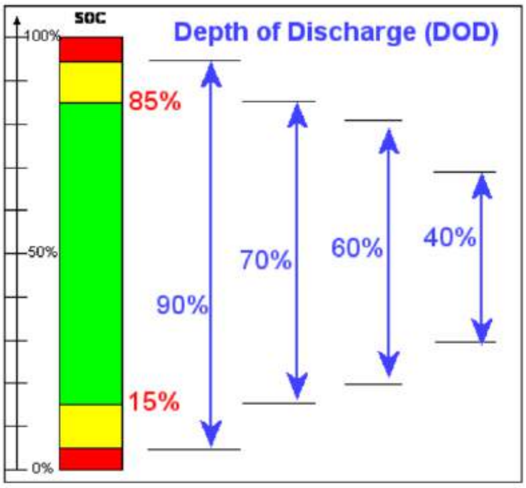


Fig. 4. Various levels of battery discharging, where:
Source: https://www.ev-power.eu/blog/Tests-and-diagnosis/Depth-of-discharge-DOD.html, (access: 20 September 2018).

Systems supervising the battery operation

The system supervising the battery operation is necessary for the battery operation in photovoltaic systems. Its superior purpose is to protect energy storage from damage through the overrun of its required ranges in the area of voltage, temperature or current, including short circuit.

Its second important task is the communication and exchange of information with the charging system concerning the generally understood energy exchange between PV systems, receivers and energy storage (Fig. 5).

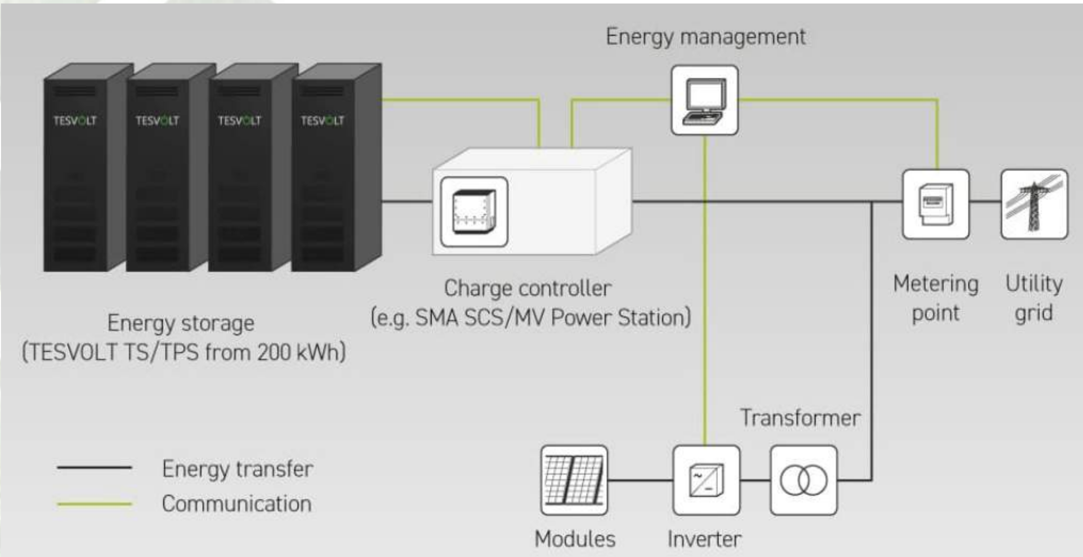


Fig. 5. Communication scheme between energy storage and PV system, where:
Source: https://zerohomebills.com/product/tesvolt-tps-200-864kwh-lithium-battery-storage-all-in-one-20ft-container/, (access: 20 September 2018).

Operation of storage with charge regulator

In simple systems without the inverter, the charge regulator constitutes a device with which energy storage communicates (Fig. 6). It ensures proper charging process through the supervision over the value of the charging current, maximum charging voltage, and in some cases it also controls the battery's operating temperature.

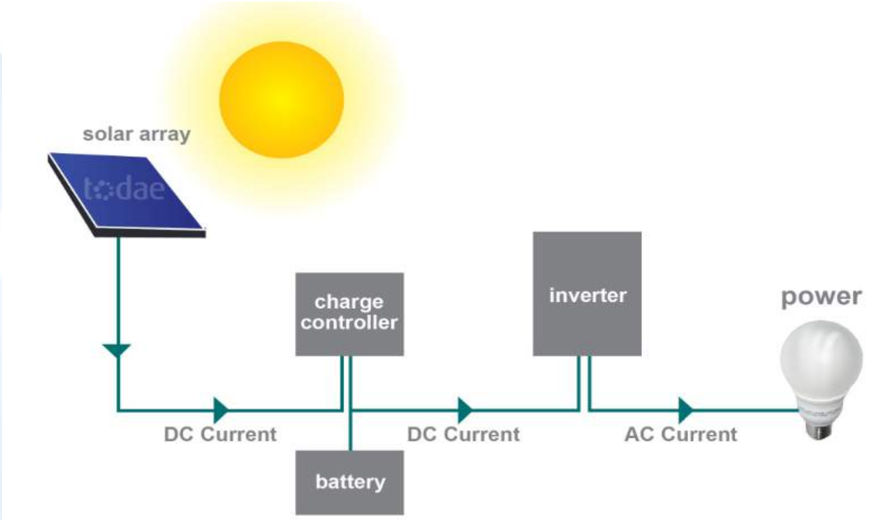


Fig. 6. Energy storage in the PV system with the charge controller, where:
Source: https://maandus.com/en/pvsystemeng.html, (access: 20 September 2018).

Operation of storage with inverter

In systems equipped with the inverter (on-grid, off-grid or hybrid (Fig. 7)), the supervision system (BMS) exchanges information online with the inverter during the charging and discharging process. Advanced BMS systems provide the system with information on SOH, SOC and DoD (Fig. 8). Current information on the above parameters allows for optimal operation of the energy accumulator, thus improving its lifetime and increasing the number of cycles that it is able to perform.

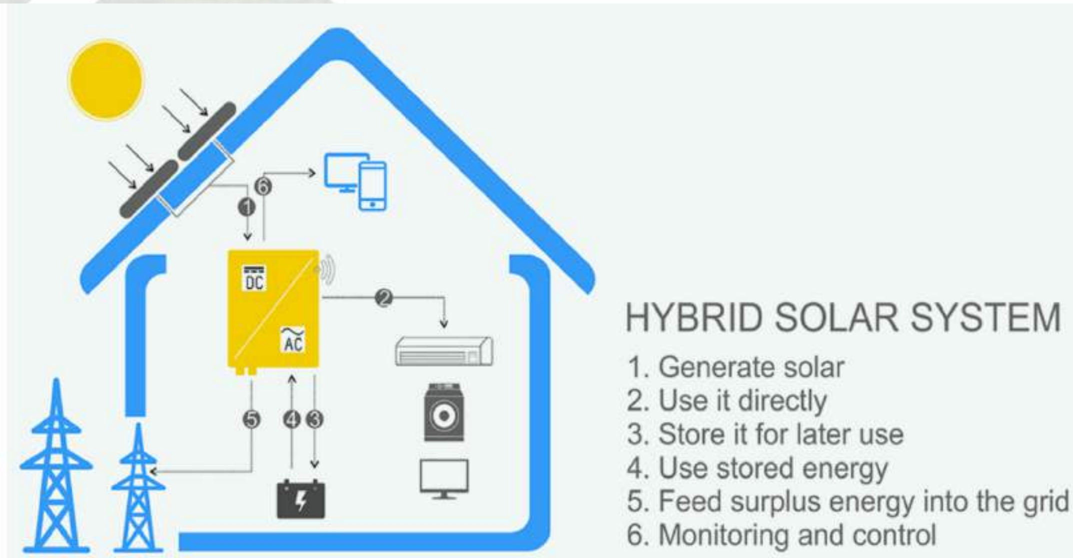


Fig. 7. Energy storage in the PV system with the inverter, where:
Source: https://www.solarminer.com.au/solar-battery-storage/, (access: 20 September 2018).

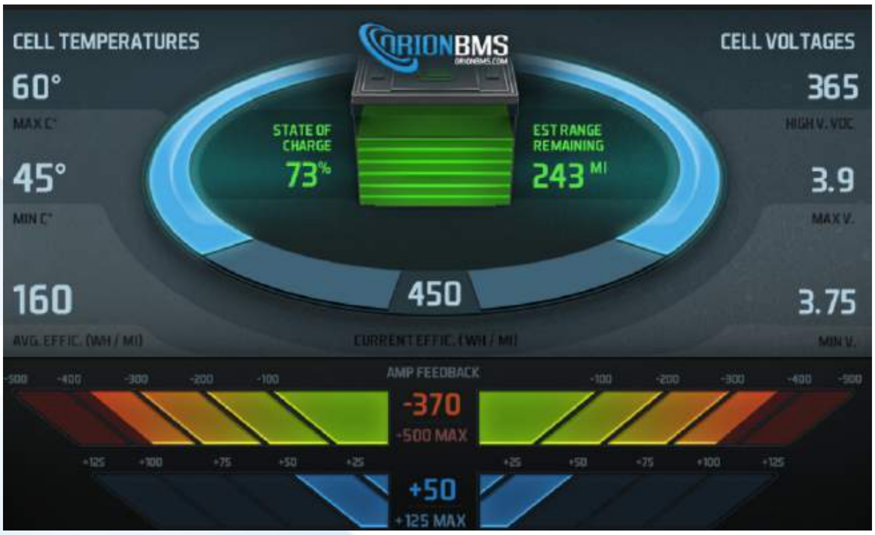


Fig. 8. Exemplary appearance of the energy management system screen in the PV system
Source: https://www.orionbms.com/, (access: 20 September 2018).

4.7. Power surge protection in photovoltaic installations

The PV installation connected to the external electrical grid is exposed to damage in several areas:

– in the DC installation between modules and the inverter (e.g. formation of short-circuit currents caused by module shading, short circuits in wires, formation of hot spots, lightning),
– in the AC installation in the place where the inverter is connected to the grid (e.g. due to increased voltage in the inverter connection place, voltage fluctuations in the network, incorrect selection of protections).

In view of the above, in the PV installation the following is applied:

– fuses of the first level – for single PV collectors,
– fuses of the second level – for the entire PV generator,
– arresters,
– earthing installation,
– lightning installation.

Also other protections included in the same elements occur in the PV installations, such as e.g. bypass (bridging) diodes.
Fig. 1 Protections applied in the DC circuit of the PV installation are presented.

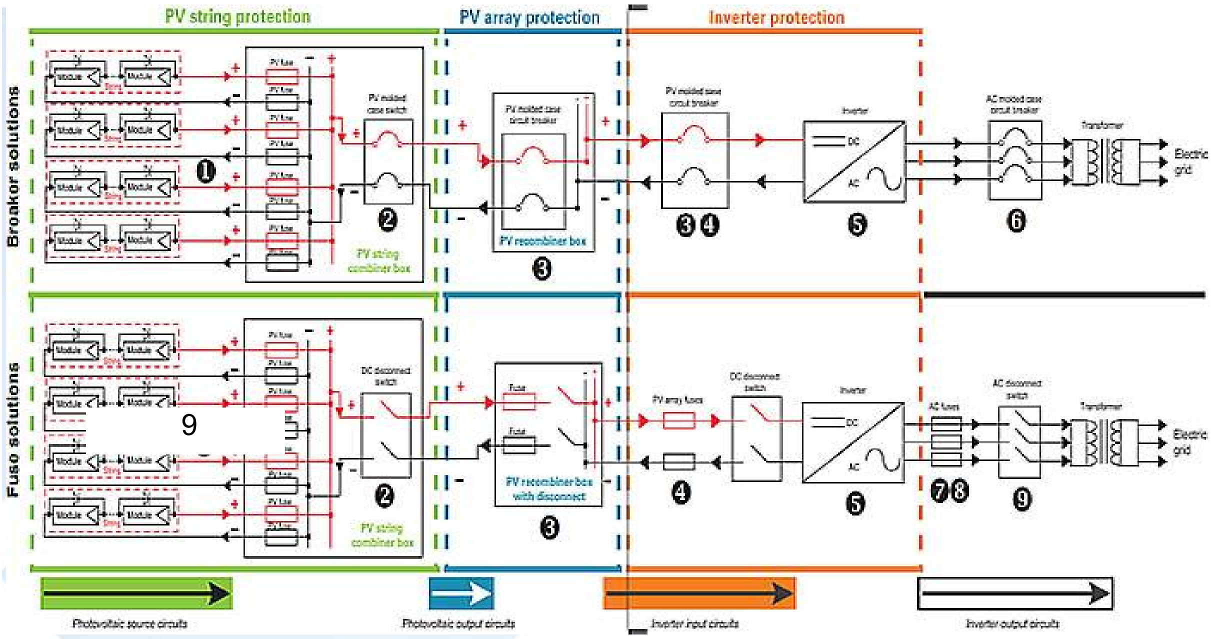


Fig. 1. Protections in the PV installation, where:
Source: http://www.cleanenergybrands.com/shoppingcart/categories/pv-circuit-protection/pv-circuit-breakers/, (access: 20 September 2018).

Fuses

At parallel connection of many serial circuits (strings) of photovoltaic panels, shading of one of modules causes that the entire current flowing in other chains flows through the chain with a shaded module (Fig. 2). This is the so-called backward current or "reverse". Its value depends on the quantity of parallel chains and comes to:

$$I_n = (n - 1) \cdot I_{SC}$$

where:
In – value of the reverse current,
N – number of parallel chains,
I_{SC} – value of the module short-circuit current.

