RENEWABLE ENERGY TECHNOLOGIES

MAINTENANCE OF LOW AND MEDIUM VOLTAGE PANELS

DigiEnergy 4.0

DIGITALIZATION IN ENERGY 4.0 TECHNOLOGIES

2021-1-TR01-KA210-VET000034519

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EXPLANATIONS

AREA	**Renewable Energy Technologies**
BRANCH/PROFESSION	**Solar Energy Systems**
THE NAME OF THE MODULE	**BASIC RENEWABLE ENERGY SYSTEMS**
DESCRIPTION OF THE MODULE	This module will cover basic level content regarding the maintainance of low and medium voltage panels
DURATION	**40/32**
PRECONDITION	This module has no prerequisites.
COMPETENCY	It completes definition and installation of solar energy system
PURPOSE OF THE MODULE	**General Purpose: Learn basic level information about the maintenance of low and medium voltage panels** **Purposes** Learn basic information about the parts of the photovotaic system Learn basic information about the maintenance of the maıntenance of photovoltage modules and other equıpment Learn basic information about the monıtorıng of the regular operatıng condıtıon of the ınstalled photovoltaıc system
EDUCATIONAL ENVIRONMENTS AND EQUIPMENT	**Environment:** Renewable energy technologies field, renewable energy systems workshop **Equipment:** Basic electrical knowledge, basic electronics knowledge

MEASUREMENT AND EVALUATION	You will evaluate yourself with the measurement tools given after each learning activity in the module.At the end of the module, the teacher uses the measurement tool (multiple choice test, true-false test, fill in the blank, matching etc) to evaluate the knowledge and skills you have gained through module applications.

INTRODUCTION

Dear Students,

The sun is the largest natural source of energy and it gives us the necessary light and heat and influences numerous natural factors that encourage life on Earth. Considering the above fact, and the amount of available natural energy, we can easily come to the conclusion that, in addition to achieving ecological production of electricity from renewable sources, solar energy is interesting to consider and produce a significant amount of electricity. Every technological progress rests on the idea and desire that we want to achieve, including the development of components for photovoltaic systems.

Throughout this module, you will learn about the components that make up the photovoltaic system, namely photovoltaic cells (modules), DC/AC converter, voltage regulator and storage battery. The structure of the most important component of the photovoltaic system (photovoltaic cell - module), the principle of operation and the manufacturing process will also be presented.

The problem of regular maintenance of the photovoltaic system and monitoring of the regular operating condition will be presented to you in order to indicate the need for extraordinary maintenance in case of malfunctions (irregular operating condition is detected by comparing the characteristics obtained by measuring key quantities with the nominal characteristics of the photovoltaic system, and results in notifying the operator on duty for maintenance of the photovoltaic system system). system). The scope of the prescribed periodicity, inspection, servicing, tests and control measurements is emphasized, along with the examination of essential actions that belong to the maintenance of photovoltaic systems.

At the end of the work, you will learn about the communication equipment used for larger photovoltaic systems is described, and in the function of connecting the plant with a computer (which monitors, collects, processes and archives operating data), i.e. connecting the plant via a computer with the end user system or the on-duty power dispatcher that leads drive.

LEARNING ACTIVITY –1

PURPOSE

You will learn basic level information about the basic parts of the photovoltage system including their description and function.

RESEARCH

- Research online about the use of photovoltaic cells throughout history

1. BASIC PARTS OF THE PHOTOVOLTAGE SYSTEM

1.1 Photovoltaic cells (modules)

Photovoltaic cell is the basic component in the architecture of photovoltaic module or photovoltaic system, therefore the construction, use and properties of photovoltaic cell characterize the operation of photovoltaic system, i.e. production of electricity from renewable sources. The main types of photovoltaic cells and modules that are in use today are characterized by the material from which the cell itself is made. The silicon photovoltaic cell was a key factor in the development of this industry for many years, and is currently responsible for over 80% of the world's electricity production from solar energy.

