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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.U3. Modernization and maintenance of photovoltaic installations

GUIDE FOR THE TRAINEE AND THE TRAINER

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Cooperation for innovation and the exchange of good practices
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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

Module unit M2.U3. Modernization and maintenance 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.U3. Modernization and maintenance 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.U3. Modernization and maintenance 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.

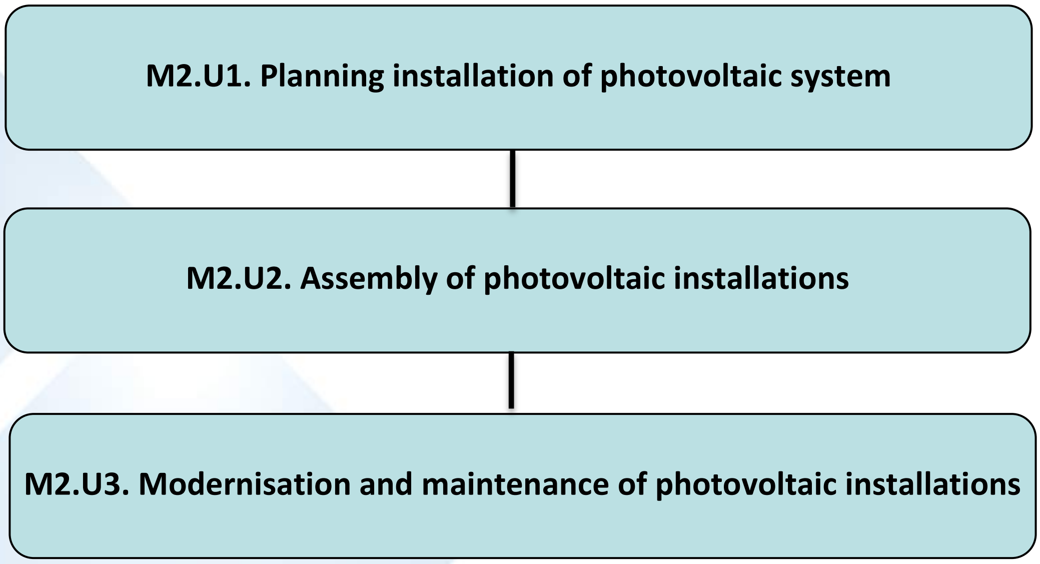
While developing the teaching material, experience of the project partners within the scope of teaching classes on courses preparing future photovoltaic installation installers. Teaching material has been supplemented with e-learning training including e.g. instructional videos.

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*.



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 installation of photovoltaic system	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.U3. Modernization and maintenance 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.U3. Modernization and maintenance 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 at work regulations, environmental protection. – Health protection during modernization works and maintenance of photovoltaic installations. – Safety rules for the maintenance and maintenance of a photovoltaic installation. – Photovoltaic maintenance program. – Monitoring of photovoltaic system properties – guidelines and measurement requirements and their analysis. – Analysis of typical errors related to modernization and maintenance. – Types of typical disturbances and failures in systems. – Methods and repairs or replacement of photovoltaic components. – Records of inspection, maintenance and repair of photovoltaic installations. – Estimate, offer, contract for works related to the modernization and maintenance of photovoltaic installations.	– Applies health and safety at work, environmental protection, health protection during modernization and maintenance of photovoltaic installations. – Performs measurements of current-voltage characteristics of photovoltaic modules / generators. – Performs measurements of the PV generator's efficiency. – Performs and analyses the results of thermographic tests of photovoltaic installations. – Performs periodic evaluation of the photovoltaic plant operation. – Performs periodic photovoltaic plant maintenance. – Diagnoses and repairs damaged components of photovoltaic installations. – Evaluates the quality of modernization, maintenance and repairs carried out on photovoltaic installations. – Keeping documentation of inspection, maintenance and repair of photovoltaic installations. – Settles the costs of works related to the modernization and maintenance of photovoltaic installations.
Social competence:	
– Demonstrate some autonomy in the resolution of small contingencies related to their activity. – 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. – Interpret and execute working instructions. – Respect the internal procedures and standards of the organization.	

4. TEACHING MATERIAL

4.1. Health and safety at work regulations, environmental protection

The content of this chapter is complemented by the issues presented in chapter 4.1. Health and safety regulations for the installation in the module M2.U2. Assembly of photovoltaic installations.

The PV installer performs a profession of the higher risk probability. This is due to the fact of constant contact with live electrical equipment, as well as hazards caused by work at a height, and related to the movement of loads of different dimensions and capacities. The application of health and safety regulations is therefore very important from the point of view of securing the health and life of employees performing specific activities. It is also important from the point of view of the legal security of the company's owners. Unfortunately, many rules of safe work are often forgotten. Therefore, these issues should be taken under the consideration in order to not disregard those regulations.

The PV system installer should be equipped with individual protection measures in the form of personal protective equipment against falling from a height consisting of braces and a safety rope with a shock absorber and a ladder or scaffolding, or a lifter.

The PV system installer is not only responsible for the health and safety of employees at the installation site, but also for the health and safety of customers and other people for whom the assembly work may be affected. The installer is also responsible for the long-term security of the installed system. Thus, it is the responsibility of identifying hazards associated with PV installation by taking appropriate steps to control and minimize these hazards.

Each installation is different, so this study is not able to list all cases of violation of work safety rules in the complete and definite way.

Health and safety rules

Health and safety rules are laid down in Directive No. 89/391/ECC of the European Commission of June 12, 1998 regarding the introduction of measures to support the improvement of occupational health and safety (OHS).

The application of health and safety rules makes it possible to determine:

a) Can the danger be prevented or avoided? Is it possible to eliminate it, for example, by considering whether a given task or job is necessary or removing the danger through the use of other materials or work processes.
b) If the risk cannot be avoided, it is to determine how it can be reduced to a level where the health and safety of workers will not be endangered.

The following preventive measures should be used, among others:
- combating the risk at the source;
- adaptation to technological progress;
- replacement of a device, material or other risk factor, its less dangerous alternative);
- developing a coherent general preventive policy covering technology, work organization, working conditions, social relations and the impact of factors related to the work environment;
- presenting collective protection measures over personal protective equipment (e.g. controlling exposure to fumes through an exhaust ventilation system, rather than using individual respiratory protection devices);
- issuing appropriate instructions to the employee.

European requirements on occupational safety are generally available, among others, at: https://osha.europa.eu/pl/legislation/directives, www.hse.gov.uk. National regulations have been adapted to European regulations. The companies that have implemented the occupational health and safety management system most often rely on the requirements of OHSAS (Occupational Health and Safety Management System) standards:
- BS OHSAS – 18001 – or PN-N-18001: 2004 Occupational health and safety management system - Specification.
- BS OHSAS – 18002 – Occupational health and safety management system - Guidelines for occupational risk assessment.
- BS OHSAS – 18004 – Occupational health and safety management system – Implementation guidelines.

Health and Safety Plan

In order to ensure the implementation of the project with the assumed safety guarantee, a Health and Safety Plan should be developed, which does not have to be extensive, but should always contain:
- List and description of the work to be carried out.
- Risk assessment with a list of threats and existing precautions.
- Description of the security rules to be followed and a list of security measures that must be taken.
- Provisions which are applicable.

When preparing Health and Safety Plan, make sure that its content is clear and concise, so that the installer can understand it and apply the appropriate guidelines.

Potential hazards when working with PV systems

Installation of PV systems creates a combination of hazards that an installer may not come across during previously performed works, including handling heavy loads, working at a height, or risk of electric shock. In practice, there are many hazards characteristic of PV installations, which should be taken into account when preparing a work organization plan and risk analysis for the installation of photovoltaic systems. More important of these threats are given below. It should be noted that due to the constantly changing nature of PV systems, the following information does not exhaust the risks that may occur and to avoid them, update the knowledge in this area and take appropriate protective measures. When preparing the work organization plan and risk assessment, attention should be paid to the equipment necessary to ensure the installer's safety during installation (e.g. personal protection equipment) and the hazards associated with the assembly of PV system components (e.g. selection of appropriate measuring and control equipment).

Risk assessment

Implementation of the principle of good practice at the workplace should start with a proper assessment of the risks and threats involved. This assessment should take into account all types of hazards and dangers in the workplace to ensure that the exposure of workers and others is effectively reduced, not just to replace one risk, the other. The risk has been defined as the probability of occurrence of undesirable events (threats/risks) related to work performed, causing losses and their effects on the health or life of employees in the form of occupational diseases and accidents at work. The assessment of such a risk is an in-depth examination of whether sufficient precautions have been taken and whether more can be done to prevent damage. The risk analysis consists of the identification of hazards related to the undertaking (resulting from the work being carried out or other factors, e.g. workplace, weather conditions) and the assessment of their size, taking into account the existing precautions. The results of a properly conducted risk assessment should help determine the most appropriate principles of good practice at the workplace. Risk assessment should always be done before applying the principles of good practice at the workplace. It must be adapted to the specific circumstances and needs.

Steps to be taken before starting the work

The installer of photovoltaic installations should:

1) Carefully read the job safety instructions at the workplace.
2) Listen to the supervisor's instructions.
3) Wear the uniform and protective clothing intended for use in a given work station (work overalls, reflective vest, headgear, shoes with metal toes and a puncture resistant sole, knee pads, protective gloves); take off all unnecessary items, such as jewellery, etc.
4) Wear personal protective equipment: protective helmet, belt or harness protecting against falling from a height, sunglasses, dust masks when working with asbestos.
5) Prepare the equipment (portable ladders - technically efficient), power tools, meters and materials needed during work, etc.
6) Remove all unnecessary objects in the workplace; ensure that the base around the workplace is stable and even.
7) Make sure that the commencement of work will not cause hazards for persons staying near or in the immediate vicinity of the workplace.
8) Familiarize with the tasks for the current day.
9) If no hazards are found on a given workstation, the tasks may be performed.

Steps to be performed during the work

During the work, the PV installer should:

1) Strictly adhere to the recommendations of: workplace safety instructions and instructions and instructions of superiors.
2) Observe the order of work.
3) Perform only the work commissioned by the direct superior.
4) While concentrating all work, concentrate all your attention only on the activities performed; work at a speed corresponding to the natural rhythm of work.

5) Materials used during the work process should be stored so that they do not create any accident hazards; tools should be placed in strictly designated places.
6) If during work it must use ladders, platforms or scaffoldings, it must be kept in order that they are technically sound and that they should be set in accordance with applicable regulations.
7) Ladders should be used only for tasks of low risk, for short-duration work.
8) Work at heights should be done so as not to disturb other employees performing their tasks.
9) If it is necessary to leave the workplace, the installer is obliged to check whether the work tools left behind pose a threat to, for example, other workers passing by.
10) In case of doubts as to the manner of performing the task, the installer should ask the superior or trained experts for detailed instructions; work can be resumed after removing doubts and (preferably) under the supervision of the supervisor.
11) Remember that photovoltaic modules exposed to sunlight generate current and voltage and cannot be switched off, which means that the installer works with live electrical circuits.
12) In order to prevent the generation of electricity by the solar module, cover its entire surface with an opaque cover.

PV installation installer is not allowed to:

1) Perform dangerous methods of work, so as to pose hazards for yourself or the environment.
2) Do not follow specific instructions and recommendations of superiors.
3) Use improper working methods.
4) Work without prescribed personal protection.
5) Use technically inefficient ladders, platforms, scaffolding.
6) Use the wrong, unserviceable tools, power tools.
7) Perform work during a storm, strong winds or other threats.
8) Damage the roof elements and cause leakage of the building.
9) Perform work at a height (on a ladder, platform from scaffolding, etc.), with a bad mood; it should have been reported to the supervisor, who will decide about the further course of the employee's work.
10) Repair live electrical equipment (if the employee does not have the appropriate permissions).
11) Touch live electrical wires.
12) Illuminate workplaces with portable lamps with a voltage greater than 24 V.
13) Allow other people to work in their workplace without the knowledge of the supervisor.
14) Disturb others at work.
15) To block the way to workstations, fire-fighting equipment and electric switches.
16) Leave after closure work, used rags, etc.
17) Smoke and use open fire while working; smoke only in places designated for this and appropriately marked.
18) To consume alcohol in the workplace.
19) Exceed the permissible load transfer standards in manual transport.