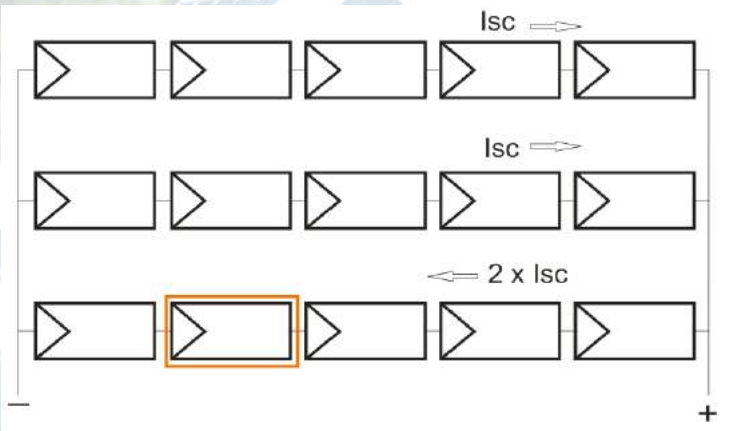


Fig. 2. Reverse current flow through the circuit with a shaded PV module
Source: Own work

The majority of modules offered on the market is able to resist the reverse current coming to 1.5-2 ISC, so the protection necessity appears usually only at three and more parallel connected chains. Protection from reverse current is here constituted by the fuse with fuse link. Fuse links gPV (to protect photovoltaics) have been designed in the way ensuring efficient disconnection of small power surges that would be able to damage photovoltaic modules.

According to the IEC 60269-6 standard, the fuse links should not operate for the current 1.13 In, while it should blow in a specific time for current coming to 1.45 In. Fuse links other than gPV or gR/gPV do not protect photovoltaic modules.

DC circuit breakers present on the market can be used only for the DC/AC inverter protection, but they should not be applied for the protection of photovoltaic modules, as in the case of short circuit in the module there may appear reverse current flowing to the other side and the solenoid in the circuit breaker may not work.

Cylindrical fuse links constitute the so-called fuses of the first level – their task is to disconnect short-circuit currents in the area of panels, so they should be installed as close to the last PV panel in the string as possible, while assembly should take place on the side of positive and negative pole.

Second protection level for the PV installation occurs directly before the DC input in the inverter where overall total current flows from the entire PV generator. Of course, when the inverter has many inputs, every independent input circuit must have such a protection. Here PV DC fuse links operating on DC current and voltage 750-1100 V are applied. Links are placed in fuse bases and allow for quick disconnection of the inverter from the entire PV generator. In addition, they are installed in the positive and negative pole.

Large PV installations may have a decentralised system of many small inverters or one central PV inverter with power of event several hundred [kVA]. In the second case, many photovoltaic module chains are connected in parallel and then total currents occur, flowing to the inverter from more than dozen to several hundred amperes.

For such large installations, fuse links gPV with standardised size of NH1 from 32A to 160A on 750V and 1000V DC and NH links (Fig. 3), but with elongated body – these are links NH1xl, NH2xl and NH3xl to 450A on 1100V DC and to 350A on 1500V DC. These links may be installed in single-pole bases, switches (up to 630A and voltage 1000-1200V DC, utilisation category DC20B) and in special bipolar fuse blocks for voltage up to 1500V DC for the system of bus bars with gauge of 370 mm. The last solution is particularly attractive, as it allows for the construction of cable control cabinets in polyester cases and switchboards for voltage 1100V and 1500V DC with power even up to 1 MW. These solutions have simple structure and are relatively cheap.

Fig. 3. gPV fuse in NH cases
Source: http://www.eti.si/images/userfiles/en-GB/documents/products/Ultraquick/PV.pdf, (access: 20 September 2018).

Arresters

Anti-surge protection of photovoltaic installations aims at the installation protection from results of power surges in the electrical grid caused by failures in the grid or lightning. Power surges from lightning occur even 1 km away from the installation. General principles of anti-surge protection for photovoltaic systems are included in the standard **PN-EN 61173:2002 (IEC 61173:2002). Anti-surge protection of photovoltaic (PV) systems of electrical power production.**

Detailed principles of anti-surge protection are included in the following standards:
1) IEC 61643-1. Surge protective devices connected to low-voltage power distribution systems. Requirements and tests.
2) IEC-60364-4-442. Electrical installations in buildings. Protection for security. Anti-surge protection. Low-voltage installation protection from temporary surges and damage at earthing in high-voltage networks.
3) IEC-60364-4-443:1999. Electrical installations in buildings. Protection for security. Anti-surge protection. Switching and atmospheric overvoltage protection.
4) IEC-60364-7-712:2007. Electrical installations in buildings. Part 7-712: Guidelines concerning special installations or locations. Photovoltaic (PV) power systems.

In order to protect photovoltaic systems and electronic devices connected to them from surges and couplings, there are applied special **surge protection devices (SPD)** dedicated for photovoltaic systems on the DC voltage and standard surge protection devices on the AC side. In DC installations, there is no "current passage through zero", which hampers quenching of short-circuit currents. Selection of improper surge protection devices may pose a fire hazard for electrical and electronic devices.

Table 1. General guidelines for selection of SPD protections in photovoltaic systems

Is there LPS?	Is "s" insulation spacing from LPS maintained?	Distance between PV modules and the inverter	SPD DC PV modules	SPD DC inverter	SPD AC
yes	yes	< 10 m	–	Type 2	Type 1
		> 10 m	Type 2	Type 2	
	no	< 10 m	–	Type 1	
		> 10 m	Type 1	Type 1	
no	–	< 10 m	–	Type 2	Type 2
		> 10 m	Type 2	Type 2	

Source: *PN-HD 60364-7-712:2007 Electrical installations in buildings. Part 7-712: Guidelines concerning special installations or locations. Photovoltaic (PV) power systems.*

Arrester types

1) **Surge protection devices of type 1** (B class) protect from direct and close lightning.
2) **Surge protection devices of type 2** (C class) protect the majority of electrical receivers from commutation surges and surges reduced by surge protection devices of type 1.
3) **Surge protection devices of type 3** (D class) additionally protect particularly sensitive and expensive electrical and electronic devices.
4) **Sets of surge protection devices of type 1+2** (B+C class).

Currently, in PV systems on the DC side the especially dedicated surge protection devices with the SCI (Short Circuit Interpretation) are more and more often applied, with a three-degree DC switch system.

Surge protection devices for photovoltaics

Single photovoltaic panels produce direct current at relatively low voltage of 30-40V. While connecting them in series, we increase total voltage of the DC circuit to the value of several hundreds of volts and sometimes even more, as inverters to 1200 or 1500V DC are available on the market. For the PV installation protection, special surge protection devices are constructed and usually they are adjusted to rated voltages within the range of 500 to 1500V DC, but there are also versions for lower voltage.
Depending on the structure and location of the photovoltaic installation, wire length, their arrangement and presence of lightning installation, calculations are made and on this basis the decision is made whether surge protection devices of type 1+2 should be applied, or whether type 2 is enough (Table 1).
Two-module surge protection devices for photovoltaics to protect positive and negative poles constitute the cheaper, but technically worse solution (Fig. 4).

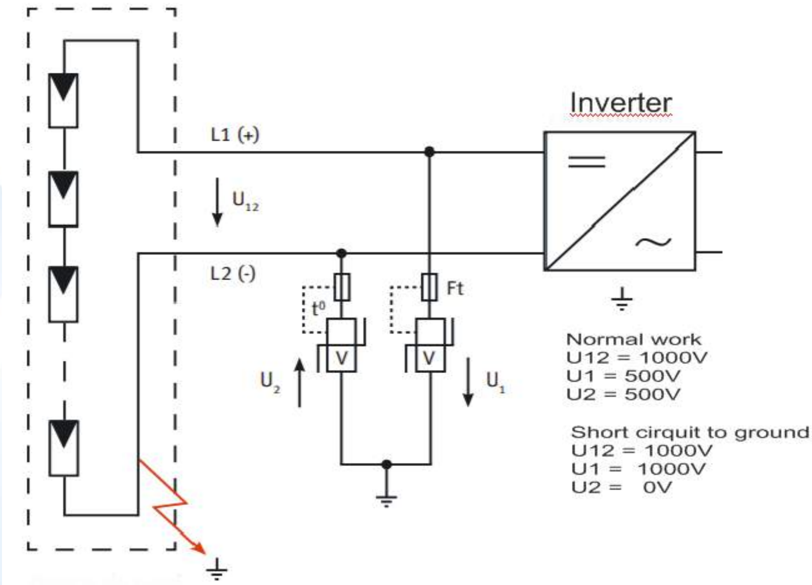


Fig. 4. Bipolar surge protection device in the photovoltaic circuit, where:
Source: http://www.jeanmueller.pl/pliki/ochrona-instalacji-fotowoltaicznych-2016.pdf, (access: 20 September 2018).

During normal network operation, there occurs maximum voltage 500V DC on the positive pole and 500V DC on the negative pole, while total output voltage of the generator comes to 1000V. Modules in the surge protection devices are selected to such a rated voltage – 500V DC. In the case of short circuit, e.g. as a result of damage to cable insulation, voltage 0V appears on the pole where the short circuit occurred, and on the other pole – 1000V DC. As the SPD module was selected to voltage 500V, not 1000V DC, permanent damage of this devices shall occur.
In order to avoid this, one should apply the tripolar performance in the connection system "Y" (Fig. 5), as the third additional module connected in series against earthing is also on 500V DC, i.e. in total SPD shall handle the voltage drop of 1000V DC.

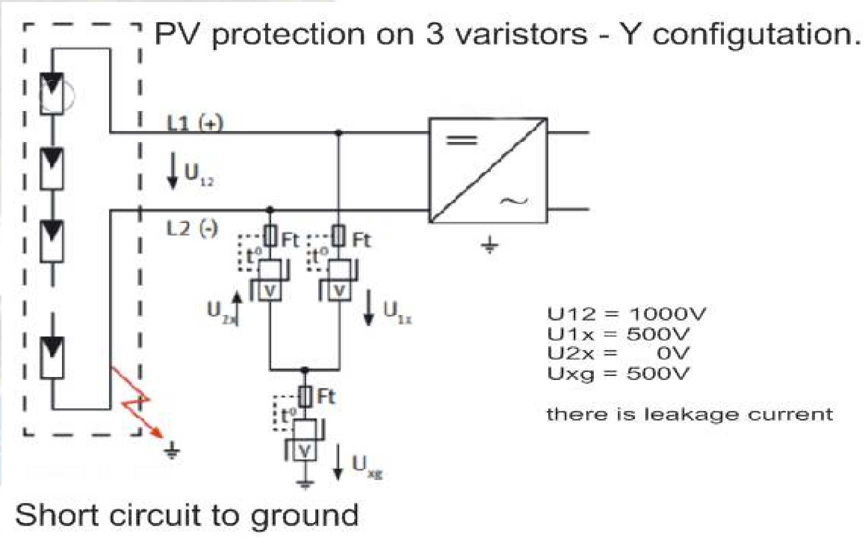


Fig. 5. Tripolar surge protection device in the "Y" configuration in the photovoltaic circuit, where:
Source: http://www.jeanmueller.pl/pliki/ochrona-instalacji-fotowoltaicznych-2016.pdf, (access: 20 September 2018).

In previous solutions, varistors were present as executive elements in this type of protections, but the occurrence of leakage currents and operating current constituted their defect. In later solutions, gas spark gaps appeared. Thanks to this, leakage current was eliminated, while low operating current between the positive and negative pole remained.

So far the best solution has been constituted by the application of spark gaps in every branch (Fig. 6), as then both leakage current and operating current shall not occur.

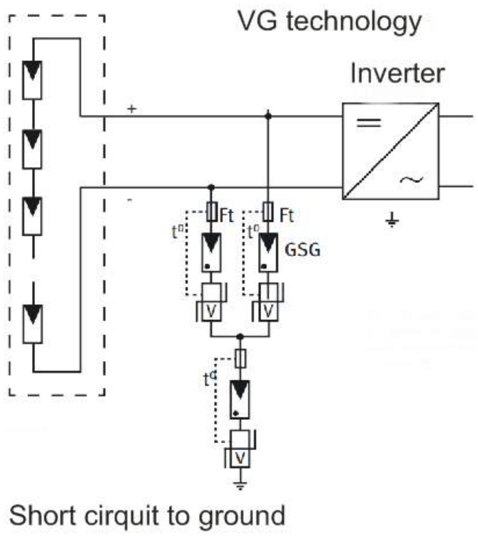


Fig. 6. Tripolar surge protection device with spark gaps in the photovoltaic circuit, where:
Source: http://www.jeanmueller.pl/pliki/ochrona-instalacji-fotowoltaicznych-2016.pdf, (access: 20 September 2018).

Disconnectors

They are usually applied on both sides of the inverter, i.e. both in the AC and DC circuit. They protect the inverter during assembly, in the case of maintenance works, replacement of elements, etc. On the market, we may find the whole range of disconnectors of various manufacturers and of various values of permissible disconnection current.
The Lorentz electromagnetic force causing the arc drawing and breaking is applied for the current breaking in this type of disconnectors. Devices have a symmetrical structure that allows for operation regardless of polarity, so the disconnector operates uniformly in both current flow directions.
The good practice is to apply disconnectors with a visible gap performed by large windows in the case, which allow for the control of the position of main contacts of the device. Disconnector's operation is insensitive to voltage surges while switching occurs at a speed regardless of an operator (quick switching on and off).
If operation is necessary in the utilisation category DC22BF, the insulation and switching off functions can be performed by devices having switching rated voltage Ue to 1100V DC and current range from 160 to 1600A.
Insulation disconnectors may have performance in an internal version, to be mounted only inside the building in dry rooms, as well as external performance in the IP65 protection class. The latter type of disconnectors has usually at once inputs typical for output circuits from the PV generator, thus eliminating the necessity of constructing temporary high-power cabling, which would constitute an unnecessary source of losses.