The first silicon photovoltaic cell was discovered in 1941 by Russell Ohl. Its efficiency was below 1%. Further development continued in 1954, when a group of researchers at the Bell Laboratory in New York made a silicon photovoltaic cell with an efficiency of about 6%, and the first photovoltaic module was created under the name Bell's solar battery. The initial price of such photovoltaic cells was very high and they could not achieve commercial use, but they were used for the first time on satellites for space research only in 1958.

Image 1 A space satellite powered by photovoltaic cells

The first serious commercial application was analyzed when it was first noticed that fossil fuel supplies are limited, and that it is necessary to search for and develop energy production from renewable energy sources that will, among other things, enable sufficient electricity production.

Nowadays, it can be said that photovoltaic modules based on this type of photovoltaic cells are characterized by a long history of high reliability, with a guaranteed lifetime of 20 or 25 years. Despite the good results from practice, newer types of photovoltaic cells and modules, made of other materials, are continuously being developed. The basic technology in the production of photovoltaic cells is that of semiconductor electronic components.

A cross-section of the key materials and technologies used today to make photovoltaic cells are:

- Silicon (Si) – including monocrystalline silicon (c-Si), polycrystalline silicon (p-Si) and amorphus silicon (a-Si)
- Polycrystalline thin-film materials (polycrystalline thin film) - including CIS compound semiconductor materials (Copper - Indium - Diselenide), CdTe (Cadmium - Telluride) and thin-film silicon (mostly amorphous silicon)
- Monocrystalline thin-layer materials (monocrystalline thin film) - mostly derived from Gallium - Arsenide (Ga - As)
- Multijunction material structures – combinations of various semiconductor materials.

The key phenomenon for the production of electricity from the energy of the Sun is the photovoltaic effect, and it can be characterized by the creation of a voltage (or corresponding electric current) in a material after exposure to sunlight. Although the photovoltaic effect is directly related to the photoelectric effect, the two processes are different and should be distinguished. In the photoelectric effect, electrons are released from the surface of the material after exposure to a sufficient amount of solar radiation energy. Photovoltaic effect is different, in it the freed electrons are conducted between the molecules of different material compounds (through different valences), which results in an increase in the voltage between the two electrodes.

Production of electricity from solar energy using photovoltaic modules implies direct production of electricity. The electricity produced is direct current and can be used for various purposes. Surplus electricity can be stored in storage batteries in the case when the production is greater than the consumption of electricity or when part of the electricity produced is to be saved for parts of the day when there is no production (eg the night period).

1.2 Photovoltaic cell construction

A typical photovoltaic cell consists of a transparent upper layer, an encapsulate (it serves as protection of the photovoltaic cell from external influences, but also as a link between the upper layer, the cell and the lower layer), the lower layer and the frame as shown in the picture.