After finishing the work, a PV installer should:

1) Ground exposed conductive elements, e.g. Frame of the PV panel set construction and ground the entire system.
2) Put on covers on electric wires.
3) Thoroughly clean the workstation, arrange the tools and auxiliary devices in the designated places.
4) Clean used personal protection and put them away in a permanent place of their storage.
5) Make sure that the left station and devices do not create any threats to the environment.
6) Provide information on the progress of work performed to your direct supervisor.

Additional notes

The PV installer shall:

1) Take care of personal hygiene and a neat appearance.
2) In case of doubts as to the correctness of their actions, ask for additional guidance to the direct superior or professional services.

Steps to be taken after finishing the work

1) Leave the work station in order. Arrange the tools and auxiliary instruments in the designated places.
2) Check the condition of personal protective equipment.
3) All circumstances that may endanger the safety of the operator or third parties oblige the installer to report them to the supervisor. In the event of imminent danger due to non-compliance of the company with occupational health and safety rules, installer of PV installations has the right to refrain from performing work (he retains the right to remuneration, however, he cannot refuse to undertake other equivalent work if immediate removal of hazards from previously performed work possible).

4.2. Health protection during modernization works and maintenance of photovoltaic installations

Safe work with electrical circuits, general rules

The basic security measures to prevent electric shock during assembly and service work on electric circuits is to switch them off from voltage. The following rules should be observed when working with electrical circuits:

- always switch off the power supply before working on the circuit;
- circuit disconnected from voltage will not cause an electric shock. Unfortunately, many accidents are caused by circuits that were considered to be disconnected from the power supply. Safe work with circuits involves checking before working, whether there is dangerous voltage in them;
- use a meter or a circuit tester, such as a pincer meter, to make sure that the circuit is not live;
- use the circuit breaker and mark it in a suitable manner;

– block the circuit breaker if it has a blockade. It should be emphasized that the sign of exclusion is not for the person the installer knows and who knows about his work, but for a person whom the installer does not know and who does not know about his work with the circuit. People exposed to such electric circuits should be notified about the danger;
– mark all circuits where work will be carried out, at points where the equipment or circuit can be switched on.

Apart the above mentioned works that must be carried out with the power disconnected, a number of control and measurement works are performed, which are included in the works performed in conditions of a particular threat to human health and life. For this reason, during their implementation, special rules of work organization and additional technical protection in the form of insulating equipment should be applied.

Safe operation with photovoltaic systems, general principles

At present, electricity is supplied primarily from the electricity grid under the control of energy utilities. For this reason, electricians are mainly familiar with installations and systems supplied with alternating current from the network. When working with PV systems, two sources of energy should be considered: a network of an external energy supplier and a solar system.

Turning off the mains supply does not cause the solar system to stop producing energy. In PV systems, work is carried out on the power source (photovoltaic module and related cabling) and this is fundamentally different from the work on the electric circuit disconnected from the network. Even poor lighting conditions can generate electrical potential that can cause an electric shock or spark. Such a fire is very dangerous because it can also cause the installer to fall from the roof or ladder.

When working with PV systems, all procedures regarding the operation of electric circuits should be observed (the basic ones are presented in item 3.1), paying special attention to matters specific to PV systems, such as:

1. Proper operation of inverters and other elements of the PV system. They can be equipped with capacitors of considerable capacity with stored electric charges even after disconnecting the power source. Read and follow the manufacturer's instructions for safe use of the equipment.
2. The method of "turning off" the solar module, which is the shut-off of the power source, i.e. the Sun. If necessary, cover the modules with an opaque cover to prevent them from generating electricity.
3. Solar radiation, even of low intensity, can generate electrical potential and create a risk of shock or sparks.
4. This may be too small voltage to start up the inverter but enough to cause an electric shock that can harm the non-concealed installer.
5. When working with a PV module chain that requires connection or disconnection from the system, you must use a DC voltage switch. Mark and block the circuit using standard procedures.
6. PV systems connected to the power grid have two sources of energy.
7. Disconnecting the mains supply does not affect the output potential of the PV modules, even after the inverter is turned off. This means that such disconnection does not cut off

the power source from the PV panels. Wiring from the PV side can still be under voltage that can cause a significant current flow even in low solar conditions.

8. DC switch disconnectors can isolate PV panels, but do not turn off power sources. It should be remembered that even after disconnection, the lead from the PV modules to the disconnector is live. Therefore, you should treat the cabling from the PV modules with the same caution as the power line side circuits. A small PV system can generate voltage up to 600 V DC.
9. There is a risk of sparking when connecting or disconnecting the PV module chains.
10. Never disconnect the PV module connectors or associated live wiring.
11. When connecting or disconnecting the PV module chain, if the circuit is closed or the module chain is under voltage, sparking may occur at the connector. The electric spark has sufficient energy to cause severe burns. Another danger is the surprise of the installer with a spark jump, which can cause loss of balance and fall from the roof or ladder.
12. When working on a PV system, the solar power source should be disconnected by means of a DC switch disconnector.
13. To check if there is no dangerous voltage in the circuit, it is recommended to use a pliers meter.

Electrical safety in PV systems - selection of components and their impact on safety features

Installation requirements

The basic standard for the installation of electrical systems up to 1000 V AC in buildings is the PN-IEC 60364 standard and should also be used for PV systems. It contains, among other things, regulations regarding protection against electric shock (part 4-41), overcurrent protection (part 4-43), selection and assembly of electrical equipment – wiring (part 5-52) and protection against atmospheric or switching overvoltages and protection against voltage disturbances and electromagnetic disturbances (parts 4-443 and 4-444) and in parts 7-712: 2007 Electrical installations in construction works: Requirements for special installations or locations – Photovoltaic (PV) power systems Introduces: HD 60364-7 -712: 2005 / AC: 2006 [IDT], HD 60364-7-712: 2005 [IDT] replaces: PN-HD 60364-7-712: 2006.

Generator PV

PV modules must meet the following standards:

- IEC 61215 for crystalline modules,
- IEC 61646 for thin-film modules,
- IEC 61730 – for the safety of PV modules.

The modules must have the CE mark.

All parameters of components on the DC side (cables, isolators / disconnectors, switches, fuses, etc.) must be derived from the maximum voltage and current of the corresponding part of the PV generator with which they cooperate. It is necessary to take into account the currents and voltages resulting from series / parallel connections of modules forming a PV array. The maximum powers of individual modules must be taken into account. These powers result from two parameters provided for each module by manufacturers; Voc open circuit voltage, and Isc fault current. Manufacturers give these values measured under standard test conditions (STC), i.e. at a radiation intensity of 1000 W / m², mass number

AM1,5 and cell temperature 25°C. At work, not in STC conditions, these values may be different and therefore the following multipliers are recommended for determining the maximum values:

1) For mono and multicrystalline silicon modules, all DC components must be dimensioned at:
   - Voltage: Voc (STC) x 1.15,
   - Current: Isc (STC) x 1.25.
2) This means that for N parallel connected chains, when each chain consists of M connected in series, the main DC cables must be dimensioned at:
   - Voltage: Voc (STC) x M x1.15,
   - Current: Isc (STC) x N x 1.25.
3) For other modules - all DC components must be dimensioned at least on the basis of:
   - The least favorable calculation of Voc and Isc given by the manufacturer in the temperature range from -15°C to 80°C and for radiation intensity up to 1250 W/m^2.
   - Calculations of the possible increase in Voc and Isc during system operation.

Protection against electric shock

Basic protection means that active parts of the PV system, which are under voltage, can not be in touch and the conductive parts available should not be under noticeable ground voltage. Such protection is usually guaranteed by basic insulation and/or appropriate structural solutions, e.g.:
a cover. In addition, the PN-IEC60364 standard requires protection against electric shock even in the event of damage to the "basic insulation". In the event of a malfunction, it must be ensured that a dangerous voltage does not appear on the elements that may be affected, for example, on the device housing. The simplest to use protective methods in PV systems are protective insulation and the use of very low voltage SELV circuits. It is recommended to use modules with Class II security insulation.

Such modules allow to achieve higher voltages of the PV generator and hence the general better efficiency coefficients. The risk of breaking through to the ground for these modules is minimal, so overload protection on the cables of the chains and on the modules is simple. Metal grounded parts are also recommended to avoid electric shock from dangerous contact on the equipment.

If the PV system does not have an electrical separation between the DC and AC side (e.g.: contains a transformer less inverter), and has a differential current device, it must comply with the B-type specification in accordance with PN-IEC 60755 and must also react to currents with a fixed component. To guarantee protection against direct contact, it must be set to detect current deviations of up to 30mA.

4.3. Safety rules for the maintenance and conservation of the solar installation

Protection against overload and short circuits

DC modules and cables

If the cables from the PV generator have been properly dimensioned, they are automatically protected against short circuits at the input terminals of the inverter, as the PV generator operates as a current source. Correct dimensioning of wires means:

- Selection of the wire diameter guaranteeing appropriate current density values with continuous current conduction at least 1.25 times higher than the rated short circuit current in STC conditions, respectively for the chain or module table at any system location,
- The parameters of the main power cables are designed to allow operation as above with a current load of 1.25 times greater than the nominal short-circuit current of the entire PV generator under STC conditions.

If the above conditions are not met, overload protection of the cables should be used.

In conventional generator designs, "chain" fuses can be omitted in systems with modules with rated short-circuit currents of approx. 3.5 A and temperature-resistant connection cables with a cross-section of 2.5 mm2. If the modules have higher nominal short-circuit currents, the number of chains connected together in parallel without a fuse must be reduced.

The maximum permissible return current value according to IEC 61730-2 for a PV module is 2-2,6 x Isc (Isc – short-circuit current). The reverse current depends on the number of PV modules connected in parallel and already in the case of three chains it will reach the value specified in the standard. In this case, the application of overcurrent protection is justified. Reverse currents cause the temperature of the module or its parts to increase, and in extreme cases may lead to its thermal destruction, as well as the appearance of the DC electric arc.

When securing against reverse currents in PV systems, the most important is the selection of the correct type of fuse – with the characteristics of gPV, which was introduced by the IEC 60269-6 standard. In addition to the correctly selected characteristics, the correct rated voltage of the fuse is also very important, which should be higher than the highest voltage in the PV system. When selecting the level of the rated current of the fuse, the dependence must be met:

$$1{,}4xI_{SC} \leq I_n \leq 2{,}4xI_{SC}$$

where, I_{sc} – is the rated short-circuit current of PV modules (given by the module manufacturer), and I_n – is the rated current of the fuse.

Disconnection devices

DC disconnection devices, such as switches, circuit breakers and fuses, must be derived from the maximum voltage and current of the relevant part of the PV generator with which they cooperate so that the electrical disconnection arcs are safely shut off.

Connection boxes

The method and quality of connections between components of the PV system has a very large impact on the correct operation of the entire system and security. Most faults can be avoided by using industrial spring clips or specially designed plug connectors. A good PV module connection box should:

– enable a simple connection method using spring clips or plug connections,
– have watertight conduit entries with mechanical shape adjustment,
– enable the introduction of cables from the module downwards in every allowed position of the module assembly,
– be made of flame-retardant materials,
– meet the requirements of protection class at least IP54.

AC page

An isolator and appropriate overcurrent protection must be installed on the AC cables between the inverter and the grid connection point.

Safe operation with batteries

Working with PV systems equipped with batteries can be the most dangerous part of PV installation and maintenance work.

Batteries can be dangerous!