4.8. Lightning protection and earthing installation

Devices of the photovoltaic system do not increase the lightning risk.
However, installation of the photovoltaic system on the roof increase the risk of penetration of lightning current into the building's interior in the case of lightning directly in the panel.
It is recommended that photovoltaic installations are protected against lightning effects through the application of lightning installations. If there is no lightning installation and devices on the roof are performed in the protection class lower than the class II, such an installation should be performed.

According to the law of physics and forces of nature, the earthing system connecting the electrified body with the ground allows for dissipating an appropriate number of positive charges, striving for electrical neutralisation. Carrying away to the ground surge currents of lightning shall protect the building and people located in it from negative lightning effects.

The fitter should become acquainted with elements applied for the performance of horizontal and vertical air terminals. Based on the standards concerning earthing installations, one has to be able to classify the facility for a relevant group of facilities and design the earthing installation according to the standard provisions. Earthing constitutes a significant element of the lightning installation.
Earth electrode should be characterised with resistance lower than the one specified in the standard, so that it is able to dissipate to earth the potential produced during the lighting.

Tasks and principles of application of the lightning installation

During the assembly of the photovoltaic installation on the roof, according to the requirements of applicable provisions, it should protected from effects of direct and close lightning. While analysing the risk of occurrence of lightning damage according to the recommendations of the standard EN 62305-2 (standard concerning risk management at lightning protection), if it is significant, the lightning protection system (LPS) should be assembled to create the protective zone proportioned as appropriate to place all devices assembled on the roof inside this zone.
It is responsible for the facility protection against shock resulting from lightning.

Lightning installation is composed of (Fig. 1):

1) **air terminals** that determine direct reception of lightning which are then dissipated to the earth. They are placed on building roofs and walls or on masts near the protected building. Air terminals shall be deemed the natural external structural elements of the roof - antenna masts, vents, metal beams, reinforced concrete rods and any metal parts protruding from the roof. Air terminals may be also artificially introduced rods and wires installed vertically or horizontally. Artificial air terminals are made from stainless steel, copper or galvanised steel at least 6 mm thick;
2) **earth** (between exhaust wires and earthing) and **exhaust wires** (between air terminals and earth wires) applied for the connection of particular installation elements in whole;
3) **earthing** responsible for dissipation of an electrical charge from lightning and intercepted by metal installation parts to the earth. Earthing has the form of wire made of conductor

(natural use of metal underground parts, not insulated reinforced concrete foundations, metal water pipelines);

4) **test clips** for the control and measurement of earthing resistance and galvanic continuity in the system's overground part.

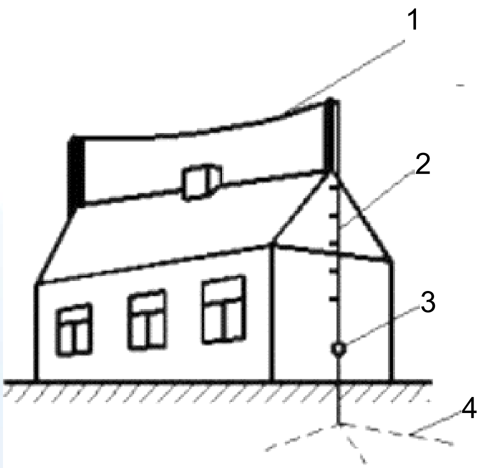


Fig. 1. Schematic drawing of the lightning installation, where:
Source: https://www.researchgate.net/figure/Lightning-protection-system-LPS-transfer-the-lightning-current-safely-to-the-ground_fig1_282924315, (access: 20 September 2018).

Distribution of the lightning installation on roofs and building facades

In the world, four basic methods specifying the distribution of the lightning installation elements for proper protection of buildings from lightning.

1. Rolling Sphere Method

This is a very simple method to determine the area that should be protected. It applies for the determination of lateral discharges. In this method, the sphere rolls on the surface of the building structure and the point where the sphere touches its wall is the most susceptible to lightning.

Here the end of the lightning air terminal should be placed.

The sphere radius specifies which protection class is required for proper protection.

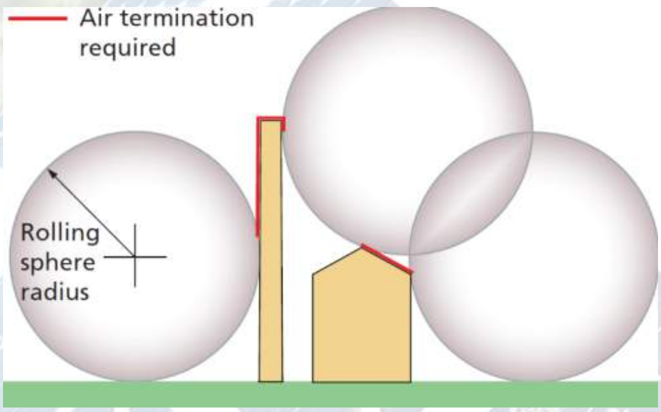


Fig. 2. Protection determination scheme in the Rolling Sphere Method, where:
Source: https://www.lsp-international.com/bs-en-iec-62305-lightning-protection-standard/figure-15-application-of-the-rolling-sphere-method/#iLightbox[postimages]/0, (access: 20 September 2018).

Table 1. Protection classes and radiuses in the Rolling Sphere Method

LPS protection class	Rolling sphere radius (m)
Class I	20
Class II	30
Class III	45
Class IV	60

Source: https://sep.com.pl/opracowania/opracowania_ochr_odgrom_bud.pdf

2. Protective Angle Method

This method constitutes a mathematical simplification of the Rolling Sphere Method. Protective angle is measured between the radius of the circle constituting the sphere projection on the protected surface and the height of the protective air terminal.

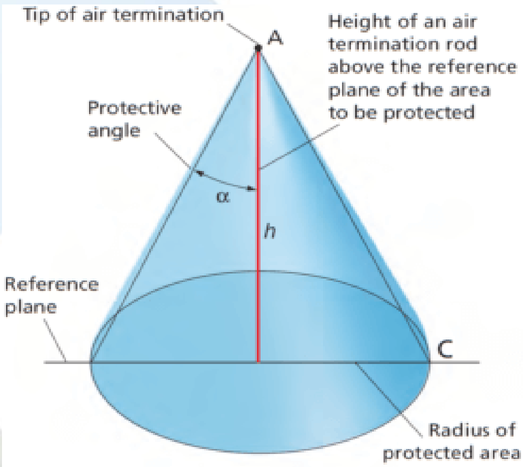


Fig. 3. Protection determination scheme in the Protective Angle Method, where:
Source: https://www.lsp-international.com/bs-en-iec-62305-lightning-protection-standard/figure-16-the-protective-angle-method-for-a-single-air-rod/, (access: 20 September 2018).

Protective angle changes together with the height of the protective air terminal, and thus the LPS class changes. This method is limited to the height of a single rod equal to or smaller than the sphere radius.

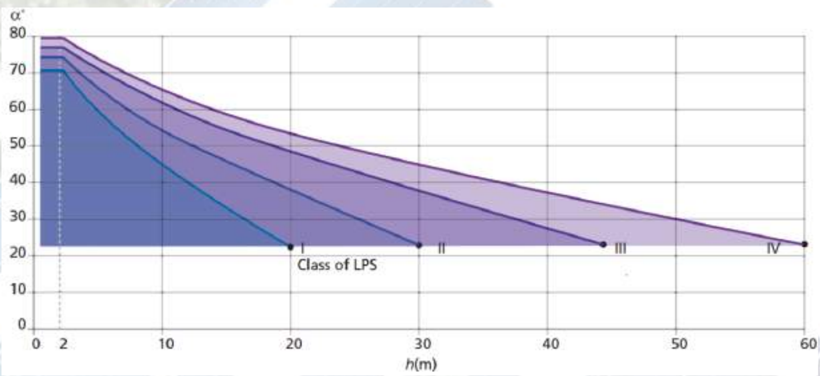


Fig. 4 Dependence of the protective angle α° on the height *H* of the air terminal and the LPS class
Source: https://www.lsp-international.com/bs-en-iec-62305-lightning-protection-standard/#post/0, (access: 20 September 2018).

3. Mesh Method

This method applies for the protection of flat roofs or flat surfaces. This method is used only when wires have the form of mesh and:

– mesh wires are placed on the surface edges,
– mesh size is compliant with the standard table,
– no metal structure should protrude outside the mesh area,
– at least two separate paths to the mass should exist from every point.

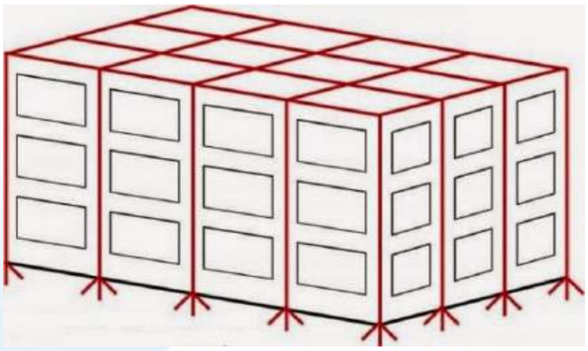


Fig. 5. Protection determination scheme in the Mesh Method
Source: https://www.electrotechnik.net/2014/09/how-is-mesh-protection-for-lightning.html, *(access: 20 September 2018).*

Table 2. Protection classes and mesh surfaces

Protection class (LPS)	Mesh size
I	5m x 5m
II	10m x 10m
III	15m x 15m
IV	20m x 20m

Source: https://sep.com.pl/opracowania/opracowania_ochr_odgrom_bud.pdf, (access: 20 September 2018).

4. Mixed system

In practice, all three methods are jointly applied for the effective building protection. According to the protected place, we choose the method that is the most optimal for this building fragment.

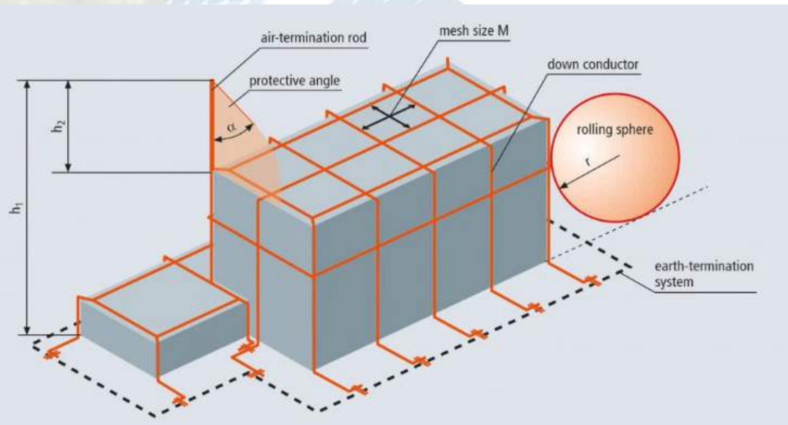


Fig. 6. Protection determination scheme in the mixed system, where:
Source: http://eurovolt.eu/en/post/5-1-air-termination-systems, (access: 20 September 2018).

Anti-surge protection of the photovoltaic installation on the building without the lightning installation

If the photovoltaic installation is founded on the facility without the existing lightning installation, such an installation should be performed after previous risk assessment. In Europe, many insurers require such a protection in the class III.

Basic principles of protection from direct impact of lightning current say that *"all roof devices from insulating or conducting materials, which include electrical equipment and/or equipment beneficial for information processing, should be located in the protective zone of the air terminal system"*.

Thus, it is clear that if we do not follow this recommendation, direct lightning in the PV system elements may lead to the destruction of the photovoltaic system and electrical installations and devices installed inside the building.

Therefore, the entire photovoltaic system must be located in the protected space. Such a space may be created by applying appropriately selected systems of vertical or horizontal air terminals. In addition, relevant insulation spacing between the system devices and air terminals or exhaust wires should be maintained.

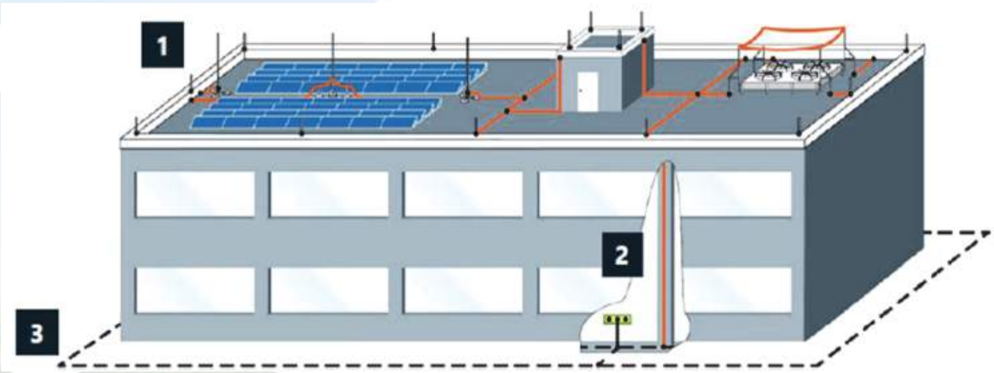


Fig. 7. Photovoltaic installation on the building without protection, where:
Source: http://www.ee.co.za/article/lightning-protection-leave-experts.html, (access: 20 September 2018).

Anti-surge protection of the photovoltaic installation on the building with the lightning installation

If the lightning installation is already on the building, during mutual adjustment of protection of the photovoltaic installation to the lightning installation, it is important to maintain appropriate insulation spacing.