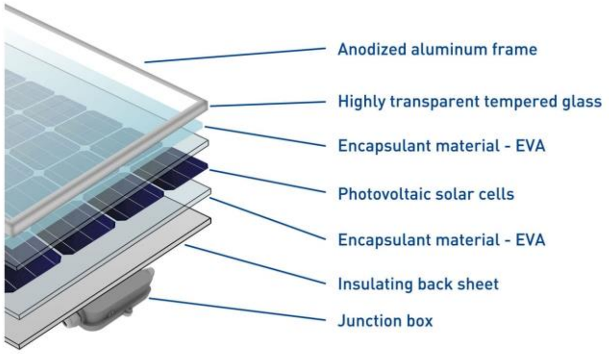


Image 2 Components of a photovoltaic cell

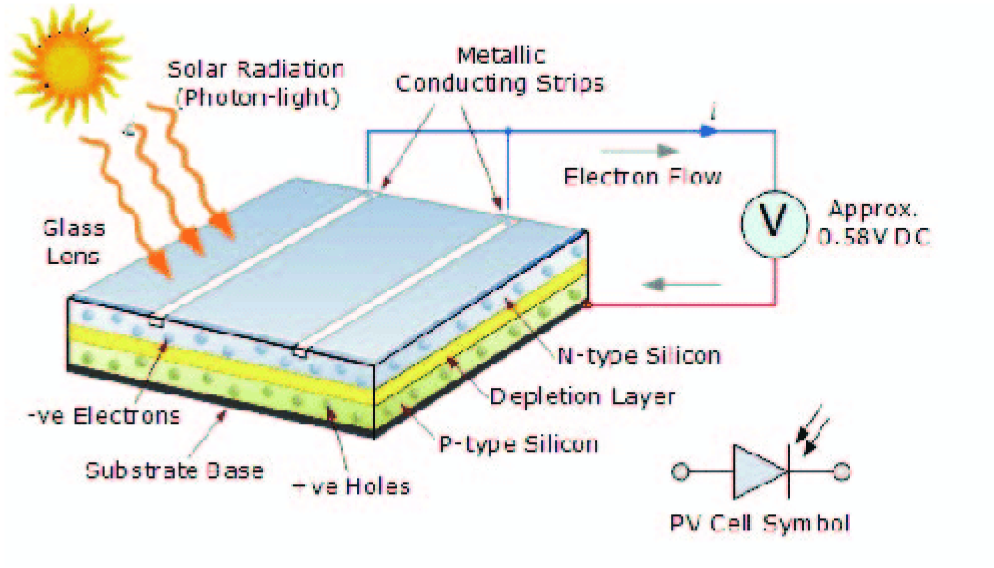


Image 3 Components of a photovoltaic cell

1.3 The principle of operation of a photovoltaic cell

The principle of operation of a photovoltaic cell can best be explained by an alternative scheme. In the diagram, the photovoltaic cell can be viewed as a current source to which a light diode is connected in parallel

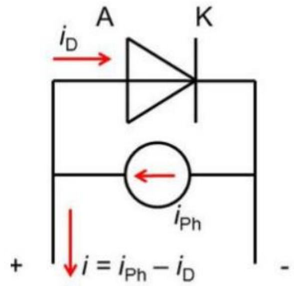


Image 4 Photovoltaic cell as a current source

and [A] – the output current of the photovoltaic cell
iPh [A] – photocurrent
id [A] – diode current

If we act on the light-emitting diode with a light source, the energy of the light creates free electric charge carriers, the flow of which constitutes an electric current. Depending on the level of illumination, the current source represents a constant electric current created by the energy of photons. Illumination and amperage are proportional in size.
The characteristic of a photovoltaic cell is also identical to the characteristic of an ordinary diode. It shows the characteristic of a photovoltaic cell when we do not act on it with a light source. If we act on the photovoltaic cell with some light source, this characteristic "slides" down (along the y axis) and we get the external characteristic of the photovoltaic cell at some constant illumination as shown in the picture.

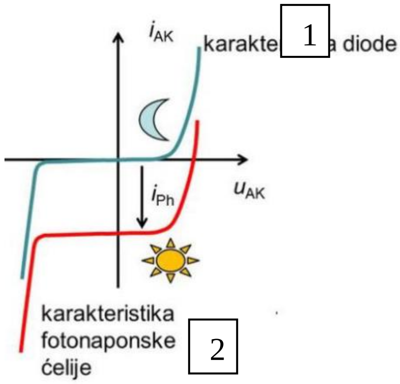


Image 5 Current-voltage characteristic of a photovoltaic cell

1 - Diode characteristic
2 - Photovoltaic cell characteristic

1.4 Making a photovoltaic module from photovoltaic cells

The basic properties of series and parallel connection of electrical elements (photovoltaic cells) in a circuit are used to make photovoltaic modules of certain characteristics. By connecting photovoltaic cells in series, the voltage of the serial series or module increases, while the current remains unchanged. By connecting photovoltaic cells in parallel, the total current of the module increases, while the voltage remains unchanged on all cells.