The EN 50272-2:2007 standard specifies the requirements for the safety of secondary batteries and battery installations – Part 2: Stationary batteries. It applies to stationary batteries with a maximum voltage of 1500V: lead acid and nickel cadmium. Security requirements related to assembly, use, control, maintenance and decommissioning have been established.

Make sure that all employees understand the dangers and safety rules for battery systems:

– it is obligatory to familiarize with the manufacturer's recommendations regarding the proper handling of batteries, their installation and disposal,
– until recently, lead-acid batteries have been typical batteries. Both of these chemicals are dangerous. Lead can cause reproductive toxicity and the acid can cause severe burns. Currently, gel and lithium-ion batteries are increasingly used,
– prevent sparking on / near the battery connection terminals,
– before starting servicing or other work with battery batteries, disconnect the DC voltage circuit between the batteries and the inverter,
– battery packs can store a very large electric charge, which can cause an electric arc hazard. Metal tools and personal jewellery can cause sparks resulting in severe burns and battery explosion. Remove jewellery and use only appropriate tools when working with batteries,
– eye protection is recommended when working with batteries
– Used batteries should be considered as dangerous and should be recycled in an appropriate manner.

Protection against lightning

When installing a solar system on the building's roof, it should be considered the lightning protection (LPS – Lightning Protection System) and special attention should be paid to limiting currents and surges in the electrical installation and DC circuits. Only such comprehensive treatment of lightning and surge protection issues can ensure protection and failure-free operation of photovoltaic systems. Installed in accordance with the art, PV systems do not increase the risk of lightning strikes if they do not protrude significantly above the original height of the building. Therefore, when the PV system is installed on the roof, additional lightning protection for the house is not usually needed. However, it should be considered whether the lightning protection system protecting the PV system should be used. It depends mainly on the assessment of the risk of such a threat and on the requirements of, for example, PV system insurance.

Safety measures at work at heights

The risk of working at heights

If the work is planned at heights, a risk assessment must be prepared. It should include the overall assessment of safety and health protection. Do not over-complicate this process. The risks associated with working at heights is recognized and most of the control measures that are needed are easy to apply.

The law does not require the complete elimination of hazards, but the installer is obliged to protect people by minimizing the risks in a reasonable manner, possible to implement.

If the work at heights is inevitable, it should:

- use existing secure access to the workplace at heights. Do not look for "shortcuts" if secure access already exists, such as a fixed staircase or platform with barriers.
- provide employees or themselves with equipment to prevent falls, such as scaffolding, mobile platforms or aerial platforms with safety barriers,
- minimize the height and consequences of a fall, for example by organizing short work at a low altitude.

Platforms movable

The installer must have the ability to erect and dismantle scaffolding, must always read and follow the manufacturer's instructions and in no case may use the equipment in excess of its capabilities. Well-known constructions, such as scaffolding or mobile platforms, are constructed from prefabricated components made mainly of aluminium alloys or fiberglass. The wheels or legs of the platform or scaffold must rest on hard ground. The supports must be laid out in accordance with the manufacturer's instructions.

Aerial platforms

Aerial platforms provide a safe way of working at heights, because:

- they enable a quick and easy way to access the place of assembly,
- have safety barriers and curb limitation to prevent falling,
- can be used both indoors and indoors,
- include various types, such as jib cranes, scissor lifts and truck mounted aerial platforms.

Ladders

Ladders should only be used only for tasks with a low degree of risk and for work of short duration. Ladders are classified according to the method of use: for commercial and light industrial use; for use in heavy and industrial works; for domestic use. The manufacturer must always provide information about the specifications of his ladders and specify the maximum working load. Users should be trained and instructed about the safe use of ladders.

Personal protection

The purpose of using the personal protective equipment is to protect employees against the risk of injury by creating a protective cover against the threat in the workplace. They are not a substitute for good engineering, administrative supervision or good work practice, but should be used in conjunction with these surveillance measures to ensure the safety and health of workers.

Employers should provide and finance the equipment with personal protective equipment that the employee needs to work safely. The employer must make sure that employees use these funds and keep them clean and functional.

Fire protection

Installation of a PV system on a building may affect the fire safety protection:

- for roof installations, PV system modules should be installed above the non-flammable roofing using a mounting system suitable for the roof construction and cover, and the remaining elements of the PV system in places that meet the conditions specified by their manufacturers,
- do not install or use PV modules near the hazardous locations that contain flammable gases.

Other hazards related to PV systems

1) Unlike roof or facade materials, PV modules are often made of laminated tempered glass. This means that the glass elements do not break when damaged and can fall in the form of one sheet.
2) The edges of PV modules, especially in exposed areas, can be sharp.
3) Although these are not hazardous quantities during assembly and use, some solar products contain cadmium, which may create a risk of harmful dust if the product is crushed during utilization.
4) PV modules produce electricity when exposed to sunlight and can not be switched off. This means that photovoltaic installation often takes place when electrical circuits are live.
5) PV modules produce DC voltage different from AC voltage. The DC voltage can cause sparking in an air gap several millimetres wide (depending on the voltage) until the voltage is disconnected or the gap enlarged. This sparking may cause a risk of fire and / or significant damage.
6) The short circuit current in the cabling of the PV module is usually slightly higher than the operating current. This means that other protections must be applied on the DC side than on the AC side, and that the safety of the entire system depends on their proper choice.

7) An improperly grounded PV installation may cause hazardous DC voltage to occur on accessible conductive parts.
8) The PV system can be described as "low voltage", even if it generates a voltage of up to 1500 V. The voltage of 60V DC when touched is usually considered sufficient to cause an electric shock hazard (this value depends on environmental conditions).
9) The risk of burns is usually significantly increased if the PV module or installation is damaged.
10) In order to maximize efficiency, PV modules are usually mounted in unprotected locations. This means that the risk may be low temperature, wind and rain during installation and maintenance.
11) Elements of PV modules may heat up to high temperatures (approx. 80°C) during normal operation.
12) The surface of PV modules can reflect large amounts of sunlight falling on them, which can damage the eyesight.

4.4. Photovoltaic maintenance program

System control

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. The principles of their implementation are described in chapter 4.11. Collection conditions and technical documentation of the installation in guide for the trainee and the trainer M2.U2. Assembly of photovoltaic installations.

System test

The PV system electrical wiring testing must be carried out according to the requirements of the IEC 60364-6 standard. Measuring and monitoring devices, as well as methods of measurement are selected according to relevant parts of the standard IEC 61557 and IEC 61010. If other measuring equipment is applied, it should ensure an equal level of quality and safety. Test methods described in this section are provided as reference methods; other methods are not excluded, provided that they enable to receive comparable results.
All tests should be appropriately conducted and performed in the order specified on the list.
If the measurement result indicates the error, the defect must be repaired and measurement – repeated, as well as all previous measurements should be repeated if the detected defect affects their result.
In case of any test indicating non-compliance with requirements, this test and all previous tests that might be affected by the error should be repeated.

Test systems and additional tests
The test system applied in the photovoltaic system must be suitable for the scale, type, place and complexity of a given system. This document defines two test systems, together

with a series of additional tests that may also be conducted when the standard sequence is ended.

Maintenance/Inspection

The PV installer should:

1) Remember that PV systems are not "serviceless" – they require periodical inspector to make sure that they operate properly and that there are no defects or damage;
2) Conduct maintenance activities and tests recommended by the manufacturer;
3) Verify the registered data with regard to unexpected values;
4) Prepare a control list of maintenance actions and inspections prior to the system visit;
5) Note down all necessary tools and equipment that should be carried in order to avoid unnecessary repeated visits;
6) Calibrate measuring instruments, if necessary;
7) Use relevant personal protective equipment (see: installation advice);
8) Switch off circuits prior to the commencement of work with them;
9) Cover PV panels, if necessary, with a non-transparent covering; work during the night (with use of proper lighting);
10) Remember that switching off the main voltage switch does not make PV modules stop producing electricity;
11) Take into account that the PV inverter has condensers of significant volume, which may remain charged, even after cutting off the power supply;
12) Verify with current clam whether the circuit is not electrified prior to the commencement of work with the PV set;
13) Clear the PV modules of dust and dirt with use of water. Do not apply detergents, rough brushes or sharp tools;
14) Verify modules with regard to the presence of damage (e.g. cracks) during cleaning;
15) Verify whether the installation frame shows no signs of corrosion;
16) Search for new sources of shading that were not considered during installation;
17) Trim near trees, if necessary;
18) Check whether there are any loose connections and corrosion;
19) Compare the system AC output in a given moment with expected value, using basic conversion formulae for sun exposure and temperature;
20) Check and compensate electrolyte in batteries (in autonomous systems);
21) As soon as possible replace damaged or non-functional system elements.

4.5. Monitoring of photovoltaic system properties – guidelines and measurement requirements and their analysis

Monitoring of parameters of PV system operation is necessary in order to compare design parameters with actual ones or, more advanced, estimation of impact of specific weather and climate conditions corresponding with the system installation site on its energy yield or pace of degradation processes depending on applied technologies. Such an approach may be useful for a more precise design of reliable and more efficient PV systems.

This study aims at the definition of recommendations for effective monitoring and analysis of collected data to determine quality of the PV installation connected to the energy network and possible diagnostics of irregularities in its operation.
Formally, requirements concerning PV system monitoring – measurements, data exchange and analysis – have been specified in the standard IEC 61724 (*Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis*)

Monitoring of the PV system

Purpose:

- comparison of design parameters (e.g. energy prediction) with actual ones,
- estimation of impact of specific climate and weather conditions corresponding with the system installation site (more advanced), on its energy yield,
- pace of degradation processes depending on applied technologies.

Result:

- diagnostics of errors in the PV system functioning,
- more precise design of reliable and more efficient PV systems.

Formally, requirements concerning monitoring of PV systems

- measurements, data exchange and analysis – have been specified in the standard IEC 61724 (Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis).

Use of data from monitoring with IEC 61724

Measuring instruments and sensors applied in the monitoring system should meet requirements of the standard IEC 61724. This condition concerns in particular bigger PV systems. In case of smaller systems, when the budget is usually very limited, cheaper and of lower quality elements may constitute the only available option, but even in such a situation the system monitoring is recommended.

The study specifies procedures applied to monitor quality, reliability, data registration, together with events that should be registered and recommended system quality control procedures.

Parameters depending on the assumed purpose and advancement of the monitoring system:

1. Assessment of quality of PV technologies applied in the system:
    a) basic monitoring,
    b) advanced monitoring (analytical).
2. System diagnostics.
3. Degradation and analysis of uncertainties of system parameters in time.
4. Comprehension of sources and reduction of losses in the system through comparison of received data with data obtained from modelling (prediction).
5. Prediction of energy yield (and not only) of the PV system.
6. Interaction of the PV system and energy network.
7. Integration of distributed generation, energy storage and control of load (energy intake).

Figure 1 presents a photovoltaic system with marked all significant parameters measured in case of advanced monitoring.