Their task is to protect elements of the photovoltaic installation from arc flashes or electrical arcs, which could origin from air terminals or lightning protection wires during the lightning strike. Insulation spacing according to the standard PN-EN 62305-3:2009 are determined based on the following formula:

$$S \geq k_i \cdot \frac{k_c}{k_m} \cdot l$$

Where:

- S – minimum insulation spacing,
- k_i – coefficient depending on the protection class 0.4 for III and LPS class,
- k_m – coefficient depending on the insulation spacing material 1 – for air,

k_c – coefficient depending on current distribution in wires 1 – for 1 exhaust wire, 1…0.5 – for 2 exhaust wires,

l – length in metres, measured along the air terminal or exhaust wire from the point where the insulation spacing is considered to the point of the nearest equalising connection.

Usually the sufficient insulating spacing S is between 0.5 and 1 m. Some problem appears when between the PV installation elements and the lightning installation elements the insulation spacing cannot be maintained, e.g. due to steel structure of the roof or its surface or due to full filling of the roof surface with panels. In this case, to protect the photovoltaic system from electric charge jumps from the lightning installation, metal elements of the panel structure should be connected with the lightning installation.

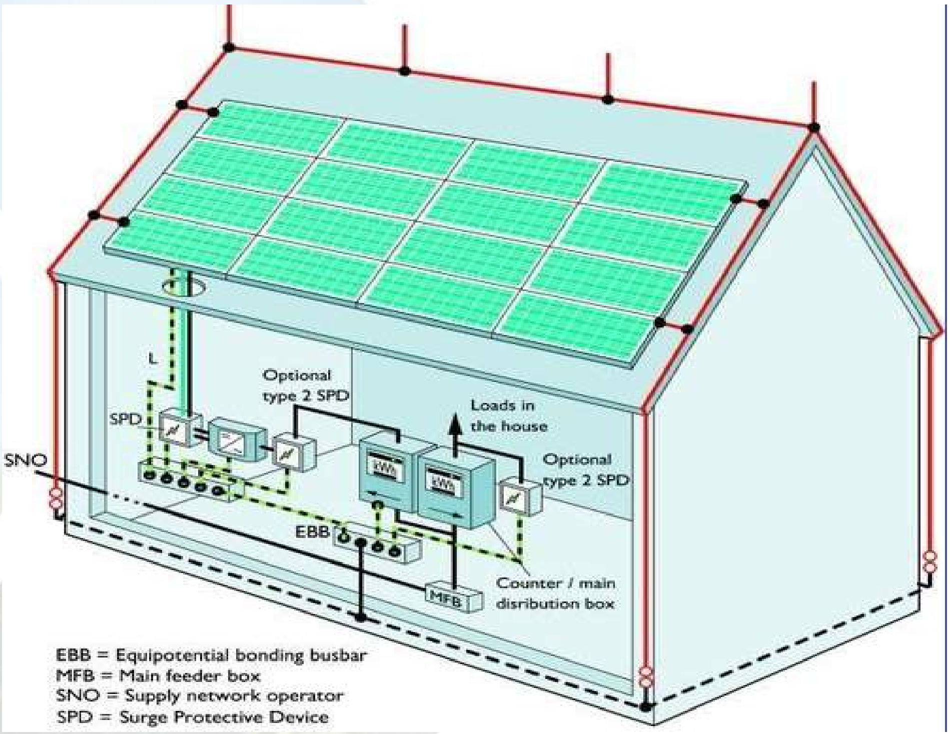


Fig. 8. Photovoltaic installation on the building with the lightning installation, where:
Source: https://www.indiamart.com/satcomelektronics/r-f-surge-protector.html, (access: 20 September 2018).

In practice, we have to do with two cases:

1) Building is equipped with LPS and distance of the PV elements does not meet the requirement d < s; in such a case the supporting structure of the PV elements should be covered with equalising connections.
2) Building is equipped with LPS and distance of the PV elements meets the requirement d < s; in such a case the supporting structure of the PV elements should be connected with the lightning air terminal system.

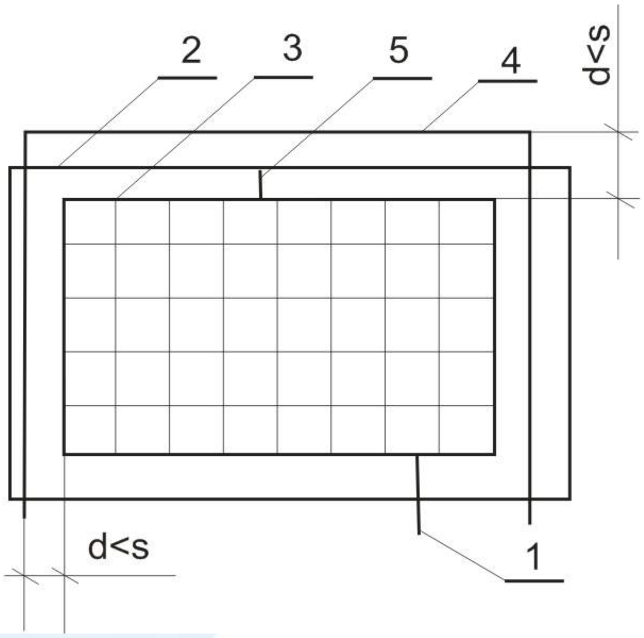


Fig. 9. Equalising connections when d<s, where: 1 – Equipotential bonding conductor to GSU, 2 – Roof edge, 3 – PV generator, 4 – Horizontal air terminals, 5 – Connection of the PV supporting structure with LPS
Source: own work

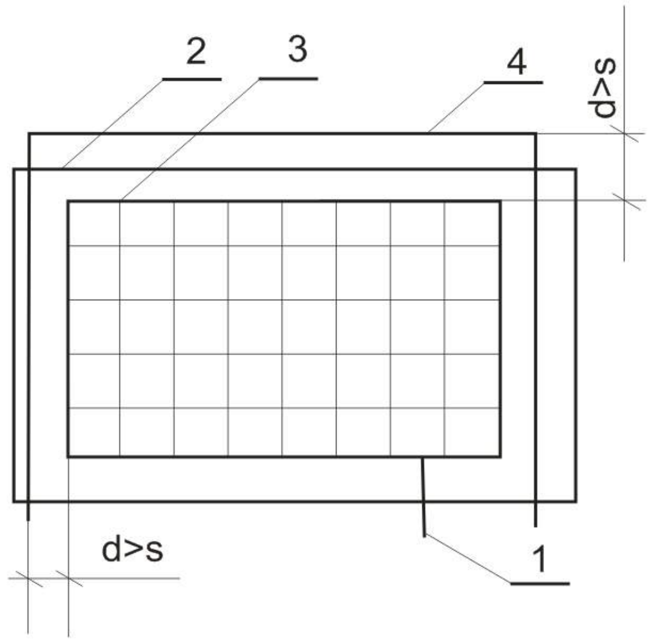


Fig. 11. Equalising connections when d>s, where: 1 – equipotential bonding conductor to GSU, 2 – roof edge, 3 – PV generator, 4 – horizontal air terminals
Source: own work

4.9. Installation rules for solar systems

While commencing the photovoltaic installation process, some rules and sequence of action performance throughout the entire process should be followed. Such a procedure guarantees that our actions will be reasonable, effective and efficient, while service performed for the customer will be rendered on time, with maintenance of good quality and costs assumed in the cost estimate.

1	• Verification of input data
2	• Confirmation with the investor of the terms and conditions of the agreement prior to the commencement of purchase
3	• Performance of deliveries of particular components and tool picking
4	• Protection of the installation site
5	• Installation performance
6	• Final activities and acceptance

Fig. 1. Verification of input data for the design
Source: own work

Verification of input data for the design

There should be conducted the facility's site inspection and one should verify whether delivered technical documentation is compliant and adjusted to the facility. This action is significant when we perform installations from the documentation prepared by the third party and we, as fitters, did not participate in any site inspection and we commence work as a company hired for the above mentioned works. If the design is our, this action may be omitted, as at the design stage we have been in permanent contact with the facility.

Confirmation with the investor of the terms and conditions of the agreement prior to the commencement of purchase

The good practice verified in every case is the confirmation with the customer of the terms and conditions of the agreement (prices, work start dates). Maybe the customer needs small changes as to work commencement for various reasons. If such changes occur, they should be agreed in writing and confirmed with bilateral signature. Then we will avoid possible misunderstandings and disputes as to the terms for the agreement performance.

Performance of deliveries of particular components and tool picking

The next stage is constituted by the picking of all components necessary to perform installation works and by the assurance of relevant working tools. Elements and tools delivered on site should be protected (preferably in agreement with the investor – maybe it has some room where they can be stored in appropriate conditions without an obstacle for any party). If our installation is large and divided into stages, one should consider the

possibility of deliveries to particular stages, thus allowing for better organisation during works, without detriment to timeliness of its performance.
An initial control of delivered elements (modules, inverter, cabling together with joints and other installation elements) is very important. Such a procedure shall allow to avoid possible disputes with the supplier in the case of defective delivery, as our intervention will be immediate. If we perform purchase on our own, control measures should be performed directly on the purchase site.

Protection of the installation site

As our works will be electrical works on the one hand and works at height on the other hand, the installation site should be protected according to the OHS regulations.
Employees participating in works should be healthy and have all necessary permits confirmed with relevant valid certificates necessary to perform particular activities.

Fig. 2. Exemplary site protection
Source: http://odnawialnezrodlaenergii.pl/energia-sloneczna-aktualnosci/item/514-farma-fotowoltaiczna-w-lipsku-na-finiszu, (access: 20 September 2018).

Performance of installation works

In the next step, we proceed to the installation that is performed by stages.
In the case of small installation teams (of two people), stages are performed one after another, while in the case of larger teams, we may perform particular stages concurrently.

Particular stages result straight from the system structure logic and are as follows:
1. Assembly of the supporting structure (on the roof or on the ground)

Fig. 3. Supporting structure on the roof
Source: http://solarsystemmanufacturers.com/metal-roof-mounting-structure/metal-roof-mounting-structure-manufacturer/, (access: 20 September 2018).

Fig. 4. Supporting structure on the ground
Source: https://www.solarbuildermag.com/wp-content/uploads/2013/05/Solar-FlexRack.jpg, (access: 20 September 2018).

2. Assembly correctness control.
3. Assembly of photovoltaic modules to the supporting structure.

Fig. 5. Assembly of modules on the roof supporting structure
Source: http://www.solarpanelsindustry.com/p/portfolio.html, (access: 20 September 2018).

Fig. 6. Assembly of modules on the ground supporting structure
Source: http://www.ticktockenergy.com/ground-mounted-solar-panels/, (access: 20 September 2018).

4. Assembly correctness control.
5. Electrical connection of modules and DC installation provision.

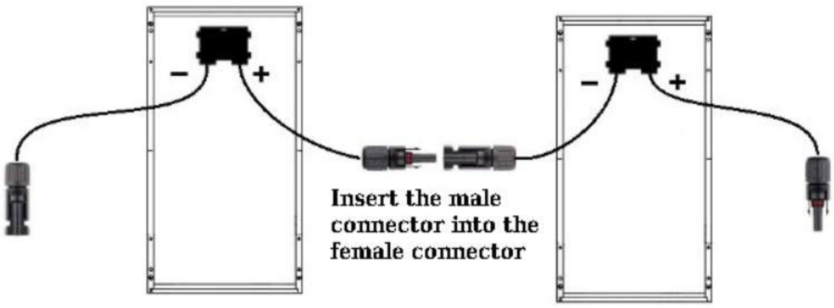


Fig. 7. Electrical connection of modules, where:
Source: https://www.solar-electric.com/learning-center/wiring-cabling/how-to-use-mc4-connectors-cables.html, (access: 20 September 2018).

6. Control and necessary measurements with regard to electricity.
7. Assembly of the lightning installation (if present) and protections on the DC side.

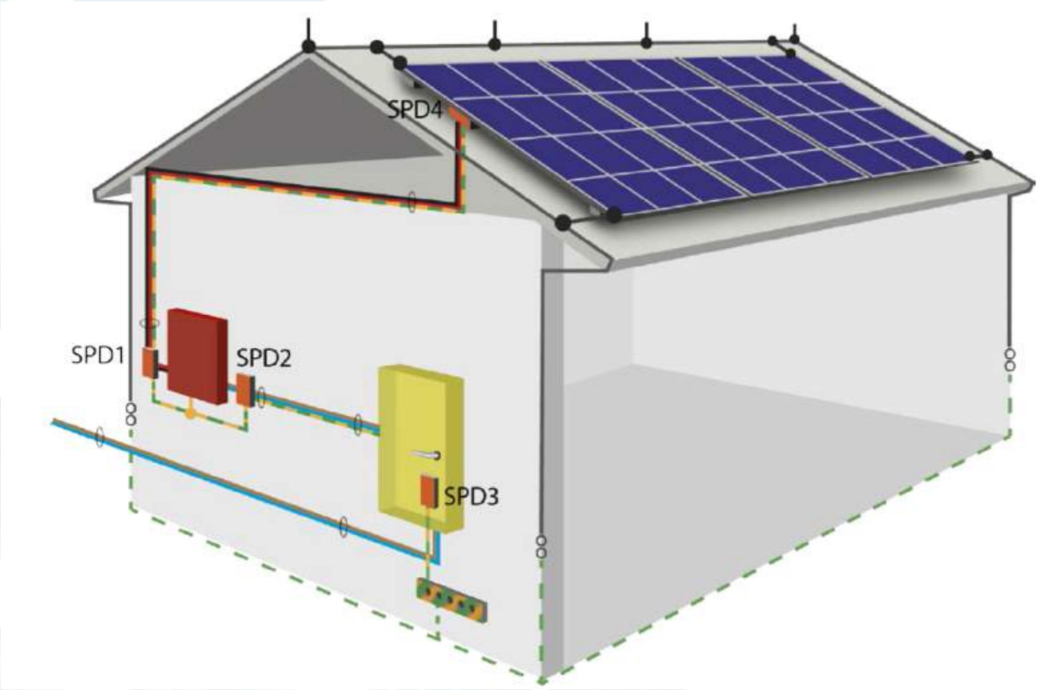


Fig. 8. Lightning installation
Source: http://www.novaris.com.au/wp-content/uploads/2016/02/0015-D29V2-Protection-for-PV-Systems-Australia.pdf, (access: 20 September 2018).