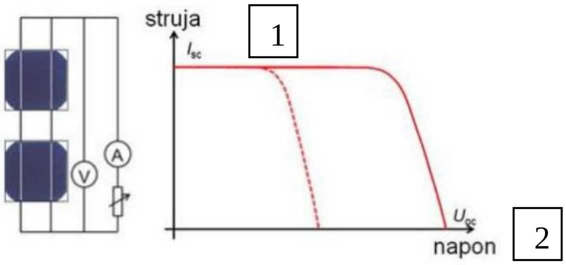


Image 6 Series connection of photovoltaic cells and current-voltage characteristic

1 – current
2 - voltage

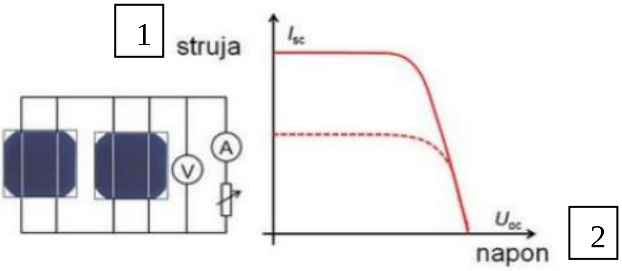


Image 7 Parallel connection of photovoltaic cells and current-voltage characteristics

1 – current
2 - voltage

Combining series and parallel connection of photovoltaic cells is performed in order to make the total output power of the photovoltaic module as high as possible, taking into account the key characteristics of series and parallel connection. They are made in different shapes and sizes of installed power. The two most well-known types of photovoltaic modules are the polycrystalline photovoltaic module and the monocrystalline photovoltaic module (depending on the type of photovoltaic cells from which the module is made).

Image 8 Polycrystalline and monocrystalline photovoltaic module

The manufacturing process of the photovoltaic module begins when a layer of thermoplastic EVA film (ethylene vinyl acetate) is placed on the tempered glass, which must have good anti-reflective properties (it does not reflect the sun's rays and captures direct and diffused light well). After that, rows of photovoltaic cells (photovoltaic cells connected in series) are placed on the glass, which are then connected, i.e. soldered, with a special device. When a certain number of rows of photovoltaic cells (usually 6 pieces) are placed on the glass, they are connected in parallel.

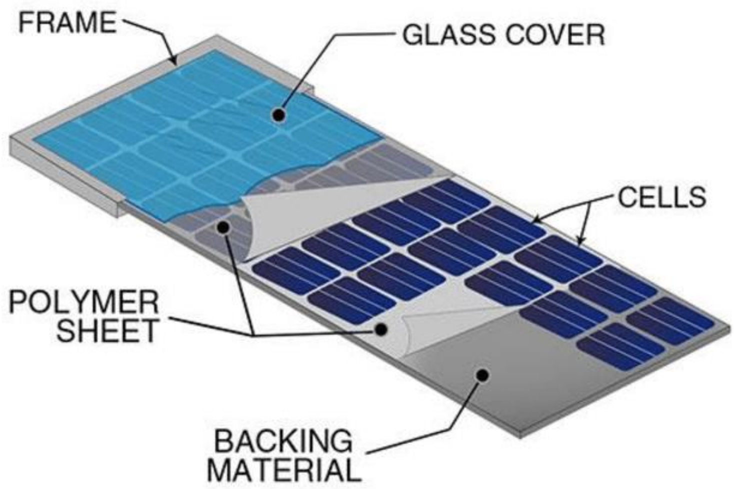


Image 9 Components of a photovoltaic module

In the next phase, the module is covered with another layer of EVA film and with hard waterproof paper that serves as a quality waterproof protection, after which the photovoltaic modules are placed in the laminator where they are laminated at 150 °C. The final stage is the installation of the photovoltaic module in the junction box, and aluminum frames are placed on it with the aim of achieving greater robustness and more stable mounting.

1.5 Other important parts of the photovoltaic system

A photovoltaic system is simply called a solar power plant. It contains at least one photovoltaic module and a number of other components (depending on the number and type of remaining system components, the type of photovoltaic system is determined). The goal of the photovoltaic system is to provide power to direct and alternating electrical consumers with or without another source of electrical energy. The simplest photovoltaic system (without converter) only supplies direct current loads, and if a converter is connected to it, it can also supply alternating current loads, i.e. it can deliver the excess electricity produced to the distribution network of the distribution system operator.