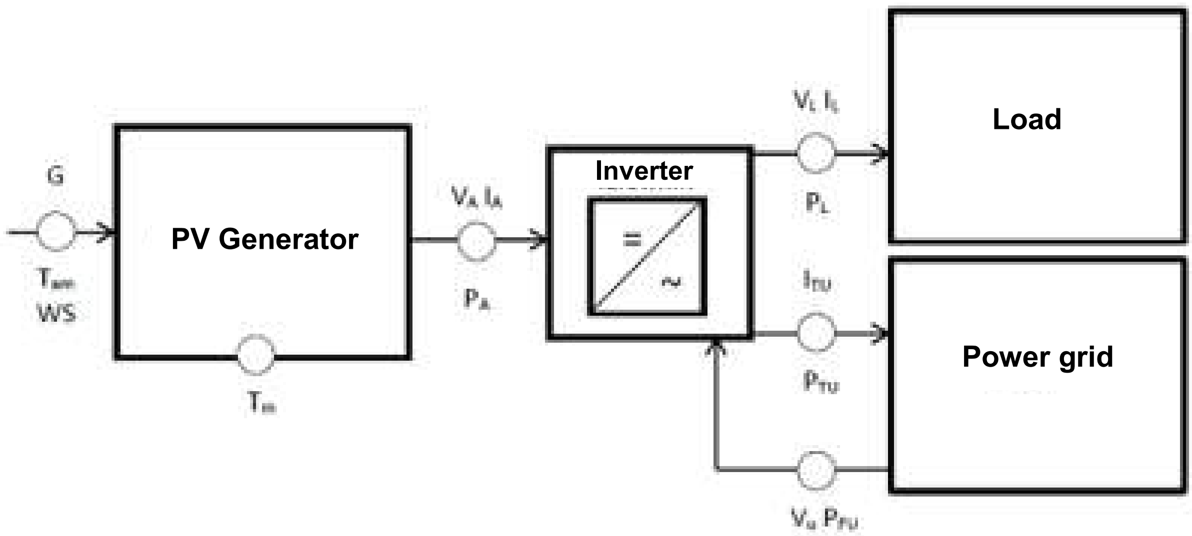


Fig. 1. Photovoltaic system with marked all significant parameters measured in case of advanced monitoring

If the inverter is equipped with functions allowing for system monitoring, it is important to verify accuracy of applied sensors according to the recommendations provided hereinafter. Modern inverters usually enable the measurement of AC and DC voltage, current and power of PV generator and power consumed and transferred from and to the network. Such a functionality of the inverter reduces a number of needed additional sensors, so it reduces also the monitoring system costs, however in some cases it may be necessary to verify accuracy of performed measurements with regard to compliance with requirements of the standard IEC 61724. Unfortunately, the majority of inverters available on the market does not meet such requirements, thus limiting the possibility PV system quality assessment based on the analysis with use of data acquired by them. Monitoring of such parameters as voltage, current and power with use of inverter is not recommended in situations related e.g. to financial decisions or measurements for purposes specified in trade or consumer agreements.

Measurement of solar irradiance

Initial electric power of the PV system directly depends on the level of irradiance striking the surface of PV generator modules. Thus, in order to assess whether the PV system operates according to the design assumptions, measurement of irradiance and determination of solar radiation energy is essential. According to the definition, irradiance means a temporary value of power of radiation striking the surface unit expressed in W/m^2, while radiation energy or insolation, expressed in Wh/m^2 or kWh/m^2, constitutes a value of radiation energy striking the surface unit in a strictly specified period of time (e.g. day, week, month, year).

In case of rigorous requirements, it is recommended that the measurement of irradiance in the place of the PV module field is performed according to the standard IEC 61724 with use of a properly calibrated sensor – cell or pyrometer. If the cell or module is applied, it should be calibrated and maintained according to the standard IEC 60904-2 (cell) or IEC60904-6 (module). If possible, it is recommended that it is an element adjusted with regard to its spectral sensitivity to modules, of which the PV system module field is composed. In practice, it is recommended to apply silicic sensors for systems composed of silicic modules or module of the same type as those applied in the PV system in case of other technologies. In the second case, it is possible to apply silicic sensors equipped by the manufacturer with a relevant optical filter. According to the standard IEC 61724, accuracy of sensors, including measuring system, should not be less than 5%.

Measurement of insolation directly on the installation site allows for the highest accuracy, assuming proper calibration, installation and appropriate procedures of sensor maintenance.

The majority of high-class pyrometers required periodic recalibration (usually every two years), which requires their disassembly from the system to send them to a relevant instituting performing this type of services. In such a case, possible breaks or shortages in data collection from the monitoring system should be considered.

Regardless of a type of sensor and its class, its installation site in the system should correspond with the requirements of insolation of the PV module field. The sensor should be fixed in one plane (coplanar) with PV modules with the maximum deviation not exceeding 2^{o} in the area without overshadowing (even if a part of the module field is still overshadowed). In addition, there should be ensured access to the sensor to clean it regularly.

Other methods of obtaining insolation parameters

Although generally it is recommended, in particular in case of larger PV systems, to use sensors compliant with the standard IEC 61724, sensors of a lower class or data from the source other than own measurements – in particular measurements of meteorological parameters – often can be the only possible option in case of low-budget systems. However, it should be kept in mind that the value of data on the monitored system obtained in this way may have a lower research and diagnostic value.

In case of small PV systems (usually < 5kWp), solar irradiance in the plane of the module field may be (1) measured on the installation site (recommended), or (2) measured in a different, close, representative location, or (3) determined from measurements originating from distant locations and/or calculated based on the combination of data from ground measurements and satellite data, depending on accuracy required for monitoring.

Use of satellite data may be effective in order to define radiation in the PV field plane in cases, where expenses and technical requirements related to the installation and maintenance of insolation sensor(s) are not justified. Satellite data on insolation concern usually the horizontal plane, so it is necessary to know methods of conversion of these data to the plane corresponding with a specific PV system. These methods, relatively simple in case of the direct component, are very complicated in case of the distributed component of radiation and thus exceed the scope of this study. It should also be emphasised that the satellite data conversion method, as always less accurate than direct measurements, is less useful, e.g. at the analysis of the PV system losses. Another disadvantage is the fact that satellite data are in principle not provided less frequently than every 1 hour.

NOTE: Direct measurement of insolation parameters on the installation site is a recommended solution, regardless of a size of the monitored PV system.

Measurement of ambient (air) temperature

Knowledge about air temperature, in connection with measurements of solar irradiance in the PV module field plan and the wind speed, is usually applied to assess losses of the PV module power as compared to parameters specified for standard conditions (25°C).

Similarly, as before, here also the measurement according to provisions of the standard IEC 617124 is recommended in case of the most rigorous requirements. Therefore, measurement of air temperature should be conducted on the installation site or in a different representative location, while this sensor should be placed in the cover protecting it against direct impact of solar radiation and wind. Temperature sensors should be placed far from any sources and, if possible, at a height not less than 1 m over the ground level (German document DERlab TG 100-01 recommends location even 2 m above the ground). Sensor accuracy, together with the signal conditioning system, according to IEC 61724 should not be worse than 1°C.

Wind speed

Wind has a beneficial impact on the speed of exchange of heat (convection) generated in PV modules with surrounding air. Higher wind speed results in lower temperature of PV modules. However, this effect is not so significant to declare that wind speed is an important parameter requiring monitoring. Impact of this element on the PV system operation is much less significant than impact of ambient temperature. However, it is important at the determination of a relationship for determination of module temperature, thus more accurate analysis of the same PV system when no direct measurement of module temperature is conducted. Measurement of wind speed should be conducted in case of PV systems, where the module field is exposed to extreme weather conditions.

In this case, also at high requirements concerning monitoring, recommendations of the standard IEC 61724 should be applied. It recommends the wind speed measurement on site and at a height adjusted to conditions of the PV system operation. Sensor accuracy should not be worse than 0.5 m/s for wind speed ≤5m/s and better than 10% for wind speed >5m/s. A perfect place to install the wind speed sensor (anemometer), according to the IEC 61215 recommendations, should be 1.2 m away on the western or eastern side and at a height of 0.7 m above the upper edge of the PV module field.

Module temperature

Measurement of the module temperature is recommended, as this parameter directly affects the PV system parameters. This impact depends on the applied PV technology. Typically, commonly installed modules from cells for (mono- or multi-) polycrystalline silicon significantly lose their output (~0.5%/^{o}C) together with temperature rise. Just like in case of previously discussed parameters, here also the standard IEC 61724 defines the most rigorous level of measurements. According to the mentioned standard, the module temperature should be measured in places representative for the entire module field, with use of sensors placed on back module surfaces. It should also be emphasised that sensor presence cannot significantly affect temperature of the cell itself, under which it was fixed. Sensor accuracy, together with the signal conditioning and processing system, according to the standard IEC 61724 should not be worse than 1°C.

Electrical parameters – voltage, current and power

Electrical parameters of the PV system, both on DC and AC side, are the most significant from the point of view of operation of the entire system, while in connection with measurements of solar radiation parameters they allow for its diagnostics and assessment. In case of large systems, where the module field is composed of many sub-systems and chains, it is useful to measure AC and DC electrical parameters separately for each sub-assembly, thus facilitating the location of malfunctioning system fragments. A number of monitored system sub-assemblies depends on the assumed monitoring level, while in each case initial parameters of the entire system must be measured.

Measurement of DC electrical parameters provides with additional diagnostic possibilities in case the entire system malfunction is diagnosed. For example: relation of power on the AC side to power generated on the DC side allows for determination of the inverter efficiency, while the value of DC power allows for the calculation of energy yield directly on the PV generator output and is a parameter recommended to assess the level and speed of degradation of PV modules. Additional measurement of DC voltage, after comparison with theoretical (expected) value may be applied for the identification of module/chain short circuits (diagnostics of the PID (potential induced degradation) effect). AC power measurement, in connection with AC values of current and voltage may be used for basic estimation of the power factor. Moreover, AC voltage measurement from the network side may be applied for direct diagnostics of failure reasons in case of inverter damage.

Electrical power can also be calculated in real time as a product of measured samples of current and voltage values, or can be measured directly with use of relevant power sensor. Direct power measurement is recommended, while if this parameter is calculated indirectly, current and voltage values applied for this purpose must constitute simultaneously sampled values and cannot be averaged values. At such an approach, one should pay attention to sampling time and interval (frequency) between sampling of mentioned parameters.

Also in this case, the standard IEC 61724 specifies the most rigorous conditions for measurement, according to this accuracy of current and voltage sensors, together with the signal conditioning system cannot be worse than 1%, while accuracy in case of application of the power sensor should not be worse than 2%. Sensors should be selected in such a way that their scope is compliant with the upper value of initial parameters of the PV module field, i.e. for voltage 1.3◊V_{OC}, for current 1.5◊I_{SC}, while their presence affects minimally the measured parameters (e.g. resistors applied for current measurement should be characterised with such a low resistant that voltage reduction on it is insignificantly low as compared to the PV module field voltage). In places where monitoring is conducted to verify the quantity of energy for resales or other similar situation, current, voltage and AC power sensors of class 1 or 0.5 are required.

Note: Modern inverters are usually equipped with functions of current and voltage measurement, both on DC and AC side, as well as power generated by the PV generator, as well as power transferred and consumed to and from the network. It allows for the reduction of a number of sensors needed for sensor system monitoring, thus costs of the monitoring system, however accuracy of measurements conducted by the inverter should be verified with regard to compliance with requirements of the standard IEC 61724. Unfortunately, most inverters do not meet such requirements, so the capacity of analysis of qualitative parameters of the PV system may be limited. System monitoring with use of options of built-in inverters is not recommended in situations, when produced energy is subject to financial turnover or constitutes the basis for an investment and financial decision.

Sampling frequency

The PV system monitoring requires the measurement of a significant number of values of particular parameters. Measurement quality depends not only on accuracy of applied sensors and measuring equipment, but also on the method of acquisition and processing of measured values. Sampling frequency and alternatively, if needed, data filtration process constitute one of important factors affecting the quality of acquired data.
Recommended value of maximum interval (ts) between subsequent measurements (samples) for averaged values comes to 1 second.

4.6. Analysis of typical errors related to modernization and maintenance

Typical errors and damage

PV systems should work for many years, so information on typical errors and issues is useful. Typical errors and damage of PV systems are described in chapter 4.10. Typical assembly installation errors in guide for the trainee and the trainer M2.U2. Assembly of photovoltaic installations.

Problem solving

A method of error/failure elimination depends on its type and on the PV system type. Firstly, information should be obtained from the user on when and how the error was detected. The system scheme and technical description is very helpful in such situations. Prior to the commencement of measurements, the system should be controlled visually, in particular mechanical appearance of panels and their contamination. Cabling and electrical connections should also be verified. Measurements to be performed to detect errors are practically the same as those conducted during the system's technical acceptance. Currently, it is possible to perform remote measurements through the telecommunications network. Below you may find a step-by-step damage detection procedure:

Step 1: Inverter and PV box

Measurement should be started from the control of a correct cable connection. Data from the inverter may be obtained by checking the display status, i.e. LED or code error, or by using a laptop with relevant software. Firstly, the DC side is checked and then AC. Then, cables on the DC side and main switch on the DC side are checked. In case of resistance measurement, insulation to earth should not be lower than 2 MOhm.