8. Control and necessary electrical measurements.
9. Assembly of the DC connection box and the main DC switch associated with the DC circuit.

Fig. 9. Assembly of the DC box
Source: https://www.etigroup.eu/solution/protection-of-photovoltaics-systems/dc-distribution-and-protection, (access: 20 September 2018).

10. Final control of the entire DC system on the side of PV collectors.
11. Provision of the main DC cable installation and to the connection box to the inverter.
12. Assembly of the inverter as instructed

Fig. 10. Assembly of the inverter
Source: http://greenpowerco.com.au/wp-content/uploads/2016/11/sma-inverters-1024x354.jpg, (access: 20 September 2018).

13. Control of correct installation of the main DC cable and the inverter assembly.
14. Provision of the AC installation from the inverter to the main switchboard.
15. Assembly of protections on the AC side.

Fig. 11. AC protections
Source: https://solarbay.com.au/projects/drury-farm-dairy-commercial-solar/dairy-farm-solar/, (access: 20 September 2018).

16. Control of correct assembly of the AC circuit.
17. Connection of the inverter to the network (if any).
18. Assembly and connection of the energy storage (if any).
19. Pre-commissioning of the inverter without the connected DC circuit in order to verify the correctness of the AC installation.
20. Temporary disconnection of the inverter from the network.
21. Connection of the DC circuit to the inverter and its re-activation.
22. Performance of necessary adjustments and programmatic operations in the inverter.
23. Activation of the remote communication system.
24. Disconnection of additional devices, if any (e.g. Solar Log), for analysis.

Final activities and acceptance:
1. Basic user training.
2. Signing the acceptance protocol, issuance of guarantee documents ending the installation.
3. Final settlement with the customer.

4.10. Typical assembly installation errors

PV systems should work for many years. Therefore, any information on typical errors and issues during the system assembly is useful.

Insulation failures (breakdowns)
Recently, the quality of wires and connections between modules has been significantly improved through the introduction of plug connectors. Application of cables and cable connections with little resistance to temperature and UV radiation created many problems.
Proper connection is also related to proper mechanical resistance. All connections and insulations are getting old. Lifetime of cables applied in power supply systems is determined as 45 years.
Cable insulation may be damaged by UV radiation, voltage breakdowns and mechanically. Any insulation damage on the DC side may cause sparking posing a fire risk.

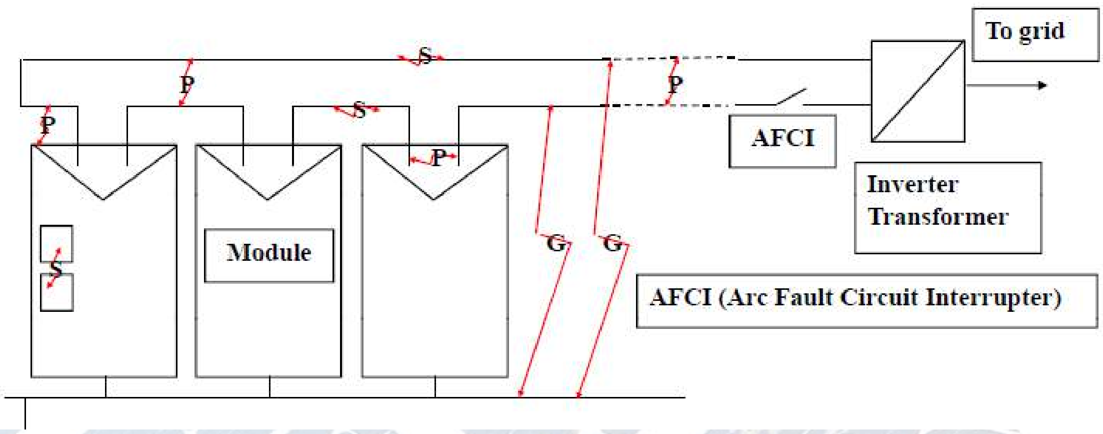


Fig. 1. Probable places of cable damage in the photovoltaic installation, where:
Source: https://www.agcs.allianz.com/assets/PDFs/ARC/Tech%20Talks/TTVol8-FireHazardsofPVSystems.pdf, (access: 20 September 2018).

Therefore, cabling must be periodically verified with regard to mechanical and thermal damage. Measurement of insulation resistance is the best solution.
Automatic insulation monitoring applied in inverters is a very useful function. The monitoring system signals insulation damage and switches off the PV system from the energy network. However, current from PV panels shall still be supplied. It means that failure cannot be eliminated by the inverter. If such a failure is signalled, an action to eliminate it should be started as soon as possible.

Inverter failures

Inverter failures are the most frequently signalled failures (63%). However, significant improvement within this scope can be observed. Improper dimensioning or voltage adjustment with the PV panels constitutes the common error. Many installation companies have overcome this problem by applying software tools allowing for proper simulation of system parameters. Another source of problems with inverters is constituted by breakdowns caused by electrical impulses or network switchovers, ageing or overheating.

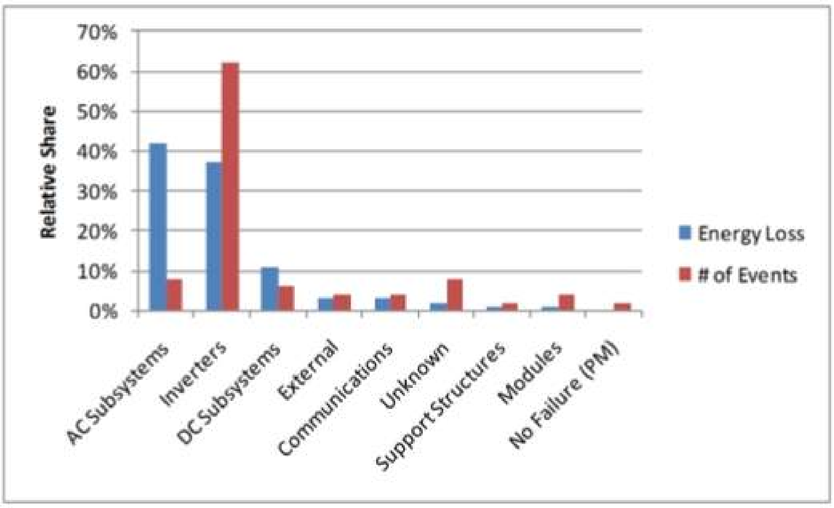


Fig. 2. Percentage distribution of damage to the PV systems, where:
Source: https://www.scottmadden.com/insight/solar-photovoltaic-plant-operating-and-maintenance-costs/, (access: 20 September 2018).

Mechanical failures of modules

Destruction of PV modules during installation on the roof, during their arrangement to obtain flat surface, constitutes a typical failure. Lack of dilatation between modules or too rare fixings not considering the wind power constitute a typical error in the PV assembly. An improperly selected module for environmental conditions under the influence of temperature and wind or as a result of ageing may be subject to quicker degradation and e.g. glass may brittle, while a mismatched material for assembly frameworks may cause their corrosion.

Fig. 3. Damage of the PV generator under the influence of wind
Source: https://www.renewableenergyworld.com/articles/print/volume-18/issue-4/features/solar/ensuring-your-solar-array-doesn-t-get-caught-in-the-wind.html, (access: 20 September 2018).

Errors and damage in the PV installation can be minimised through the proper design, installation and maintenance of the photovoltaic system. Usually, the most errors in photovoltaic systems occur during installation.

Frequent errors during the panel installation and configuration:

1) Change in cabling, without making alterations on the circuit diagram.
2) Change in a module type or manufacturer due to problems with supplies.
3) Exceeding the module or inverter voltage as a result of incorrect panel design.
4) Arrangement of too small number of serial modules for proper operation of the inverter during high summer temperatures.
5) Installation of photovoltaic modules without considering the Impp parameter of every module (grouping)

Frequent installation errors in cabling:

1) Human errors in performance of connections during installation.
2) Insufficient mounting of cables to the ground (cable tracks).

Fig. 4. Incorrectly arranged PV cables
Source: https://solarprofessional.com/articles/design-installation/common-residential-pv-system-code-violations#.W9Hs1nszapo, (access: 20 September 2018).

3) Cables touching roof or other abrasive surfaces exposed to physical damage.
4) Incorrectly mounted cable tracks – mounting at too large distances.
5) Too many cables in one clip.

Fig. 5. Incorrectly arranged PV cables without the cable route
Source: https://newenglandcleanenergy.com/energymiser/2013/05/09/shady-solar-installers-installment-2-why-wires-matter/, (access: 20 September 2018).

6) Lack of bearing elements to conduct cables.
7) Too tightly tensioned or too loose cables.
8) Not fully applied plug connectors.
9) Cable bending too close to the socket.
10) Incorrectly connected plug connectors (not blocked).

Fig. 6. Proper connection of the PV cables with use of plug connectors
Source: https://www.homepower.com/articles/solar-electricity/equipment-products/array-wire-management, (access: 20 September 2018).

Typical installation errors in the earthing of photovoltaic modules:

1) Lack of earthing installation on the panel.
2) Not connected various module parts in order to achieve equal earthing potential.

Fig. 7. Connection equalising potentials of module earthing in PV systems
Source: https://solarprofessional.com/articles/design-installation/common-residential-pv-system-code-violations#.W9Hs1nszapo, (access: 20 September 2018).

3) Use of improper earthing grips to earth photovoltaic modules and supporting structures.
4) The assumption that aluminium frames driven into earth to support structures ensure efficient earthing.
5) Wrongly dimensioned earthing installation.
6) Incorrectly installed lightning protection.

Fig. 7. Fragment of the lightning installation in the PV system
Source: https://www.solarinsure.com/protect-your-solar-power-system-from-lightning, (access: 20 September 2018).

Typical errors concerning installation of electric boxes, cable tracks and uninstallation:

1) Breaking of installations adjusted to vertical mounting in non-vertical application - installation of switches intended for vertical operation in non-vertical setting.
2) Installation of fuses of improper value.
3) Incorrectly located electric boxes and cable tracks, due to which they are almost unavailable for service.

4) Non-compliance with the manufacturer's instruction concerning disconnection of cabling on the DC side.
5) Cable installation without insulation or with improper insulation in humid places and inside boxes not resistant to soaking.
6) Application of incorrect fixtures to introduce cables to external boxes.

Typical installation errors connected with mounting systems:

1) Application of improper assembly equipment.
2) Wrongly performed roofing processing.
3) Application of incorrect roof mountings for a specific roof type.
4) Application of incorrect screws for roof endings, for roofing elements.
5) Drilling incorrect openings for wall plugs and broken roof endings (roofing elements).
6) Incorrect distance of modules from the roof.

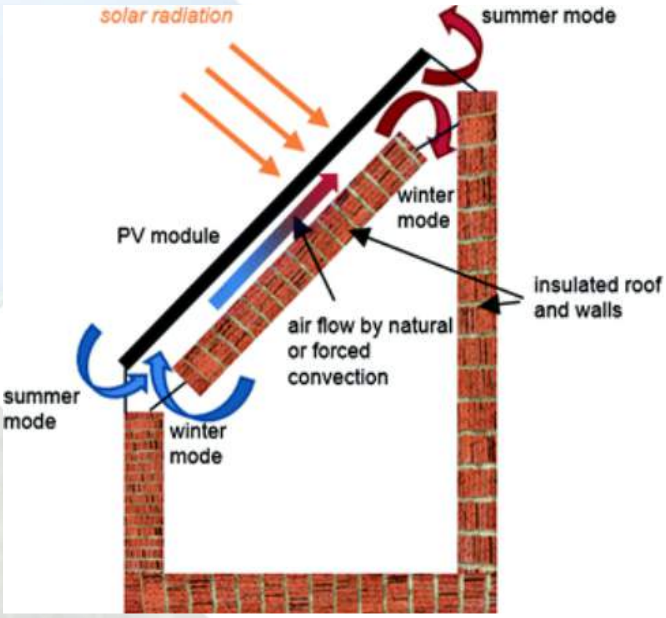


Fig. 8. Air exchange at the well assembled PV module, where:
Source: Olivier Dupré, Rodolphe Vaillon, Martin A. Green; Thermal Issues in Photovoltaics and Existing Solutions Springer International Publishing AG 2017.

4.11. Collection conditions and technical documentation of the installation

Technical documentation

The majority of PV installations operates in the on-grid mode, i.e. it is connected to the electrical grid. Such a connection of every device requires meeting the specific technical conditions required by a local grid operator.

In the case of microinstallations, one of the conditions is the presentation of the installation's technical documentation at the stage of filing a connection application.

Documentation should include:

- diagram of the facility's electrical installation,
- method of connection of the microinstallation to the facility's electrical installation and to the grid,
- if the applicant is constituted by an entrepreneur, the connection system should include the measurement system for electrical energy produced in the microinstallation.

Moreover, the application for connection of the photovoltaic installation should include detailed information concerning particular installation elements:

1. Information on the photovoltaic installation

a) Location ground/roof/facade/other ……………………………………….
b) Number of sections* …… [pc.].
c) Section rated power ….. [W].
d) Maximum permissible voltage …… [V].
e) Type permanently assembled on: ……..
f) Max height of the structure** ………. [m].