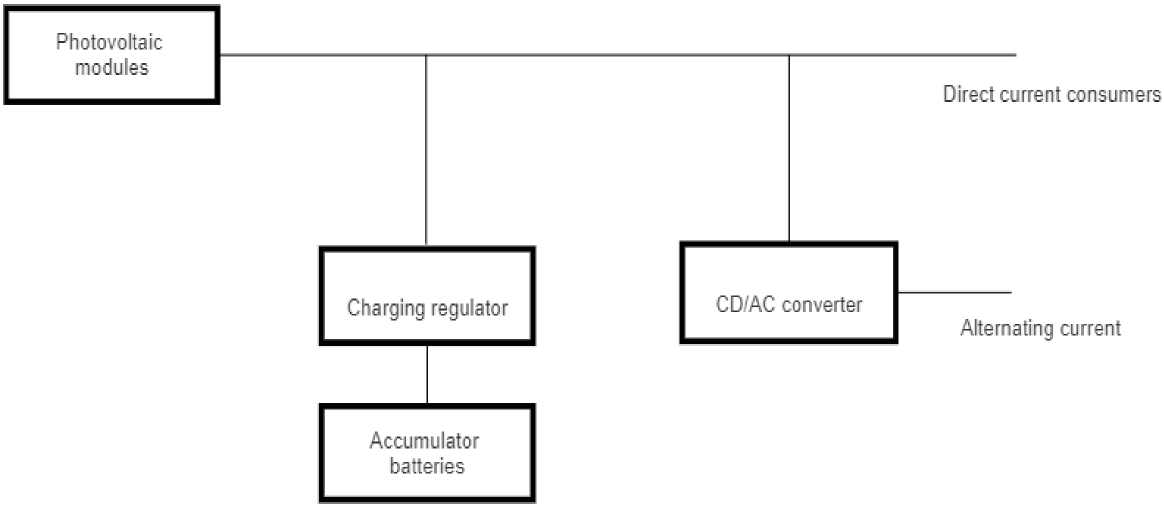


Image 10 Independent photovoltaic system for DC (direct current) and AC (alternating current) consumers

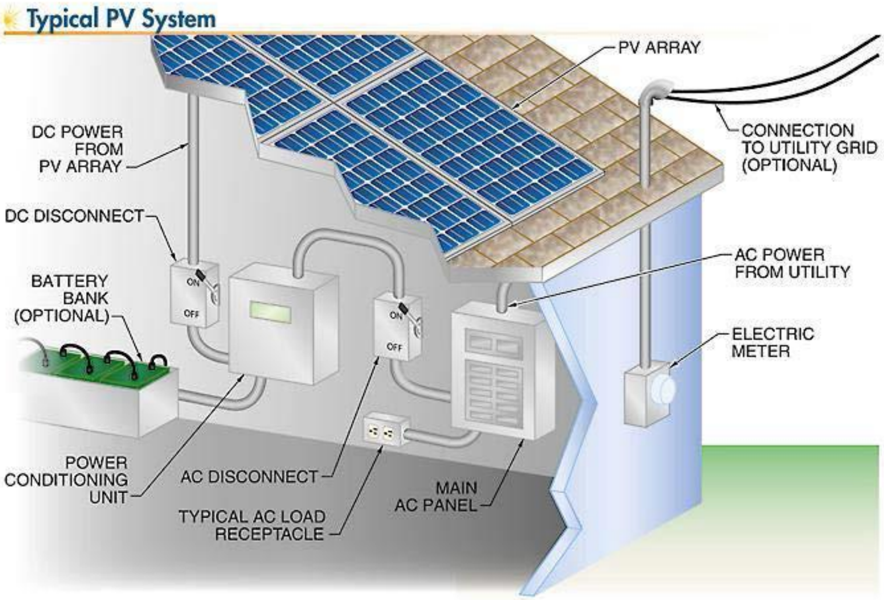


Image 11 Photovoltaic system for supplying electricity to own consumers and handing over excess

A DC-AC converter (inverter) is an electronic circuit that converts direct current into alternating current, which is then sent to the distribution power network or used to power its own electrical consumers. According to the DC voltage source, they can be divided into two groups:

- converters for systems independent of the electrical network (stand alone) where the source of DC voltage is the accumulator battery, and the converter converts the battery voltage into regulated alternating voltage of a stable amount and frequency
- converters for systems connected to the public distribution network (network-controlled) where photovoltaic modules are directly connected to the input, and their output is connected to the distribution network. The direct voltage of the photovoltaic module is converted into alternating current, whereby there is synchronization of the converter with the mains voltage. A battery is not required in this version. The flow of electricity is always from the photovoltaic module to the distribution network.