Step 2: Earthing and short circuit errors

The earthing and short circuit error detection procedure may be commenced after disconnection of PV module bands that should be measured individually. To do this, firstly, the inverter should be turned off and, if present, the switch or DC switches should be disabled. Then, one module in every band should be completely overshadowed, covered against sun. Only after these actions, module bands may be disconnected without the risk of sparking and the measurement may be commenced.

Step 3: Fuses/diodes/modules

Voltage on fuses of particular module bands and diodes can be measured during the system operation, connecting the sensor in parallel. If there occur significant differences in measured voltage value, it may indicate mismatch in the generator or electrical error in a given band of PV modules. Then, it may be necessary to conduct measurements on particular modules in the band. At longer module bands, they should be divided in half and verified in which half the issue occurs. With use of this method, a damaged module should be identified. Module connections and protecting diodes should also be controlled.

Step 4: Voltage in open circuit – short-circuit current

These measurements are very important due to monitoring of the system operation, but current irradiance of the area should also be measured.

Tab. 1. Typical errors found in photovoltaic installations are mentioned in the table below. The right column includes possible types of these errors, while the left one - some preventive measures to avoid errors and activate the system properly

Typical errors	Preventive measures and problem solving
No current from panels	Open switches or burnt fuses, damaged or rust-eaten cables
Too weak current from panels	Some modules overshadowed. Incorrect panel inclination or orientation. Some modules damaged. Dirty modules.
No charging of batteries.	Measure voltage from PV panels in open circuit (no-load) and check whether it is within normal limits. If voltage is low or zero, check connections on the PV panel. Disconnect PV panels from the driver during the PV system operation. Measure voltage on clamps of charging controller (PV and battery), if voltage on clams is the same, PV panels charge batteries. If voltage on PV clamps is close to no-load voltage of panels and voltage on battery clamps is low, charging controller does not charge batteries and can be damaged.
Too high voltage	Disconnect PV panels, disconnect cable from a positive battery clamp, leaving PV panels disconnected. Charging controller charger lamp should not glow green. Measure voltage on charging regulator clamps to which PV panels were connected. If a green lamp glows or voltage is present on clamps, he controller may be damaged.
Improper charging	Check fuses and switches.
Too low voltage	Shorten cables or use cables of larger section, re-charge batteries, ensure better cooling for devices, place the device in a cooler environment.
No AC voltage	The AC receiver load exceeds the inverter power, disconnection resulting from overload. Load not adjusted to continuous operation of the inverter. Power surges.
Reverse connection/polarisation of the inverter	Check connection to the battery, the inverter is probably damaged and must be replaced.
Incorrect charging deactivation	Controller does not receive proper voltage from the battery, check the battery connection. Lower value of charging deactivation voltage is too high. Reset regulated disconnection at lower voltage, changing power,
Burnt PV panel fuse	Short circuit occurs in the circuit PV panel - battery. Disconnect the battery to check. Charging controller of too low volume
No voltage at the inverter output	Burnt fuse or open circuit/switch, damaged cable. Turned off inverter due to incorrect charging switching off or open circuit of charging regulator. High voltage of the battery.

Diagnostic procedures

Visual inspection

Mechanical problems are usually visible: loosening, bending or corrosion may be usually detected during visual inspection. During such an inspection, the instruction referred to herein should be followed.

Performance monitoring

Performance verification

The PV system may be funded based on energy production within the framework of tariff support systems, so the user should measure its performance and compare results with obtained settlement. Complexity and cost of such a measurement depends on the quantity and accuracy of measurements to be performed.

Displays

Displays constitute the basis for monitoring. A simple indicator being a part of the inverter is the easiest solution. Most manufacturers of PV inverters offer an optional display. However, it may create serious limitations concerning the inverter location, as normally it is on the roof or in another solitary place. If the display is to be efficient, it must be located in a place where it is visible during everyday activities. The solution is constituted by remote displays, to which data may be delivered from the inverter by cable.

Sensors

There are no limitations as to the number of parameters that may be monitored by the PV system, but most systems measures input and output energy and some environmental and systemic variables.

Data analysis

After data collection, a detailed analysis of the PV system operation may be conducted. Recorded data allow for monitoring and assessment of the system effectiveness. Such parameters as monthly production, panel performance, etc. constitute standard methods to define efficiency of the entire PV system. Data can also be presented on bar graphs in order to analyse significant parameters of the PV system.

User documentation

After the installation completion, the installer performs tests and controls the system operation, records test results on the activation report. This process may last from several to a dozen or so days, depending on the PV installation size. The activation/acceptance report should be signed by an authorised person upon stating that the PV system operation is satisfactory. A report copy belongs to the owner, together with proper certificates of compliance and warranties. Warranties for every system part are transferred to the owner (usually manufacturer's warranties). Also the entire instruction for use and maintenance, together with a full system description should be transferred to the owner. The owner should require a warranty of performance of the activated PV system. An installer should determine the assumed energy production by the PV system, indicating the minimum amount of kWh that should be produced annually by the system. An agreement with the installer may contain provisions specifying its responsibility in case the actual energy production is lower than provided in the agreement.

4.7. Types of typical disturbances and failures in systems

Typical failures in PV systems – possibilities of diagnosing and recommended monitoring precision are presented in the table below.

Tab. 1. Typical failures in PV systems

Failure type	Impact on the system operation	Parameter applied for diagnostics	Required accuracy
Breaks in DC chains (burnt fuses in DC connection boxes, damaged wires, connections, junction boxes of PV modules	average-large / long-term	DC current in DC chain (as compared to other)	25% (current in the chain)
Break in the main DC line (burnt fuses on the inverter input, damaged connection, cable)	large / short-term	DC current on the inverter input	15% (depending on a number of entries)
Internal inverter failure (electronics, switches, firmware)	large / short-term	DC power, AC power, internal inverter data logger	25%
Electrical insulation (defected cables / modules)	large / short-term (causes inverter disconnection)	Measurement of insulation resistance in the inverter	Established by the inverter manufacturer
Fluctuations of network parameters	large / short-term (causes disconnection from the network)	Network parameters monitored by the inverter	see "AC parameters" below
Parameters of module(s) below rated	average / long-term	Current and DC voltage in the chain, irradiance, temperature of module(s), comparison with values measured for other chains and/or previous values	<2%
Excessive heating / hot spots (as a result of bad electrical contact)	small / long-term (may cause breaks)	Visual inspection, thermal camera	50%
"Optical disorders" (overshadowing, dust, snow, frost, delamination, etc.)	small / long-term	Visual control, see also "parameters of module(s) below rated"	
Broken modules / mechanical damages	small / long-term (may cause insulation damage)	Visual control	good / bad

Interpretation of the Curve IV shape

General information

Normal, correct curve I-V measured in conditions of stable irradiance has a smooth shape from which three areas may be distinguished:

- "horizontal" part, from the side of current axis (sometimes slightly going down),
- "vertical" part, from the side of voltage axis,
- "knee" area between two above parts where maximum power point is determined.

In case of normal curve, all three mentioned parts are smooth and continuous, although their inclination as the "knee" shape depends on technology and quality of cells od which the PV module is composed. Crystalline silica cells have usually sharper knees, while thin-layer modules have often more rounded knee.

A series of factors may affect the Curve IV shape. The scheme below presents main distortion types that may occur in practice. Changes in shape may occur individually or jointly.

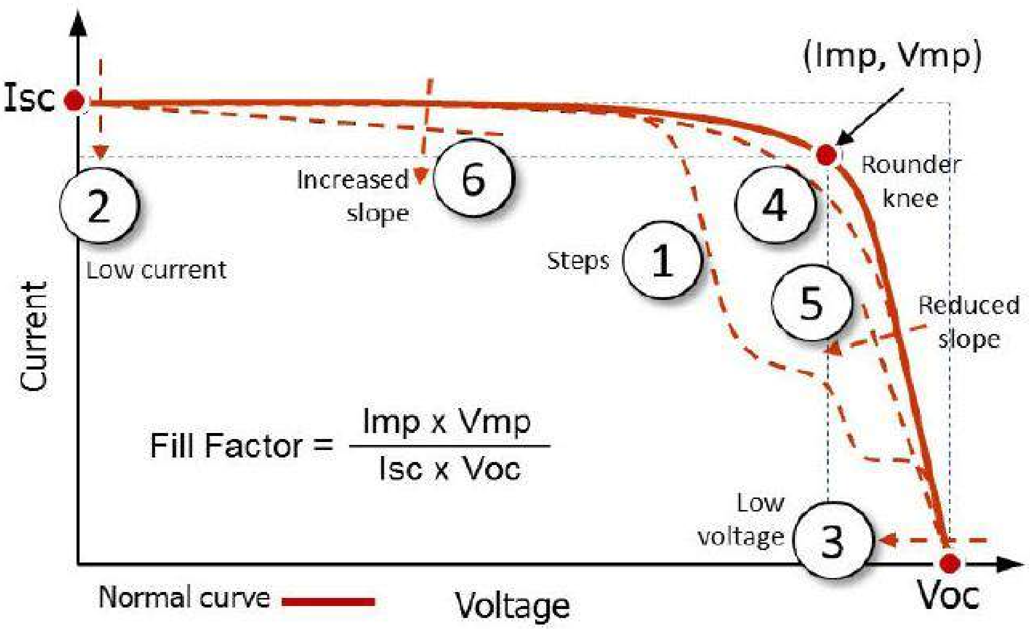


Fig. 1. Shape of curve IV in various conditions of module lighting (explanations in text)
Source: IEC 62446-1: Grid connected PV systems – Part 1: Requirements for system documentation, commissioning tests and inspection.

Due to uncertainty related to the measurement of lighting intensity and module temperature, small differences may be expected between the planned curve I-V. Small differences may also happen between photovoltaic modules from the same manufacturer and in case of the same model. In addition, small overshadowing and contamination of the module may affect a result of the curve I-V measurement.

When deviations are visible, control should be performed to check whether differences in shape between the measured and expected curve do not result from measurement errors (e.g. different configuration of measuring equipment) or due to incorrectly entered data of PV modules/PV module chains.

Deviation 1 – "steps" or cutaways in curve

Steps or cutaways in curve IV marked on Fig. 1 no. 1 indicate discrepancies in the value of generated current between various areas of the PV field or tested module. Distortion of curve I-V is a result of the fact that bypass diodes are active and generated current bypasses a series of protected cells/modules (chain is not able to transfer the same current as other chains). Such a situation may be caused by a series of factors, including:

- module field or module is partially overshadowed,
- module field or module is partially decontaminated or covered in other way (snow, etc.),
- PV cells/modules are damaged,
- short circuit (damage of bypass diode).

Note Even partial overshadowing of only one cell in the module may cause activation of a bypass diode and clearly visible cutaways in curve I-V.

Deviation 2 – too low current

Many factors can be responsible for a difference between the expected and measured value of current from the PV module/PV module field. They are presented below.

Reasons related to the PV module field:

- uniform dirt,
- overshadowing strips (modules in vertical orientation),
- residual dirt (modules in vertical orientation),
- photovoltaic modules are degraded.

Note: Overshadowing strips and residual dirt have a similar impact as uniform dirt, because they reduce current proportionally in all groups of cells/modules mounted nearby at the same height.

Reasons related to incorrectly entered data of PV modules/PV module chains:

- incorrectly entered data of the PV module,
- incorrectly entered number of parallel chains.

Measuring reasons:

- problems with calibration of irradiance sensor or measurement error,
- irradiance sensor is not mounted in the system plane or is overshadowed,
- change in irradiance during the curve I-V measurement,
- effects related to light reflection (albedo), which may cause that illuminance sensor has recorded too high value,
- illuminance is too low or sun is too close to the horizon.