** A group of panels connected to one inverter should be treated as sections.*
*** Refers only to structures assembled on the ground, counted from the ground to the highest protruding element of the structure / panel.*

2. Photovoltaic cell

a) Manufacturer/country/type:
b) Foreseen operation duration in years: …………
c) Maximum rated power: …………………[W].
d) DC open circuit voltage (V): ………… [V].
e) Maximum DC voltage: …………………………….. [V].
f) Short-circuit current: …………………………………………………[A].
g) Maximum current for optimal conditions: ………..[A].
h) Rated efficiency ……… [%].
i) Dimensions (width/height) ………. [m].

3. DC/AC converter (inverter)

a) Converter type
b) Manufacturer/country ....
c) Number of converters …… [pc.].
d) AC rated power …. [kW].
e) DC rated power …. [kW]
f) Maximum input voltage …. [V].
g) Output rated voltage …. [V].
h) Range of output voltage change …. [V].
i) Input rated current …. [A].
j) Output rated current …. [A].
k) Min/max output current …. [A].
l) Power consumption in the night mode …. [W].
m) Frequency …. [Hz].
n) Range of frequency changes …. [Hz].

o) Distortion factor …. [%].
p) Power factor …. [--].

Installation performance

Moreover, it should be emphasised that the construction of the microinstallation and its connection to the electrical grid can be performed only by a person holding relevant permissions specified in provisions of the given country.

Final tests, start and commissioning.

The installation process ends with the stage of testing and start. This stage is preceded by the procedure of drawing up a written report by the installer, including results of run tests, including those specified in the instruction for installation by manufacturers of applied PV devices.
Test measurements should be preceded with initial system inspection that should be conducted even before the installation power supply connection. Inspection should be carried out according to the requirements of the standard IEC 60364-6.
Note: In case of electrical wiring which may be found in hardly accessible places after the system installation, it may be necessary to check them before the installation works or in their course.
It should be verified whether the following elements, typical for photovoltaic systems connected to the network, shall be controlled during the initial inspection:

DC side of the PV system - general check

General check of the DC installation should verify whether:
1) The DC system was designed, specified and installed according to the requirements of the standard IEC 60364, in particular its part IEC 60364-9-1.
2) Maximum voltage of the PV module field is appropriate for the PV system location (IEC 60364-9-1 and local regulations may stipulate that installations above some voltage may be located only in specific sites).
3) All system elements and installation structures were selected and assemble in the way allowing for the standing of an impact of expected external conditions, such as wind, snow, temperature or exposure to corrosion.
4) Roof fixings and cableways for electrical wiring are resistant to atmospheric conditions (if applicable).

DC system - protection against electrocution.

Control of the DC installation should cover at least the verification of assumed measures of protection against electrocution in case of defects of insulation, including:
a) Protective measures foreseen at the application of very low voltage (SELV/PELV) – yes/no;
b) Protection through application of class II or equal insulation on the DC side – yes/no;
c) Wires and connections of PV chains and PV module field were selected and installed in the way minimising the risk of short-circuits among them and ground faults; usually accomplished by the application of cable with protective and strengthened insulation (often named "double insulation") – yes/no;

DC system – protection against consequences of insulation damage.

Control of the DC installation should cover at least the verification of valid measures of protection against consequences of insulation damage, including:

a) Galvanic isolation inside the inverter and on the AC side - yes/no;
b) Functional ground of every conducting element - yes/no;
   NOTE: knowledge of galvanic isolation and functional grounds are necessary for the establishment whether measures to protect against results of insulation damage were properly specified;
c) The alarm system to detect low insulation resistance between the PV module field and earth – compliance with the standard IEC 60364-9-1 requirements.
   NOTE: option usually ensured by the inverter.

DC system - overcurrent protection.

Control of the DC installation should cover at least the verification of overcurrent protection in DC circuits:

a) In case of the system without overcurrent protection in PV module chains, one should ensure that:
   - $I_{MOD\_MAX\_OCPR}$ (maximum rated current of serial fuse in the chain) is larger than possible reverse current;
   - PV module chain cabling is selected in the way allowing for transfer of maximum short-circuit current from chains connected in parallel.

   Note: the standard IEC 60364-9-1 should be applied to calculate reverse current of the PV module field;
b) In case of systems with overcurrent protection in chains, one should ensure that overcurrent protective devices are appropriate, properly installed and compliant with requirements of the standard IEC 60364-9-1; similar procedure should be implemented when overcurrent protection has been installed for the entire field of PV modules or its section.

DC system – earthing installation

Control of the DC side earthing installation should cover at least the verification of:

a) When the PV system contains functional earthing of one of DC wires - compliance of specification and installation of this earthing with requirements of the standard IEC 60364-9-1;
b) When the PV system has direct connection to the earth on the DC side - compliance of the applied switch with requirements of the standard IEC 60364-9-1;
c) Compliance of the method of earthing connections of the PV module field frame with requirements of the standard IEC 60364-9-1.
   NOTE: Local regulations may require various connections.
d) If protective earthing and/or level-equalising wires are installed, it should be verified whether they are arranged in parallel to the DC wires and connected with them.

DC system – protection against consequences of lightning and power surges

Control of the DC installation should cover at least:

a) In order to minimise voltage caused by lightning, verification whether the surface of loops created by electrical wiring is as small as possible;

b) Verification of measures aiming at the protection of long cables (e.g. through screens or installation of earth fuses - SPD);
c) If earth fuses SPD are applied, verification whether they are installed according to requirements of the standard IEC 60364-9-1.

DC system – selection and installation of electrical equipment

Control of the DC installation covers at least verification whether:

a) All elements are dedicated to DC continuous work and at maximum possible values of voltage and current, as defined in the standard IEC 60364-9-1;

   NOTE: Knowledge of maximum voltage and current of the system is required during the DC system control.

   – **maximum system voltage is the function of configuration of PV module chains/PV module field, open circuit voltage (V_{OC}) of modules and the multiplier considering changes in temperature and lighting intensity (usually 1.3),**
   – maximum possible short-circuit current is the function of configuration of PV module chains/PV module field, short-circuit current (Isc) of modules and the multiplier considering changes in temperature and radiation intensity (usually 1.5);

b) Electrical installations have been selected and installed to withstand expected impact of external factors, such as wind, icing, temperature, solar and UV radiation;
c) Method of isolation and disjoining chains, PV module field and PV module section has been compliant with requirements of the standard IEC 60364-9-1;
d) DC disconnector is installed on the DC inverter side according to requirements of the standard IEC 60364-9-1;

   Note: The standard IEC 60364-9-1 defines four different methods of switch installation; the applied type and place of the switch should be presented on the system acceptance report.

e) If blocking diodes are installed, it should be verified whether their reverse rated voltage comes to at least 2 x V_{OCSTC} of the PV module chain, where diodes were installed (standard IEC 60364-9-1);
f) Plugs and connection slots are of the same type and from the same manufacturer and they correspond with requirements of the standard IEC 60364-9-1.

AC side of the PV system – general check

Check of the photovoltaic system on the AC side includes at least the verification whether:

a) Switch disconnector of the inverter is placed on the AC voltage side;
b) All disconnecting and switching devices applied in the PV installation are wired from the side of "loads", while the public network – from the "source" side;
c) Inverter parameters were programmed according to the local regulations;
d) If the RCD element of differential protection was installed in the circuit of alternate current supplying the inverter, it should be verified whether that element was selected in accordance with requirements of the standard IEC 60364-9-1.

   NOTE: In case of some inverters, B-type RCD fuses (slow-burn) may be required.

Labelling and identification

Check of the photovoltaic system includes at least the verification whether:

a) All systems, protective devices, switches and terminals were labelled according to requirements of the standard ICE 60364 in general and 60364-9-1 in particular;

b) Warning labels were placed on all casings of DC electrical connection boxes (PV generator and PV module fields) showing that active parts inside the box are supplied from the PV module field and can be still electrified, even after disconnection from the PV inverter and public network;
c) Switch disconnector on the AC side was clearly labelled;
d) Connection points of the system and the network are equipped with warning labels notifying of double power supply;
e) Single-line scheme of electrical wiring is available at the installation site;
f) Installer's data are available at the installation site;
g) System deactivating procedures are available at the installation site;
h) Alarm procedures are available at the installation site (if applicable);
i) All labels are fixed permanently.
   NOTE: requirements for the photovoltaic system labelling and identification are specified in the standard IEC 60364-9-1.

A copy of test results must be provided to the customer. After the system start, the installer issues a certificate for the customer, containing the following data:

- Real property address.
- Contact data of the installer.
- Types and serial numbers of installed devices.
- Commissioning date of the PV system.
- Power rating of the PV system.
- Estimated annual energy efficiency of the PV system.
- Warranty period granted by the installer.
- Manufacturer's guarantees for PV modules and inverter, and contact details of these component providers' services.

Such information is particularly important when an installation company does not exist. In addition, it enables the customer to verify an attempt to avoid responsibility for invalid installation.

Warranties and service

After the installation process completion, the customer must be sure that it has support in case of any issues with the PV system. Details of warranties covering the quality of products and installation works should be included in the start documentation provided to the customer by the installation upon the installation completion.

Installers should propose conclusion of a service agreement, but should not insist on its use. It is a good practice to leave for the customer an instruction copy, describing requirements concerning the system maintenance.

All installers should have and apply a transparent complaint procedure, as well as leave its description at the customer.
A returnable customer satisfaction survey is a useful tool to monitor the customer satisfaction. Therefore, leaving such a form in a set of documents provided to the customer constitutes a good practice.

4.12. Estimate, offer, contract for the installation of solar devices and systems

Quality-related principles

Every installation company must construct PV systems according to valid standards and in entire construction process it should apply good practice in order to install PV systems in the recurring way at the same high level of quality.

The quality management system (QMS) constitutes a tool for this purpose.
The basic idea of the QMS is that the entire process, from the first contact with the customer, i.e. from making an offer, through assembly, activation and commissioning of the PV system, should be specified in a written plan that is implemented by an installer during all installations.

Standard procedures, forms and software creating the quality management system contribute to the coherence of activities and their traceability. Traceability becomes important in the case of issues right after the activation, but may help also many months or years later.

Such a documentation helps understand where e.g. installer made a mistake or prove that the installer did not make any mistakes and fault is somewhere else (it is particularly useful in case of dispute).

The ISO 9001 standard is an example of quality management system applied by many medium and large enterprises and may be a useful guide for everybody who considers how to configure the quality management system in its activity. It should be kept in mind that every company is different so every entity must develop its own QMS, which suits the best its method of action.

Implementation of the entire ISO 9001 system is not necessary to accomplish qualitative purposes.

Shortened, but covering key procedures version of the system is more accurate for smaller companies and individual entrepreneurs.

The list below is a sample of some elements that may be considered while writing operating procedures for a company installing PV systems:

1. Procedure of data collection for the project, offer form.
   a) Data to initial offer,
   b) Data from the site inspection.
2. Offer specimen.
3. Specimen of a contract with the customer.
4. Procedure for selecting software tools that are to be applied for the PV system design.
5. Procedure for purchase and control of delivered PV system components.

6. Procedure for performance of the PV system installation: design, arrangements, assembly.
7. Procedure for the PV system acceptance
8. Procedure for the QMS update, including documents applied in it
9. Other documents that should be included in the QMS, e.g.:
   a) List of domestic regulations related to the PV system construction: technical standards, building regulations and sectoral guides.
   b) Manufacturer's instructions for every photovoltaic product installed by the company.
   c) List of documents to provide to the customer, including those concerning maintenance works.
   d) Performance bond with specific warranty requirements.
   e) Principles of health and safety protection, with particular consideration of specificity of photovoltaic systems (e.g. development of electric arc and different rules for fire risk than at alternating current).
10. Other documents covered by the QMS that may be applied:
    a) List of devices (including serial numbers) that require calibration, who is responsible for equipment calibration on time, calibration schedule.
    b) Records of employee training - useful to establish who is properly prepared to implement a given procedure and to establish a path of development of employee skills, in order to motivate them adequately to perform the action plan.
    c) Complaint procedure and complaint log (no matter if they are justified or no) to record issues, even single cases, and to know how they were solved.

Exemplary offer form for the project:

Address data:

Project: no., name	
Construction site address:	
Name and address of the investor:	
Investor contact:	
Contractor contact:	
Architect/building designer:	
Phone no.	E-mail address
Electrician	
Phone no.	E-mail address
Roofer	
Phone no.	E-mail address

Electrical grid data:

Grid distributor	Phone no.	E-mail address
Power and supply	Situation description	
Power planned for installation is not higher than the one specified in the issued connection conditions – necessary notification.		
Power planned for installation is higher than the one specified in the issued connection conditions – necessary application.		
Grid supply authorised by the distributed under the following conditions:		

Enclosed documents:

☼ Building plan	☼ Floor plan	☼ Roof plan
☼ View from the side	☼ Building section	☼ Building description
☼ Photo of the roof	☼ Photo of the house	☼ Photo of the shading
☼ Photo of the electric meter	☼ Photo of the house's connection to the grid.	☼Energy consumption history
☼Other…….		

Customer's requirements:

Nominal power of the PV system, in kWp:	Planned investment funds in PLN:
Expected production of electrical energy in kWh/year:	Maximum roof surface for the PV system in m²:
Other:	

Details of the roof shape:

Nominal power of the PV system, in kWp:	Planned investment funds in PLN:
Expected production of electrical energy in kWh/year:	Maximum roof surface for the PV system in m²:
Other:	

Details of the roof shape:
Roof surface available for the PV generator (it is recommended that width of distance from the edge from every side comes to at least 0.5 m):

Length in m =	Width in m =	Surface in m² =

Roof elements causing shading of panels of the PV generators:

☼ Chimney	☼ Antenna	☼ Window
☼ Lightning rod	☼ Dormer window	☼ Other

Enclosed drawing/sketch of the shaded area.