Image 12 DC-AC converter (one of various manufacturers and types)

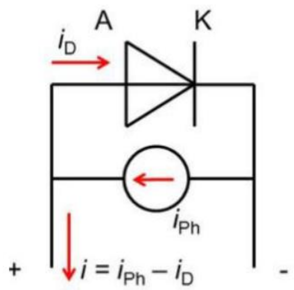
The voltage (charging) regulator is a device that is connected between the photovoltaic module and the battery, and its main task is to control the charging of the battery, making sure that it is not overcharged or completely discharged (which directly affects the extension of the life of the battery The voltage regulator also serves as a safety device for the entire system because it integrates the protection of electrical consumers and other system components (from short circuit, overvoltage and under voltage protection of storage batteries, from overload and short circuit of the converter).

Image 13 Voltage regulator (one of various manufacturers and types)

Accumulator batteries are used to store the electricity produced by the photovoltaic module. The greatest need for storage batteries is justified during the night and in periods when the photovoltaic module cannot produce a sufficient amount of electricity (reduced intensity of solar radiation), so consumers in these periods are supplied with electricity stored during peak production periods.

Image 14 Accumulator battery (one of various manufacturers and types)

APPLICATION ACTIVITY

Process steps	Suggestions
Describe the functioning of the photovoltaic cell using the following scheme: 	Closely inspect all elements and research in the module
Explain and sketch the difference between series and parallel connection of photovoltaic cells	Investigate the differences between types of connection and advise the text and images from the module
Sketch an independent photovoltaic	Check the results in the module

MEASUREMENT AND EVALUATION 1

CONTROL LIST

Evaluate yourself by putting an (X) mark in the **YES** box for the skills you have gained from the behaviors listed below within the scope of this activity, and the **NO** for the skills you have not gained.

Evaluation Criteria	YES	NO
1. Have you learned about the history of photovoltaic modules' usage?		
2. Can you list key materials and technologies used today to make photovoltaic cells?		
3. Can you explain how the photovoltaic module is made from photovoltaic cells?		

4. Do you know the difference between two types of DC-AC converters?		

EVALUATION

At the end of the evaluation, review your "No" answers again. If you do not think you are proficient, repeat the learning activity. If all your answers are “Yes”, move on to “Assessment and Evaluation”.

Circle the letter T if you think the statement is true, or the letter F if you think the statement is false.

1. The photovoltaic module is the basic component in the architecture of the photovoltaic cell. T F
2. The key phenomenon for the production of electricity from the energy of the Sun is
3. photovoltaic effect. T F
4. For the production of photovoltaic modules of certain characteristics, basic ones are used T F
5. properties of series and parallel connection of electrical elements (photovoltaic cells)
6. in the circuit. T F
7. Combining series and parallel connection of photovoltaic cells is performed T F
8. so that the total output power of the photovoltaic module is as low as possible. T F

List the key elements or parts of the photovoltaic system

1. ________________________
2. ________________________
3. ________________________
4. ________________________

EVALUATION

Compare your answers with the answer key. Return to the activity and repeat the topics related to the questions that you gave wrong answers or hesitated to answer. If all of your answers are correct, continue to the next learning activity.

LEARNING ACTIVITY –2

PURPOSE

You will learn about the maintenance of photovoltage modules and other equipment.
You will learn abot the shading effect

RESEARCH

- Research the shading effect online? What does it look like?
- Share the findings with your colleagues