Note: When current deviation presented on Fig. 1 (case 2) is lower than expected, it is also possible that voltage is incorrectly measured, while its value is overestimated in relation to the correct value for given conditions of measurement of curve I-V.

Deviation 3 – too low voltage

Possible reasons of a reduced value of measured voltage include:

Reasons related to the PV module field:

- conductive or compact bypass diodes,
- incorrect number of PV modules in the chain,
- module degradation (e.g. PID **–** *Potential Induced Degradation*),
- significant and uniform overshadowing of entire PV cell/module/chain.

Reasons related to incorrectly entered data of PV modules/PV module chains:

- entered incorrect data of the PV module,
- incorrectly entered number of modules in the PV chain.

Measuring reasons:

- temperature of the PV cell/PV module significantly differs from the measured value.

Temperature significantly affects the PV cell/module voltage, which may cause that a difference between the real and measured temperature of PV cells/module significantly affects the shape of curve I-V. In such cases, firstly, the method of measurement of cell temperature should be verified (e.g. through verification whether temperature sensor has not come unstuck from the back module surface).

Chain groups measured subsequently often show parameter values slightly different than those expected. This should be expected, taking into account that temperature is usually measured on a single module and a profile of temperature distribution on a single PV module or a PV module field is usually not uniform and may change in time. However, if some chain of PV modules show significantly larger deviations than others, it may mean an issue, especially when deviation concerns the VOC/N value (N **–** number of cell chains in the PV module or a number of PV modules connected serially in the chain) while the PV module/module chain has N of bypass diodes.

Note When voltage deviation presented on Fig. 1 (case 3) is lower than expected, it is also possible that voltage is incorrectly measured, while its value is underestimated in relation to the correct value for given conditions of measurement of curve I-V.

Deviation 4 – too rounded "knee"

Rounding of the Curve IV bend may be a symptom of the module ageing process. In order to confirm it, it should also be verified whether inclination does not concern the curve I-V respectively within the scope of its "horizontal" and "vertical" part. If yes, it might affect the curve "bend" shape.

Deviation 5 – lowered deviation of a "vertical" part of the curve

Inclination of a vertical part of the curve IV between the maximum power point (Vmpp) and open circuit voltage VOC results mainly from serial resistance of the PV module/chain. Increased resistance causes reduced inclination of a slope in this part of curve.

Possible reasons for increased serial resistance include:

- damage or error of wires/cabling (or cables of too low section field),
- errors in connections of modules or PV module field (or bad joints),
- increased serial resistance of modules (e.g. as a result of degradation).

During the PV module field testing with long cables, resistance of these cables may affect the curve shape. In such a situation, one should either verify the measurement result with consideration of serial resistance of measuring wires (if a measuring device has available such an option), or should conduct measurement closer to the PV field (with use of much shorter wires).

If an error of increased resistance is noticeable on the curve, special attention should be paid to the quality of cabling and connections in the PV module field. This error may indicate a significant defect of cabling or damage (e.g. corrosion), which significantly affects draft characteristics of the PV module field.

Increased serial resistance of the module may result from too high resistance of connections between cells or connections inside the junction box of modules - with regard to degradation, corrosion or production errors.

IT scan, as described in test sequence 2, may constitute a useful tool for detection of errors related to too high resistance in the PV module field.

Deviation 6 – too steep slope of a "horizontal" part of the curve

Changes in inclination in the upper part of the curve IV are related to the appearance of too large leakage (bypass) and probably are caused by:

- too low resistance of leakage in photovoltaic cells,
- mismatch of currents ISCogniww module,
- conical shadow or contamination (e.g. sediment, dirt).

Bypass current is a part of generated current bypassing the cell connections. It happens usually due to located defects in the area of the cell or of connections between cells. Leakage may lead to the appearance of local so-called hot spots in cells, which can be localised with use of IR tests.

Differences in ISC current values between particular PV modules in the chain may result from production discrepancies. If these discrepancies are insignificant and randomly distributed in the chain, visible steps or cuts in the curve I-V of such a chain may not be present.

More significant overshadowing of a part of the chain or even of a single module causes usually more visible characteristic steps or cuts in the curve I-V.

4.8. Methods and repairs or replacement of photovoltaic components

Selection of the test procedure according to IEC 62446 – measurements of system parameters according to test procedures described in the standard IEC 62446

Test procedure 1

Test procedure – Category 1

Continuity of protective earthing and potential compensating conductors

If protective earthing and/or equipotential bonding are mounted on the DC side, while frames of the PV module field are connected, electrical continuity test is performed for all conductive parts. Connection to the main ground terminal should also be verified.

Polarisation test

Polarisation of all DC cables should be verified with use of appropriate test equipment. After check of polarisation, cables should be verified to ensure that they are properly identified and correctly connected to systemic devices, such as switches or inverters.

Junction box/PV chain adder test

A single chain connected in reverse polarisation in the PV chain adder field may be sometimes easily missed. Consequences of reverse polarisation, especially in larger systems with many often interconnected adder fields, may be significant. The adder box test aims at the assurance that all chains are connected with each other on the adder field correctly.

The test procedure is as follows and is conducted before the first activation of chain fuses:

- choose a voltmeter with the voltage range equal to at least twice the maximum system voltage,

- put all fuses on the "minus" side, creating a common rail "minus" for chains,
- do not put any fuses on the "plus" side,
- measure voltage in open circuit from the first chain, between plus and minus and make sure that it is an expected value.
- leave one measurement duct at the positive pole of the first tested chain and place the second duct on the positive pole of the next chain. As both chains have a common "minus" pole, measured voltage should be close to zero, within the acceptable tolerance +/- 15 V,
- continue measurements on subsequent chains, with use of the first positive circuit as reference.

The reverse polarisation condition shall be clearly visible on the chain, on which measured voltage is twice as the system voltage.

PV chain – measurement of voltage of the open circuit

Measurement of voltage of the open circuit (VOC) in the test procedure 1 aims at the verification whether modules in the chain are correctly connected, specifically whether the expected number of modules is connected serially in the chain. Lack of connections or incorrect number of modules in the chain constitutes a relatively frequent error, particularly in larger systems, while voltage of the open circuit during the test allows for quick identification of such errors.

NOTE: Voltage value much lower than expected may indicate that one or more modules in the chain has improper polarisation or defects has been caused by poor insulation, leading to damage of and/or water accumulation in junction boxes. Reading of too high voltage is usually a result of cabling errors.

Voltage of the open circuit from every PV chain should be measured with use of an appropriate measuring device. It should be done before closure of any switches or installation of overcurrent protective equipment (if applies).

Obtained values of voltage of the open circuit are then assessed in order to make sure that they are compliant with the expected value (usually with the tolerance of 5%), using one of the following methods:

a) comparison with the expected value provided in the module's catalogue card,
b) VOC measurement on one module, and then use of this value to calculate the expected value for the chain (the most appropriate when there are stable irradiance conditions),
c) in case of systems with many identical chains, where stable irradiance conditions are present, chain voltages may be compared.
d) in case of systems with many identical chains, where irradiance is unstable, voltages between chains may be compared through the performance of multiple measurement and after the establishment of a reference chain.

Chain (series) of PV modules – current measurement

The PV module chain (series) current measurement test aims at the verification whether there are no larger defects in the area of PV module field cabling. These tests should not be treated as a measurement of module/module field performance.

Two test methods are possible (short circuit test or operating test) and they provide information on proper functioning of the PV chain. Where possible, the short circuit test should be performed, as it is more beneficial because excludes the impact of inverters.

Chain (series) of PV modules – short circuit test

Short-circuit current of every photovoltaic chain should be measured with use of a proper device, intended for such a test. Activation/break of short-circuit current in the chain is potentially dangerous and an appropriate test procedure should be selected, e.g. like the one mentioned below.

Measured values should be compared with the expected value. In case of systems with many identical PV module chains, when measurement was conducted in stable irradiance conditions, results of current measurements in particular chains should be compared. These values should be the same (usually within the scope of 5% of average value of current measured in chains, at stable irradiance conditions).

Short-circuit current test procedure

One should ensure that all switching and disconnecting devices are open and that all photovoltaics chains (of PV modules) are isolated from each other.

Periodic short circuit is performed in the tested chain. It may be achieved through:

a) use of a meter allowing for short-circuit current measurement (e.g. special PV tester);
b) short cable temporarily connected in the circuit of a device disconnecting load in the tested chain circuit;
c) use of "bypass switch" that can be temporarily introduced to the circuit to create short circuit.

PV module chain – test during operation

When the system is activated and operates in a normal mode (inverter tracks the maximum power point), current from every PV chain should be measured with an ammeter with use of an appropriate clamp placed around the chain cabling. Measured values should be compared with the expected value. In case of systems with many identical chains, where stable irradiance conditions are present, measurements of currents from particular chains should be compared. These values should be the same (usually within the scope of 5% of average value of current of chains for stable irradiance conditions).

Functional tests

It is recommended to conduct the following functional tests:

Switchboards and other control devices are tested to ensure their proper operation and verification whether they are properly mounted and connected.

All inverters constituting a part of the photovoltaic system should be tested to ensure their proper operation. Procedure of such a test should be specified by the inverter manufacturer.

Test of resistance of isolation of the PV module field

DC circuits of the PV module field operate during the day and, contrary to a conventional electrical system, cannot be isolated prior to the performance of a described test.

Test of resistance of isolation of the PV module field – test method

Test should be conducted for every PV module field as minimum. Also individual chains may be checked.

Two test methods are possible:

TEST METHOD 1 – Test between the negative clamp of the PV module field and ground and then test between the positive clamp of the field and ground.
TEST METHOD 2 – Test between earth and shorted clamps (positive and negative) of the PV module field.
If the PV module field's frame is earthed, a relevant earthing point or field frame may be applied (when the field frame is used, good electric contact should be ensured and continuity on entire metal part of the frame should be verified).
In case of systems in which the PB module field's frame is not connected with earth (e.g. when there is a class II installation), a testing engineer may choose one of two tests: i) between field cables and earth) or ii) between field cables and frame.
For PV module fields that do not have available electrically conductive parts (e.g. PV tiles), test is conducted between the board cables and building earthing.
Resistance of isolation of the PV module field – test procedure
Prior to the test commencement, the following activities should be performed:

- limit an unauthorised access;
- isolate the PV module field from the inverter (usually with use of the PV module field disconnector);
- disconnect any parts of devices that may affect the isolation measurement (e.g. over-voltage protection) in the junction box/adder box.

Isolation resistance – PV module field of power up to 10 kWp

For PV fields of rated power up to 10 kWp, isolation resistance should be measured with test voltage provided in Tab. 1. The result is satisfying if every circuit has isolation resistance not smaller than the relevant value provided in Tab. 1.

Tab. 1. Minimum values of isolation resistance – PV module field up to 10 kWp

System Voltage	Test Voltage	Minimum isolation resistance
<120 V	250 V	0.5 MΩ
120 V - 500V	500 V	1 MΩ
>500 V	1000 V	1 MΩ

Isolation resistance – PV module fields of power above 10 kWp

For PV fields above 10 kWp, in order to test the isolation resistance, one of the following methods should be applied:

Method A

Isolation resistance test should be performed on:

- particular chains; or
- connected chains, where total power sum is not larger than 10 kWp.

Isolation resistance is measured at measuring voltages provided in Tab. 1. The result is satisfying if isolation resistance is not lower than the relevant value in Tab. 1.

Method B

Taking into account proper irradiance conditions, test of the curve IV ensures determination of performance of the PV module field and establishment whether it meets rated values (provided on the rating plate).

Measurements of performance of chains and the PV module field are conducted in stable irradiance conditions of a value not lower than 400 W/m^2 measured in the module field's plane.