Usable surface after deduction of the shaded place: ………………m²

Roof availability:

☼ Required jack ☼ Required scaffold ☼ Possible access for truck

Assembly of modules-lightning protection-inverter-power supply, cabling:

Module orientation	-90° = east 0° = south +90° = west
Module inclination (0° = horizontal)	
Installation on the flat roof with use of ropes and clips ☼	

Is there earthing? Required inspection ☼	Yes ☼ ☼No

Is there lightning protection? Required inspection?	Yes ☼ ☼No Yes ☼ ☼No

Type of existing protections	
Location of the generator box	
Location of the DC switch	
Location of the inverter	
Location for the meter and fuses	Yes ☼ ☼No
Required modernisation	Yes ☼ ☼No

DC cabling on the roof:

☼ **through roof channels**	☼ in roof drains	☼ built in the chassis
Length of cables from the PV generator to the splitter (m)		
Length of cables from the splitter to the DC switch/inverter (m)		

AC cabling: ☼ in the upper part of plaster	☼ below plaster	☼ in the cabling channel
Length of cables from the inverter to the meter (m)		
Length of cables from the meter to the fuse (m)		

Other assembly conditions:

Description:

Every company should develop its own QMS with a description which procedure shall be used at every stage from the first contact with the customer to the installation commissioning and after-sales services. There should also be specified who is responsible for performance of a given procedure. Such a document is specified generally as the Quality Plan.

After the QMS implementation, it is worth to conducts its periodic check in order to control how good it works (e.g. annually) and register results of each check. It allows for the avoidance of errors made earlier and application of good practice in the company's everyday work. Such checks are also an opportunity to check changes in regulations and standards that are significant at photovoltaic installations and to identify issues and any complaints, which allows for the improvement of the quality of work and cooperation with subcontractors.

Customer service

The entire process from the first contact with the customer, through start-up and commissioning of the PV system should be clear, transparent, documented and understandable for the customer. Resignation from this general principles inevitably leads to problems and complaints.

Therefore, all process stages must be documented in a form understandable for the customer, all key points should be explained orally and the project cannot be continued if it is not good for the customer and it has not accepted the presented cost estimate.

Sales of the PV system

In the sales process, the following principles should be applied:

1) **Advertisement**
   Advertising and promotional activities should present the offered products and services in the objective way and not force service performance. Basic information addressed to the customer, which is constituted by the expected system efficiency, should result from data from the insolation base in the project location, e.g. from the website http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=it&map=europe and consider the shading conditions, which may significantly affect efficiency.
2) **Personnel training**
   Sales assistants should be trained to the level enabling them to present in detail the PV system offered for installation or to advise within the scope of its required modernisation. They should also be able to properly assess the energy performance of the building and advise the customer within the scope of energy efficiency.
   Training for sales personnel should include a module concerning permissible sales methods in order to avoid an improper strategy (too strong sales pressure).
   Personnel should be informed on possible sanctions in the case of their application.
3) **Basic principles concerning the sales assistant's job**
   During the first meeting, pressure on agreement signing should not be placed.
   During the first site inspection, one cannot stay at the facility for more than two hours (inspection, measurements, etc.).
   In the initial phase of the sales process, payment cannot be accepted.
   It must notify the customer of the sales process, including the terms of withdrawal from the agreement after its signature.
   It must notify the customer of any required permits or certificates (e.g. building permit, network connection) prior to the installation commencement, so that it is clear who is responsible for their acquisition.
   It must reliably estimate the expected capacity of the PV system.

Cost estimate and agreement – estimation of energy efficiency.

The cost estimate, together with conditions for performance, often constitutes an agreement between an installing company and the customer. Contractual provisions must be clear, understandable and include all necessary information. It is a good practice to, before presentation of a financial proposal concerning the PV installation, present to one's customers the estimation of annual energy efficiency by a proposed photovoltaic system. It is important because the customer expects that production of energy from a renewable energy source improves its financial balance connected with used energy (it will be more financially beneficial in an assumed period than only power supply). So it is crucial to estimate a foreseen energy characteristics of the system, which should occur prior to the conclusion of any installation-related agreement.

Table 1. Exemplary system cost estimate

No.	System components	Type	Quantity	Parameters
Name	**Manufacturer**			
1	PV modules			
2	Assembly system			
3	Inverter			
4	Charging regulator			
5	Fittings and cabling			
6	Protections			
7	Batteries			
8	Monitoring system			
9	Assembly price PLN (gross)			
Total price PLN (gross)				

In the conditions of domestic development of photovoltaics, the most important parameter of the forecast is the accurate determination what percent of produced energy may constitute self-consumption and allows for saving energy expenses, and what should be released to the network (due to characteristics of the PV system operation) at valid, currently low rates.
At this stage, determination of energy efficiency may be only approximate. Calculations may become more complex, depending on a level of required accuracy. One should explain the customer the impact on the PV system efficiency the key factors, such as climate, geographic orientation and inclination of modules, overshadowing, temperature, and determine what calculation method was applied (manual or with use of a modelling software package).

Main assumptions adopted for calculations should also be presented to the customer to allow for verification of received results. It is important because it helps explain that the PV system performance cannot be foreseen accurately, due to differences in the amount of solar energy available in every place and year. However, in a multi-year approach, forecasts based on professional project programmes, considering all technical, metrologic and local parameters, and mainly an analysis of overshadowing, correspond with reality with a several to max. more than a dozen percent error. However, it is purposeful to provide the customer with the possibility to conduct a joint simplified analysis, e.g. with consideration of the PVIGS database.
Other information that should be delivered to the customer at the stage of request for proposal includes:
1) Explanation of any available financial incentives (e.g. subsidies, etc.).
2) Obtained price/quality ratio for the proposed system.
3) Information what elements may require replacement in the system operation period and approximate cost of this replacement.
4) A list of all main components that have been delivered, including their brand, model and serial number. These data are particularly important with regard to guarantee of trouble-free operation of the PV system.
5) Expected duration of the installation process.
6) Available possible extension of the installation time (depending on local regulations and practices).

What the fitter may expect during installation:

1) All other required services (e.g. power supply, access to water and toilet).
2) Warehouse for safe storage of equipment before assembly.

What the customer may expect:

1) Information on acceptable payment form and dates.
2) Written agreements concerning small changes in specification.
3) In case of large changes in specification by any party, there must be prepared new specification and work can be continues after its bilateral approval.

5. EXERCISES

5.1. Health and safety regulations for the installation – exercises

Exercise 1. *(to the subject 4.1)*
Complete sentence with phrase from the frame.

Performance of works at height belong to the works ...

particularly hazardous	particularly safe	not requiring special permits	performed at strong wind

Exercise 2. *(to the subject 4.1)*
Among the mentioned factors, select those that affect basic activities prior to the work commencement.

	Basic activities prior to the work commencement
Preparation of necessary tools with insulated handles protecting from direct electrocution.	
Preparation of necessary measuring equipment and necessary insulation equipment, such as dielectric gloves, protecting from consequences of an accidental touching of two wires of different potential (controlled every 6 months), gumboots, carpets, insulating platforms and protective glasses.	
Preparation of necessary warning boards.	
Making sure that all fitters are on the building's roof	
Protection of loose elements in the vehicle	
Maintenance of safe distance from the ladder in the case of the fitter's fall	
Purchase of appropriate writing and drawing materials	
Reading the documentation and planning the sequence of particular work stages.	
Reading the electrical energy sales agreement	

Exercise 3. *(to the subject 4.1)*
Cross out an item that does not suit the rest:
Assembly of direct current installation is connected with:
– assembly of wires connecting photovoltaic modules,
– assembly of MC4-type endings on wires,
– connection of photovoltaic modules in chains,
– connection of the photovoltaic generator to the inverter,
– assembly of the AC-type residual current circuit breaker.

5.2. Installation plan – exercises

Exercise 1. *(to the subject 4.2)*

Among the listed activities, select these belonging to the pre-assembly activities.

	Basic pre-assembly activities
Analysis of documentation	
Delivery completeness control	
Control of efficiency of tools and measuring instruments	
Final acceptance protocol	
Assembly and control of inverters	
Assembly and control of the lightning installation	
Assembly and control of AC cabling and AC protections	
Assembly and control of DC cabling and DC protections	
Assembly of the supporting structure	
Assembly of photovoltaic modules	
Marking of the installation site pursuant to the OHS regulations	
User training	
System pre-commissioning and adjustment	

Exercise 2. *(to the subject 4.2)*

Among the listed activities, select these belonging to the assembly activities.

	Basic assembly activities
Analysis of documentation	
Delivery completeness control	
Control of efficiency of tools and measuring instruments	
Final acceptance protocol	
Assembly and control of inverters	
Assembly and control of the lightning installation	
Assembly and control of AC cabling and AC protections	
Assembly and control of DC cabling and DC protections	
Assembly of the supporting structure	
Assembly of photovoltaic modules	
Marking of the installation site pursuant to the OHS regulations	
User training	
System pre-commissioning and adjustment	

Exercise 3. *(to the subject 4.2)*

Among the listed activities, select these belonging to the post-assembly activities.

	Basic post-assembly activities
Analysis of documentation	
Delivery completeness control	
Control of efficiency of tools and measuring instruments	
Final acceptance protocol	
Assembly and control of inverters	
Assembly and control of the lightning installation	
Assembly and control of AC cabling and AC protections	
Assembly and control of DC cabling and DC protections	
Assembly of the supporting structure	
Assembly of photovoltaic modules	
Marking of the installation site pursuant to the OHS regulations	
User training	
System pre-commissioning and adjustment	

5.3. Tools and equipment for installation of photovoltaic systems – exercises

Video 1. *(practically to the subject 4.3)*
Instructional video on how to use tools for assembly of MC4 connections

With use of an insulation stripper, remove approx. 1 cm of insulation from the photovoltaic wire. Then, without touching the wire conductors with fingers put on the metal MC4 connection pin. Place the pin and the wire in the press tool. Squeeze the press tool strongly until the blockade enables to open the press tool. Put the connection cap on the pressed wire and then stick the pin in the connection case. Screw the cap to the connection case with dedicated spanners.

Didactic aids: Solar cable 4mm2, endings MC4, press tool for MC4, insulation stripper, spanners to screw MC4 connections

5.4. Practical principles of module installation, selection and dimensioning of wires and cables – exercises

Video 1. *(to the subject 4.4)*
Video – assembly of modules on the roofline
Photovoltaic modules, assembly structure together with necessary elements and spanners (depending on the structure manufacturer), roofline (possibly roofline fragment), string, level (possibly laser).

Video 2. *(to the subject 4.4)*
Video – wire arrangement on the roof

Video 3. *(to the subject 4.4)*
Video – Connection of modules in chains and their connection to the photovoltaic inverter

5.5. Setting up and start-up of photovoltaic system – exercises

Exercise 1. *(to the subject 4.5)*
Complete sentence with phrase from the frame.

At vertical assembly of photovoltaic modules, the terminal box of the photovoltaic module should be located in ...

at the top of the module	at the bottom of the module	at the top of the module	on the left side of the module

Exercise 2. *(to the subject 4.5)*

Among the mentioned factors, select those that affect weekly energy efficiency of the photovoltaic installation.

	Factors affecting weekly energy efficiency of the photovoltaic installation
Good access to further service and maintenance of the inverter	
If the inverter has a display, it should be installed in the way allowing for an easy reading of parameters from the display	
Undisturbed air circulation	
Protection from excessive humidity and solar radiation	
Removal of heat excess from the inverter	
Limited air access to the inverter	
Operation in humid environment ensuring better cooling of the inverter	
Permanent obstruction of the display protecting from unauthorised access	

Exercise 3. *(to the subject 4.5)*

Cross out an item that does not suit the rest:

Activities performed during the inverter activation include:

- disconnection of the photovoltaic generator from the inverter.
- connection of the photovoltaic generator through the DC disconnector.
- connection of the network voltage through external fuses.
- checking whether the inverter is mounted and connected to the electrical installation.
- checking whether the photovoltaic generator provides voltage larger than the minimum DC input voltage in the inverter.
- checking whether the connection box cover is earthed and closed.

5.6. Cooperation of batteries with photovoltaic systems – exercises

Exercise 1. *(to the subject 4.6)*

Complete sentence with phrase from the frame.

Storage of electrical energy is possible thanks to the application of ...

batteries	solar collectors	energy saving bulbs	buffer tank for hot water

Exercise 2. *(to the subject 4.6)*

Among the listed parameters, select parameters describing energy storage.

	Parameters of energy storage
Frequency of output voltage f [Hz]	
Maximum charging voltage U_{max} [V]	
Minimum discharging voltage U_{min} [V]	
Rated voltage U_N [V]	
Rated capacity Q [Ah]	
Rotational speed n [rot/min]	
Internal resistance R_w [mω]	
Melting temperature [°C]	

Exercise 3. *(to the subject 4.6)*
Cross out an item that does not suit the rest.
Parameters specifying scopes of battery operation in time include:
– SOC.
– SOH.
– DOD.
– RISC.

5.7. Surge protection in photovoltaic installations – exercises

Exercise 1. *(to the subject 4.7)*
Complete sentence with phrase from the frame.

Surge protection devices of type ... protect from direct and close lightning.

1	2	3	4

Exercise 2. *(to the subject 4.7)*
From among the listed protections, select these that protect the electrical installation from effects of lightning or surge.

	Correct operating conditions of the photovoltaic inverter
Overcurrent protection B	
Overcurrent protection D	
Surge protection of type 1	
Surge protection of type 1+2	
Surge protection of type 2	
Surge protection of type 3	
Residual current circuit breaker B	

5.8. Lightning protection and earthing installation – exercises

Exercise 1. *(to the subject 4.8)*
Complete sentence with phrase from the frame.