The curve IV test procedure is as follows:

- make sure that the system is turned off and current does not flow,
- tested chain should be isolated and connected to the curve IV measuring device,
- the device should be programmed as appropriate to a type and number of PV modules examined within the framework of test,
- illuminance meter cooperating with the curve IV tester should be installed in such a way that it covers the PV field plane and is not subject to any overshadowing or reflected light (albedo). If the test uses a reference (model) cell, it should be verified whether it is from the same technology as in the tested PV field, or - otherwise - appropriate adjustment resulting from various technologies should be made,
- if the curve IV tester uses a cell temperature sensor, it must entirely touch the module behind, in the middle of the cell located in a central part of the module. If temperature adjustments are calculated by the curve IV test device, control is performed to make sure that correct module parameters (values of temperature coefficients) are entered to the device and the chain's VOC value is within the expected range.

  NOTE Verification of the VOC value is conducted to ensure that the chain has a correct number of modules – wrong number might cause an error at entering an adjustment related to the module's temperature.
- Prior to the test commencement, irradiance level should be checked to ensure that it is higher than 400 W/m^2 in the PV field's plane.

After the test completion, measured value of the maximum power should be compared to a rated value (recorded on the rating plate). The measured value should be within the provided power tolerance for modules in the test (with consideration of accuracy of equipment for the curve IV test).

Isolation resistance test should be performed on connected chains larger than 10 kWp.

Isolation resistance is measured at measuring voltages provided in Tab. 1. The result is satisfying if isolation resistance is not lower than the relevant value in Tab. 1.

If measurement results are below respective values provided in the Table 1, the system should be tested again with use of a smaller number of chains in the test system.

Measurement and analysis of characteristics of I-V PV module chains cover the following issues:

1. Principles of the measurement of characteristics of I-V photovoltaic modules. Definition of electrical parameters determined from characteristics.
2. Relation of characteristics of I-V from temperature to illumination **–** temperature coefficients.
3. Method of correct measurement of the module temperature (reference to ECT, IEC 6094-5).
4. Issues with measurements of characteristics of I-V for some technologies (a-Si, DSSC, Sunpower).
5. Shape of characteristics of I-V indicating improper working conditions (e.g. overshadowing) or module damage.
6. Selection of modules for the photovoltaic system in order to avoid/minimise losses resulting from electrical mismatch.

7. Principles of planning module distribution in the photovoltaic system to avoid losses caused by uneven lighting or uneven temperature distribution.
8. Factors affecting the system operation **–** illuminance, temperature, wind.
9. Impact of irradiance, ambient temperature and wind speed on the module temperature. Definition of the NOCT (Nominal Operating Temperature).
10. Set of IEC/PN standards related to the issues concerning items 1-9.

Test procedures – Category 2

Chain measurement – curve IV

Test of the chain's curve IV may provide the following information:
- measurements of voltage of the open circuit (V) and short-circuit current (ISC),
- measurements of voltage (Vmpp), current (Impp), in the work point for maximum power (Pmax),
- measurement of the PV module field performance,
- identification of defects of the module/PV module field or an issue related to overshadowing of a part of the module field.

Prior to the commencement of the curve IV test, a test device must be checked to ensure that its measuring ranges are properly adjusted to expected values of voltage and current in the tested circuit.

Measurement of the curve I-V-Voc and Isc

The curve IV test is an acceptable alternative (indirect) method to determine the value of voltage in the open circuit (VOC) and short-circuit current (ISC). When the curve I-V is measured, separate measurements of VOC and ISC are not required – however, provided that the curve IV test is conducted at a relevant stage in the test sequence 1.
The tested chain should be isolated and connected to a device measuring the curve I-V. If the curve IV test aims only at the acquisition of estimated values of VOC and ISC, measurement of irradiance (or module temperature) is not required.

Measurement of the curve I-V – performance of the PV module field, identification of defects of the module/PV module field or overshadowing

Shape of the curve IV may provide valuable information on the PV module field. The following defects may be identified within the framework of test:
- damaged cells/modules,
- bypass diode short circuit,
- local overshadowing,
- electrical mismatch of modules,
- resistance shunt in cells/modules/PV field,
- excessive serial resistance.

If the curve IV measurement aims at the verification whether there are any errors caused by the mismatch effect, measurement can be conducted at a lower irradiance and larger angles of incidence of light than required to test performance.
In order to obtain a better shape of the curve IV, it is recommended that irradiance value should exceed 100 W/m, but useful data may also be obtained at low levels of irradiance. If the curve IV shape at the irradiance level lower than 100 W/m is intermittent, it may be

a reason of a potential error and it is recommended to repeat the test at the irradiance value exceeding 100 W/m.

On the curve IV record, any visible deviations from the expected, correct shape of the curve or expected values of electrical parameters should be analysed. Visible deviations from the correct shape of the curve IV require special attention, as they may signal previously not detected and significant errors in the PV module field. Appendix D includes information on the interpretation of deviations from the curve IV.

In case of systems with many identical chains, where stable irradiance conditions are present, curves from particular chains should be compared (fit one on another). Curves should be the same (usually within the scope of approx. 5% at stable irradiance conditions for points ISC, VOCi Pm).

Control procedure for the PV module field with an infrared camera

Control with use of an infrared camera (IR) aims at the detection of unusual fluctuations of temperature in the photovoltaic module field. Such temperature changes may indicate issues within the scope of modules and/or entire PV field, such as reversely polarised cells, lack of bypass diodes, bad soldering, weak active connections that lead to a local temperature increase.

NOTE: In the initial verification process, the IR test may also be applied for issue solution in the module, chain or PV module field.

IR test procedure

During the IR test, the system should be in a normal operating mode (inverter tracks the maximum power point of the PV field). Irradiance in the PV field's plane should exceed 400 W/m, while weather conditions should be stable. In a perfect situation, irradiance in the PV module field's place should be at a permanent level, above 600 W/m, in order to ensure sufficient current causing noticeable temperature differences.

Results of IR tests – General information

This test searches mainly for abnormal temperature changes in the PV module field.

IR test results – hot spots

A hot spot observed on the module surface usually means an electrical issue, possible serial, parallel resistance, or (current) mismatch of cells. In each case, performance of all modules where hot spots occur should be tested. Signs of overheating may be shown also during inspections, e.g. brown or discoloured area of the module.

IR test results – bypass diodes

If any bypass diodes are too hot, the module field should be inspected, searching for such obvious reasons as overshadowing or contamination on a module protected by a diode. If there are no such obvious reasons, it may mean that the module is damaged.

IR test results – cable connections

Connections of cables between modules are not much hotter than the cable itself. If a connection is hotter, it should be checked whether it is not lose or corroded.

Test procedures – additional tests

Earthing voltage – resistance earthing systems
This test is conducted in order to assess systems that use high earth impedance (resistance). Detailed test procedures are delivered by module manufacturers who require resistance earthing systems for their modules.

Blocking diode test
Blocking diode may be damaged in both conditions, both in conducting and at barrier polarisation. This test is significant for PV installations where blocking diodes are mounted.
All diodes should be controlled to ensure that they are correctly connected (proper polarisation) and that there are no symptoms of their overheating or burning.
In a normal operating mode, voltage on the blocking diode (VBD, voltage on blocking diode) should come to:
- criterion - positive test result: VBD 0.5 V -1.65 V.

Verification of quality of the PV system – certificate

Verification report
After the end of the system verification process, the user should receive a report. This report should cover the following information:
- Basic information describing the system (name, address, etc.),
- List of circuits being subject to controls and tests,
- Control report,
- Register of test results for every tested circuit,
- Period to the next system verification,
- Signature of the verifier(s).

Specimens of verification reports are presented in appendices A, B and C.
NOTE: In some countries, a period required between verifications is specified in relevant domestic regulations.

Initial (acceptance) verification
Verification of a new installation is conducted according to requirements of item 5 of the standard IEC 62446. The first verification report should include additional information concerning a person or persons responsible for design, construction and verification of the system, as well as their scope of responsibility.

Periodic verification
A periodic verification of the existing installation is also performed according to requirements of item 5 of the standard IEC 62446. In relevant cases, results and recommendations of previous periodic verifications should be considered.

4.9. Records of inspection, maintenance and repair of solar installations

Quality of a photovoltaic installation is difficult for verification without relevant knowledge and specialised instrumentation. During the operation of the photovoltaic system (PV), there is needed the access to at least current electrical parameters of the system and data of solar irradiance on the installation site. Such parameters can be guaranteed only by proper system monitoring. It should be emphasised that a significant part of modern inverters is equipped with measuring and IT elements that allow for measurement, acquisition and on-going remote (via Internet) access to data obtained during the system operation.

This study presents and briefly describes the most important normative documents (standards) applicable in a discussed scope.

In order to ensure a high-quality PV system, its appropriate technical documentation and quality control procedures are essential. This study discusses principles of developing correct technical documentation of the PV system, method of conducting test activation and acceptance procedures, as well as periodic controls of correct functioning and technical condition of the PV system. Both test procedures and scope of information that should be found in an acceptance report or in reports after conducted periodic controls are discussed. This study part is based mainly on the European standard **IEC 62446**.

One of the most important standards for real, reliable verification of quality of photovoltaic modules are the standards IEC 61215 (for modules made of crystalline silicic cells) and IEC 61646 (for modules made in thin-layer technologies). They cover all three basic qualitative aspects of modules, i.e. degradation, durability (short- and long-term) and safety related to their operation. Both mentioned standards cover a series of tests, such as:

- inspection (visual assessment),
- electric parameters in STC (Standard Test Conditions) (so-called power rating),
- isolation test,
- temperature coefficients of electric parameters, serial resistance,
- determination of NOCT (Nominal Operating Cell Temperature),
- electric parameters in NOCT,
- electric parameters at low irradiance,
- test of presence of so-called hot-spots,
- UV resistance test,
- test of resistance to temperature cycles,
- test of resistance to freezing at high humidity,
- test of resistance to humidity at high temperature,
- output resistance (durability) test,
- torsion resistance test,
- test of resistance to static mechanical load.

IEC 61215 or IEC 61646. In practice, depending on the place where specific modules are to be installed, in what PV system and requirements of the investor, modules should hold a certificate related only to selected tests such as a test of resistance to temperature cycles (basic test), test of resistance to freezing (for areas where rapid temperature declines occur), test of resistance to static loads (e.g. for areas with massive snowfall or resistance to hail (for areas where it occurs). Basic tests that should always be confirmed with a relevant certificate include measurements of electric parameters, presence of so-called hot-spots (occurrence of such spots in modules means their lower resistance to damage in the conditions of partial overshadowing) or isolation test, which is extremely important from the point of view of safety, particularly in PV systems of high voltage on the DC side.

Operation and maintenance of the PV system

Information concerning operation and scope of maintenance of the PV system should be ensured and should include, as minimum, the following elements:

1. Procedures verifying correct operation of the system.
2. Checklist of procedure in case of system failure.
3. Procedures of emergency switching off/disconnecting of the system.
4. Recommendations concerning maintenance and clearing (if needed).
5. Notes on possible future works with the PV module field (e.g. roofing work).
6. Warranty document for photovoltaic modules and inverters – it must determine a start date and duration.
7. Documentation specifying the scope of relevant guaranteed actions (works) and warranties related to weather hazards (e.g. hail, windstorms, etc.).

Standard IEC 62446 – verification of quality and control of the PV system

This section contains a description of requirements concerning both initial and periodic procedures of verification of the PV system's electric installation attached to the electrical grid. It refers mainly to the standard IEC 60-364-6 (*Low-voltage electric installations – Part 6: Verification*), but also, where necessary, to other documents and studies.
Within the significant scope, verification of the PV system attached to the network should be performed based on requirements formulated in the standard IEC 60364-6, which defines such requirements for initial and periodic verifications of every electric installation.
Every installed sub-assembly and element of the PV system should be verified already at the installation stage, if possible, and after its completion, before the entire system commissioning, compliance with the standard IEC 60364-6 should be verified. Original verification includes the comparison of results with appropriate criteria in order to confirm that the IEC 60364 requirements have been satisfied.
Also, after each supplement or changes made in the existing installation, it should be verified whether introduced changes are compliant with the standard IEC 60364 and thus, whether they do not deteriorate safety conditions.
Both initial (acceptance) and period verification should be conducted by an expert, of qualifications adequate for performance of such works.
NOTE: Samples of typical sheets of the PV installation verification may be found in appendices to the standard IEC 62446.

Test systems and additional tests

The test system applied in the photovoltaic system must be suitable for the scale, type, place and complexity of a given system. This document defines two test systems, together with a series of additional tests that may also be conducted when the standard sequence is ended.

- Test of category 1 – minimum requirement - standard set of tests that should be applied to all systems;
- Test of category 2 – extended sequence of tests when all tests from category 1 has already been conducted;
- Additional tests – other tests, which performance may be indicated in some cases.

5. EXERCISES

5.1. Health and safety at work regulations, environmental protection – exercises

Exercise 1. *(to the topic 4.1)*

Choose the correct sentence from the table:
During the work, the PV installer should:

a) illuminate workplaces with portable lamps with a voltage greater than 24 V,
b) to prevent the generation of electricity by the solar module cover its entire surface with an opaque cover,
c) perform assembly work during a storm, strong winds or other hazards.

Exercise 2. *(to the topic 4.1)*

Cross out the statement that does not match the rest:
PV installers are not allowed to:

a) refuse to undertake other equivalent work, if it is not possible to immediately remove hazards from previous work,
b) lock passageways and access to workstations, fire-fighting equipment and electric switches,
c) ground the exposed conductive elements, e.g. the framework frame of the construction of a set of PV panels.

Exercise 3. *(to the topic 4.1)*

Individual Protection measures include (tick 3 responses):
a) Eye and face protection
b) Risk assessment plan
c) Limbs protection
d) Lifting platforms
e) Hearing protection
f) Mobile platforms

5.2. Health protection during modernization works and maintenance of photovoltaic installations – exercises

Exercise 1.

Match the norm with the subject:

IEC 61215	crystalline modules
IEC 61646	thin-film modules
IEC 61730	the scope of security for PV modules

Exercise 2.

Which word from the box does not match to the sentence:

For modules ...., all DC components must be dimensioned for voltage: Voc (STC) x 1.15, current: Isc (STC) x 1.25.

mono silicon modules	mono silicon modules	mono silicon modules

5.3. Safety rules for the maintenance and conservation of the solar installation – exercises

Exercise 1. *(to the topic 4.3)*

From the table below, select the connection that must be met when selecting the fuse's rated current level:

$0,4xI_{SC} \leq I_n \leq 2,4xI_{SC}$
$0,8xI_{SC} \leq I_n \leq 1,2xI_{SC}$
1,4xISC ≤ In ≤ 2,4xISC

Exercise 2. *(to the topic 4.3)*

Combine the norm with the issue it describes:

PN-EN 50272-2:2007	Safety requirements for rechargeable batteries and battery installations
PN-EN 62305-2	Protection against lightning
IEC 60269-6	Selection of the correct type of fuse
IEC 61730-2	Limit value of the return current according to the standard

5.4. Photovoltaic maintenance program – exercises

Exercise 1. *(to the topic 4.4)*
Complete the text with words from the box:

Testing of the electrical system of the PV system must be carried out in accordance with the requirements of the standard ...... 1 .... Measuring and monitoring instruments and measurement methods are chosen in accordance with the relevant parts of the standard ...... 2 ... .. and ...... 3 .... The requirements for labeling of a solar system are specified in the standard .... 4 ... .

1) IEC 60364 - 6	2) IEC 61557	3) IEC 6101	4) IEC60364-9-1

Exercise 2. *(to the topic 4.4)*
Complete the text with words from the box:

In the case of a system without overcurrent protection in the chains of PV modules, it must be ensured that: IMOD_MAX_OCPR (maximum rated current of the serial fuse in the chain) is greater than the possible ....

reverse current
short-circuit current
leakage current

5.5. Monitoring of photovoltaic system properties – guidelines and measurement requirements and their analysis – exercises

Exercise 1. *(to the topic 4.5)*
Adjust the parameter to the sensor being measured.

Parameter	Sensor type
Intensity of radiation in the plane of modules	Thermocouple pyranometer
Ambient temperature (air)	Termistor
Wind speed	Ultrasonic anemometer

Exercise 2. *(to the topic 4.5)*
Complete the sentences with two valid numbers from the box:

The sensors of the electrical parameters of the PV system should be chosen so that their range is compatible with the upper value of the output parameters of the PV modules field, i.e. for voltage ...1 .. * VOC, for current ...2.... * ISC, and their presence had a minimal effect on the measured parameters (eg, the resistor used to measure the current should have a low resistance so that the voltage drop on it would be negligibly small compared to the field voltage of the PV modules).

1.3	1.5	1.1	1.8

5.6. Analysis of typical errors related to modernization and maintenance – exercises

Exercise 1. *(to the topic 4.6)*
Combine the types of errors with the correct remedies to avoid them and start the system properly:

Typical errors	**Remedies and troubleshooting**
No power from the panels	Open switches or blown fuses, damaged or corroded wires
Too small current from the panels	Some shaded modules. The inclination of the panels or their orientation is incorrect. Some modules are damaged. Dirty modules
No AC voltage	The load on the AC receivers exceeds the power of the inverter, disconnection due to overload. Load unadjusted for continuous operation of the inverter. Overvoltage.
No voltage at the output of the inverter	A blown fuse or open circuit / switch, damaged cable. The inverter is switched off due to incorrect switching off of the charging or open circuit of the charging regulator. High battery voltage.

Exercise 2. *(to the topic 4.6)*
The procedure for detecting earth faults and short circuits - arrange the correct order of performed activities:
1. Turn off the inverter and if it is turn off the DC switch or switches.
2. One module in each band should be completely shaded, covered from the sun.
3. Disconnect the module chains.
4. Start the measurement.

5.7. Types of typical disturbances and failures in systems – Exercises

Exercise 1. *(to the topic 4.7)*
Complete the below sentence:

The aging process of PV modules can be identified on the basis of:

Rounding the knee curve IV
Lowering the slope of the "vertical" part of curve IV
Too steep inclination of the "horizontal" part of curve IV

Exercise 2. *(to the topic 4.7)*
Match the type of the fault to the parameter used for the diagnosis:

The type of the fault	The parameter used for diagnostics
Breaks in DC chains (burnt fuses in DC connection boxes, damaged wires, connectors, PV module connection boxes)	DC current in the DC chain (compared to others)
Break in the main DC line (burnt fuses at the inverter input, faulty connection, cable)	DC current at the inverter input
Electrical insulation (defective cables / modules)	Measurement of the insulation resistance in the inverter
Fluctuations of network parameters	Network parameters monitored by the inverter
Excessive heating / hot spots (so-called "hot spots") (due to bad electrical contact)	Visual inspection, thermal imaging camera

5.8. Methods and repairs or replacement of photovoltaic components – exercises

Exercise 1. *(to the topic 4.8)*
Tick the correct answer:

In normal operating mode the voltage on the blocking diode (VBD) should be:

0,5 V -1,65 V
0,9 V -2,65 V
1,2 V -2,5 V

Exercise 2. *(to the topic 4.8)*
Finish the sentence:
Lack of connections or incorrect number of modules in the chain is a relatively a common error, especially in larger systems. It can be diagnosed by measuring:

open circuit voltage
current of the closed circuit
maximum power point

5.9. Records of inspection, maintenance and repair of solar installations – exercises

Exercise 1. *(to the topic 4.9)*
Mark the wrong answer:

DC system - Protection against the effects of atmospheric discharges and surges
The DC installation check should include at least:

in order to minimize the tensions caused by atmospheric discharge, check that the surface of the loops created by the electric wires is as small as possible.
check the measures to protect long cables (e.g.: through screens or installation of lightning fuses – SPD).
when using SPD lightning current fuses, check that they are installed in accordance with the requirements of IEC 60364-9-1 standard.
check the alarm system for detecting low insulation resistance between the PV module field and the ground - compliance with the requirements of IEC 60364-9-1.

Exercise 2. *(to the topic 4.9)*
Complete the sentence with a word from the box:
If the blocking diodes are installed, make sure that their rated barrier voltage is at least ... . x VOCSTC of the PV modules chain in which the diodes have been mounted (IEC 60364-9-1 standard).

2	0,8	1,4

6. PROGRESS TEST

Can you:	Yes	No
1) Discuss potential threats when working with PV systems?		
2) List the activities necessary to perform before starting work?		
3) Discuss what the PV system installer is responsible for?		
4) Discuss the risk assessment?		
5) Describe the fire protection?		
6) Select the installation requirements?		
7) Explain safety work issues with electrical circuits?		
8) Discuss the dimensioning of DC components for PV systems?		
9) Name the personal protective equipment?		
10) Discuss the risk of working at heights?		
11) List the safety rules for battery systems?		
12) Describe the protection against overloads and short circuits?		
13) Identify, what should the general review of DC installations verify?		
14) Discuss what should be checked on the AC side of PV systems?		
15) Discuss what should be checked on the DC side of PV systems?		
16) Discuss the overcurrent protection of the DC installation?		
17) Name the parameters that should be monitored?		
18) Discuss measuring the electrical parameters of the PV system?		
19) Discuss the desirability of monitoring PV systems?		
20) Discuss the sampling frequency?		
21) Name frequent errors during panel assembly and configuration?		
22) Discuss insulation failures?		
23) Discuss the errors regarding the installation of electrical boxes, cable routes and when uninstalling?		
24) List typical installation errors related to fastening systems?		
25) Discuss the possibilities of diagnosing common "faults" in PV systems?		
26) Draw a normal, correct I-V curve measured in conditions of stable radiation intensity?		
27) Discuss the errors regarding the installation of electrical boxes, cable routes and when uninstalling?		
28) List the reasons for the steep slope of the "horizontal" part of the curve?		
29) Discuss the measuring of the open circuit voltage?		
30) Describe the test of the block diode?		
31) Discuss the procedure for testing wet insulation?		
32) Give the standard on the basis of which the PV system is periodically verified?		
33) Point the standard which describes the scope of information that should be included in the acceptance report or in reports after periodic audits?		
34) Describe a general overview of DC installations?		
35) Discuss the control of protection against the effects of atmospheric discharges and surges?		
36) Give what is defined in IEC60364-9-1 standard?		

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).
If necessary, use additional source of information prepared to each topic.

7. GLOSSARY

English	English
Ampere Hour	Multimeter
Array	Nominal Voltage
Balance-of-system (BOS)	One-axis tracking
Battery	Open circuit voltage
Battery bank	Parallel connection
Blocking Diode	Peak (Maximum) Power Point (MPP)
Bypass diode	Performance ratio
Clamp-on ammeter	Personal Protective Equipement (PPE)
Conversion Efficiency	Protective earthing
Current-voltage	PV array
Depth of discharge	PV effect
Diffuse Irradiance	PV Module
Diode	Pyronometer
Direct-current (DC)	Regulator
Direct Normal Irradiance (DNI)	Safety plan
Distributed system	Semiconductor
Earthing system	Series connection
Electric Current	Series controller
Electrolyte	Shunt Controller
Encapsulation	Silicon
Equipotential Zone	Stand-alone PV system
Filling Factor	Standard test conditions (STC)
Fixed Tilt Array	Stratification
Fuse	String
Global Horizontal Irradiance	Sulfation
Global In-Plane Irradiance	Thermomagnetic switch
Grid	Tracking system
Grid-connected system	Volt (V)
Grounding conductor	Voltage
Grounding system	Watt (W)
Hot spot	
Hybrid System	
Inclinometer	
Inverter	
Irradiance	
Islanding	
Isolating transformer	
Junction Box	
Kilowatt hour	
Mismatch losses	
MPP Regulator	

8. LITERATURE

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