An element of the lightning installation placed in the earth is ...

earthing	horizontal air terminal	test clip	exhaust wire

Exercise 2. *(to the subject 4.8)*
From among the listed methods, select methods specifying the distribution of lightning installation elements.

	Methods specifying the distribution of lightning installation elements
Protective Angle Method	
First Strike Method	
Lightning Method	
Impulse Current Method	
Mesh Method	
Rolling Sphere Method	

Exercise 3. *(to the subject 4.8)*
Cross out an item that does not suit the rest:

Elements of the lightning installation include:
- photovoltaic module.
- exhaust wire.
- earthing.
- test clip.
- vertical air terminal.
- horizontal air terminal.

5.9. Installation rules for solar systems – exercises

Exercise 1. *(to the subject 4.9)*
Complete sentence with phrase from the frame.

Prior to the commencement of the assembly of photovoltaic modules on the roof, the following activity should be performed:

Assembly of supporting elements for photovoltaic modules	Verification of correctness of electrical connections	Activation of the photovoltaic inverter	Assembly of overcurrent protection on the DC side

Exercise 2. *(to the subject 4.9)*
The photovoltaic system installation process covers the following issues:

	The photovoltaic system installation process covers
Final operations and acceptance	
Confirmation of the terms and conditions of the agreement	
Delivery performance	
Acquisition of investment credit	
Receipt of support in the form of subsidy	
Verification of input data	
Installation performance	
Protection of the installation site	

Exercise 3. *(to the subject 4.9)*
Cross out an item that does not suit the rest:
Performance of installation works consists among others in:
- assembly of the photovoltaic inverter
- assembly of the supporting structure
- assembly of photovoltaic modules
- assembly of protections on the AC and DC side of the photovoltaic installation
- signature of an agreement for performance of the photovoltaic installation
- connection of photovoltaic modules

5.10. Typical assembly installation errors – exercises

Exercise 1. *(to the subject 4.10)*
Complete sentence with phrase from the frame.

The most common defects in the photovoltaic installation include failures of ...

photovoltaic inverters	photovoltaic modules	cabling on the DC side	cabling on the AC side

Exercise 2. *(to the subject 4.10)*
From among the mentioned errors, select typical errors that may occur at the assembly of photovoltaic modules.

	Typical errors that may occur at the assembly of photovoltaic modules
Installation of overcurrent protections on the AC side with too low rated current	
Incorrect selection of modules to the inverter at the stage of PV installation design	
Connection of a too small number of photovoltaic modules in the PV chain	
Change in cabling, without making alterations on the circuit diagram	
Change in a module type or manufacturer due to problems with supplies	

Exercise 3. *(to the subject 4.10)*
Cross out an item that does not suit the rest:
Typical errors connected with the installation of mounting systems for photovoltaic modules:
- application of incorrect roof mountings.
- application of incorrect screws.
- application of improper assembly equipment.
- wrongly performed roofing processing.
- wrongly performed connections of photovoltaic modules.

5.11. Collection conditions and technical documentation of the installation – exercises

Exercise 1. *(to the subject 4.11)*
From among the listed information, select the information that should be placed in the photovoltaic installation-related information.

	Information on the photovoltaic installation that should be placed in documentation
Number of photovoltaic chains	
Maximum power of power supply connection	
Maximum permissible voltage in the photovoltaic installation	
Location ground/roof/facade/other	
Rated power of the photovoltaic installation	
Building purpose	
Total rated power of receivers belonging to the investor	

Exercise 2. *(to the subject 4.11)*
Cross out an item that does not suit the rest.

Technical documentation of the microinstallation attached to the application for connection to the electrical grid should include:
– flow chart of the photovoltaic inverter.
– scheme of the photovoltaic microinstallation,
– method of connection of the microinstallation to the facility's electrical installation and to the grid,
– detailed information concerning particular elements of the photovoltaic installation,

5.12. Estimate, offer, contract for the installation of solar devices and systems – exercises

Exercise 1. *(to the subject 4.12)*
Complete sentence with phrase from the frame.

Performance of the photovoltaic installation according to the applicable standards by the installation company ensures ...

introduction of the quality management system	establishment of the job of the quality specialist	compliance with the OHS principles	quick task performance

Exercise 2. *(to the subject 4.12)*

Cross out an item that does not suit the rest:

Proper planning of the roof photovoltaic installation requires the acquisition of the following information:

- shape and location of the roof against the southern direction,
- roof cover type,
- possible sources of roof shading,
- expected energy yield from the planned photovoltaic installation,
- number of persons staying in the building.

6. PROGRESS TEST

Can you:	Yes	No
1) Explain what the assembly of direct current installation consists in?		
2) List basic activities prior to the work commencement?		
3) Discuss activities related to mechanical works during the PV installation performance?		
4) Discuss activities related to electrical works?		
5) Indicate main causes of fires of the PV installation?		
6) Explain what the pre-installation activities consist in?		
7) List installation activities in an appropriate sequence?		
8) Discuss particular installation activities?		
9) Discuss activities related to assembly of the photovoltaic inverter?		
10) List post-installation activities?		
11) Explain the sense of application of dedicated assembly tools?		
12) List basic assembly tools dedicated for the photovoltaic installation?		
13) Discuss advantages of application of dedicated assembly tools?		
14) Discuss the procedure at the assembly of DC photovoltaic connections?		
15) Indicate tools needed for the assembly of the photovoltaic inverter?		
16) Explain principles of the correct assembly of the photovoltaic module?		
17) List typical wire sections applied in photovoltaic installations on the photovoltaic generator's side?		
18) Discuss the structure of the DC wire applied in photovoltaic generators?		
19) Discuss the structure of the AC wire in the photovoltaic installation?		
20) Indicate typical reasons for failures of photovoltaic installations on the photovoltaic generator's side?		
21) Explain what the assembly of the photovoltaic inverter consists in?		
22) List basic principles of the assembly of photovoltaic modules?		
23) Discuss activities related to the activation and deactivation of the photovoltaic inverter?		
24) Discuss issues related to remote communication with inverters?		
25) Indicate main principles valid at the performance of measurements of photovoltaic inverters?		
26) Explain what the energy storage consist in?		
27) List basic technologies of battery performance?		
28) Discuss operating parameters of batteries?		
29) Discuss issues related to the battery operation supervision?		
30) Indicate rated parameters, disadvantages and advantages of particular technologies of battery performance?		
31) Explain what the power surge protection of the photovoltaic installation consists in?		
32) Explain basic principles of selection of power surge protections in the photovoltaic installation?		
33) Discuss types of power surge protections?		
34) Discuss the role of the lightning installation at the power surge protection of photovoltaic installations?		

35) Indicate main principles of assembly of power surge protections?		
36) Explain why lightning installations should be applied?		
37) List basic principles of distribution of the lightning installation?		
38) Discuss methods of distribution of the lightning installation elements?		
39) Discuss issues related to the protection of the photovoltaic installation from lightning effects?		
40) Indicate when the risk of lightning strike directly in the photovoltaic installation occurs?		
41) Explain what the installation site protection consists in?		
42) Explain basic activities related to assembly of the photovoltaic installation?		
43) Discuss activities related to assembly of the supporting installation?		
44) Discuss issues related to the performance of acceptance measurements of the photovoltaic installation?		
45) Indicate main principles valid at the activation of the photovoltaic installation?		
46) Explain the impact of errors occurring at the module connection on the operation of the photovoltaic installation?		
47) List typical errors occurring at the assembly of photovoltaic modules?		
48) Discuss typical errors occurring at the assembly of supporting structures?		
49) Discuss errors related to the arrangement of wires and cables in photovoltaic installations?		
50) Indicate main errors occurring at the assembly of lightning installations?		
51) Explain preparation of technical documentation of the photovoltaic installation?		
52) List basic elements that should be included in the technical documentation?		
53) Discuss the information that should be included in a description of the photovoltaic installation?		
54) Discuss elements of the post-completion documentation?		
55) Indicate main principles of labelling elements of the photovoltaic installation?		
56) Explain what the introduction of the quality management systems consists in?		
57) List basic information helping to plan photovoltaic installations?		
58) Discuss basic principles of customer management?		
59) Discuss issues related to the conclusion of an agreement for performance of the photovoltaic installation?		
60) Indicate main components of photovoltaic installations?		

If you selected the answer "NO", we propose you returning to the teaching material and its repeated analysis in order to achieve intended learning outcomes (knowledge, skills).
Possibly, you can use additional information sources proposed at every subject.

7. GLOSSARY

English	Polish
Assembly of PV modules	Montaż modułów PV
Assembly of the inverter	Montaż falownika
Assembly of the supporting structure	Montaż konstrukcji nośnej
Battery capacity	Pojemność akumulatora
Battery discharging current	Prąd rozładowania akumulatora
Cabling assembly	Montaż okablowania
Charging cycle	Cykl ładowania
Cylindrical fuse link	Wkładka topikowa cylindryczna
Discharging cycle	Cykl rozładowania
Earth	Uziemienie
Earthing	Uziom
Energy storage	Magazyn energii
Fuses	Bezpieczniki mocy
Horizontal air terminal	Zwód poziomy
Installation activities	Czynności instalacyjne
Insulation class	Klasa izolacji
Lightning installation	Instalacja odgromowa
Lightning protection	Ochrona odgromowa
Live work	Praca pod napięciem
Maximum voltage of battery	Napięcie maksymalne akumulatora
Minimum voltage of battery	Napięcie minimalne akumulatora
Overcurrent circuit breaker	Wyłącznik nadprądowy
Overcurrent protection	Zabezpieczenie nadprądowe
Photovoltaic cell	Ogniwo fotowoltaiczne
Photovoltaic chain	Łańcuch fotowoltaiczny
Photovoltaic connection	Złącze fotowoltaiczne
Photovoltaic generator	Generator fotowoltaiczny
Photovoltaic installation	Instalacja fotowoltaiczna
Photovoltaic installation design	Projekt instalacji fotowoltaicznej
Photovoltaic module	Moduł fotowoltaiczny
Post-installation activities	Czynności poinstalacyjne
Power surge protection	Zabezpieczenie przeciwprzepięciowe
Pre-installation activities	Czynności przedinstalacyjne
PV chain wire	Przewód łańcucha PV
Residual current circuit breaker	Zabezpieczenie różnicowo-prądowe
Residual current device	Wyłącznik różnicowo-prądowy
Reverse current	Prąd rewersyjny
Specific resistance	Rezystancja właściwa
Technical documentation	Dokumentacja techniczna
Tracking system of the point of maximum power	Układ śledzenia punktu maksymalnej mocy
Vertical air terminal	Zwód pionowy
Work at height	Praca na wysokości

8. LITERATURE

1. Bernaciak A.: *Ochrona środowiska w praktyce. Aspekty ekonomiczno-prawne. [Environmental Protection in Practice. Economic and Legal Aspects]* Wydawcy Sorus sc and Ekoprofil, Poznań 1994.
2. Brzeziński W.: Ochrona prawna naturalnego środowiska człowieka. [*Legal Protection of the Natural Human Environment*] PWN, Warszawa 1975.
3. Dębski M., Luberański A., Petrukanec A., Polewka P.: *Praktyczny poradnik Instalatora. Systemy fotowoltaiczne i słoneczne systemy grzewcze.* [*Practical Fitter's Guide. Photovoltaic Systems and Solar Heating Systems*] Wydawnictwo ATUM Sp. z o.o., Warszawa 2016.
4. Jarzębski Z. M: *Energia słoneczna, konwersacja fotowoltaiczna.* [*Solar Energy, Photovoltaic Conversation*] Państwowe Wydawnictwo Naukowe, Warszawa 1990r.
5. Jastrzębska G.: Ogniwa słoneczne. Budowa, technologia, zastosowanie. [*Solar Cells. Construction, Technology, Application*] Wydawnictwa Komunikacji i Łączności WKŁ, Warszawa 2013.
6. Klugmann-Radziemska E.: Fotowoltaika w teorii i praktyce. [*Photovoltaics in Theory and Practice*] Wydawnictwo BDC, Legionowo 2010.
7. Michałowska-Knap K., Wiśniewski G.: *Stan obecny i potencjał energetyki odnawialnej w Polsce.* [*The Current Condition and Potential of Renewable Energy Production in Poland*] PIGWO studies 2008.
8. Szymańska B.: *Instalacje fotowoltaiczne. Teoria, praktyka, prawo, ekonomia*. [*Photovoltaic Installations. Theory, Practice, Law, Economy*] Kraków, Wydawnictwo Glob Energia, 2013.
9. Tytko R.: *Urządzenia i systemy energetyki odnawialnej*. [*Devices and Systems of the Renewable Energy Production*] Wydawnictwo Towarzystwo Słowaków w Polsce, Kraków 2014.
10. Tytko R.: *Odnawialne źródła energii.* [*Renewable Energy Sources*] Wydawnictwo OWG, Warszawa 2010.
11. Znajdek, K., Sibiński, M.: *Ogniwa fotowoltaiczne różnych typów*. [*Photovoltaic Cells of Various Types*] Świat Szkła, issue 9, section 16, Wydawnictwo Euro-Media Sp. z o.o., 2011.

Electronic sources *(access: 20 September 2018)*

1. Gnatowski M.: *Falownik, czyli inwerter w pigułce.* http://www.solartime.pl/porady-eksperta/item/554-falownik-czyli-inwerter-w-pigulce
2. www.zielonewrota.pl (October 2012).
3. www.gramwzielone.pl
4. www.sep.com.pl
5. www.systemy-fotowoltaika.pl
6. www.fotowoltaikainfo.pl
7. https://pvmonitor.pl
8. www.fotowoltaika.com.pl