2. MAINTENANCE OF PHOTOVOLTAGE MODULES AND OTHER EQUIPMENT

2.1. Shading effect

When installing and maintaining the correct and functional operation of a photovoltaic system, it is important to consider and prevent the shading effect of the photovoltaic cell or photovoltaic module if we look at the bigger picture, which can arise due to unforeseen circumstances. Over time and as a result of the development and production of photovoltaic modules, almost all problems that can occur and cause shading have been discovered, and they have been eliminated by improving production procedures and installing additional protective components. The natural phenomenon of the movement of the Sun and the Earth unfortunately affects the daily changes in the position and angle of incidence of solar radiation on the installed photovoltaic modules, and surrounding objects can be found on that path (surrounding buildings, trees, chimneys or satellite transmitters, i.e. all tall and robust objects), which can ultimately shade a certain segment of a photovoltaic module or several photovoltaic modules. It is not always easy to find the

ideal position and area where the photovoltaic system will be installed, so in practice, when installing the photovoltaic system, maximum efforts are made to mitigate (sometimes it is even possible to completely avoid) shading so that the system works at full capacity.

Shading of a photovoltaic cell can be defined as the effect which occurs when one cell in a row is not exposed to the same intensity of solar radiation as the remaining cells in the photovoltaic module. This phenomenon can also occur when one photovoltaic module is partially or completely shaded, but the shading of only one photovoltaic cell represents a problem for the entire photovoltaic module because that specific cell will have a lower current than the other non-shaded cells, and therefore a whole row of cells will have less current. The above results in a limitation of the total current of the entire photovoltaic module.

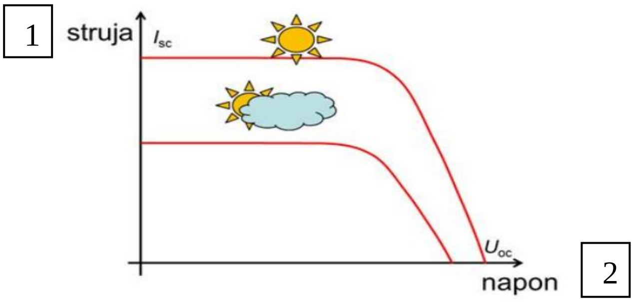


Image 15 Current-voltage (I-U) characteristic of unshaded and shaded cell

1 – current
2 - voltage

If there is a case where one photovoltaic cell is not partially but completely shaded, that photovoltaic cell no longer produces an electric current but behaves like an ordinary diode.

In that case, that photovoltaic cell represents a consumer and the total current of the photovoltaic module will flow through that cell, which ultimately results in increased heating of the photovoltaic module at the shading position. If you look at the physical picture of electricity consumption, that is, the electricity produced, all the power produced by the photovoltaic module is consumed in that shaded place. The result is an effect that is also called the "hot spot" effect or the hot spot of the photovoltaic module. This phenomenon is extremely dangerous and disastrous for the installed equipment of the entire photovoltaic system, and the prevention of such a scenario belongs to the supervision, management and maintenance of the installed photovoltaic system.

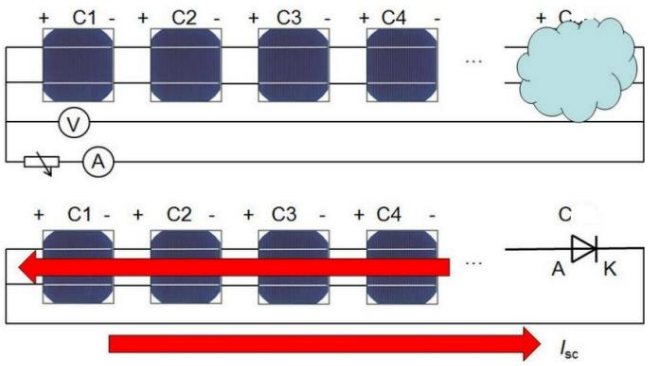


Image 16 Schematic representation of the effect that results in the shading of a photovoltaic cell

The described phenomenon can be prevented by using a bypass diode, and for a better understanding we will describe a specific example of a shaded photovoltaic cell on a photovoltaic module of a total of 36 photovoltaic cells, and on the current-voltage characteristic we will show what happens to the electric current in that case. The key task of the protective bypass diode is to prevent the appearance of a destructive reverse voltage on the shaded cell, that is, to prevent the flow of the total produced electric current of the photovoltaic module through the shaded photovoltaic cell. In this case, practically no electric current flows through the shaded photovoltaic cell, and there is no increased heating, so ultimately there is no risk of breakdown.

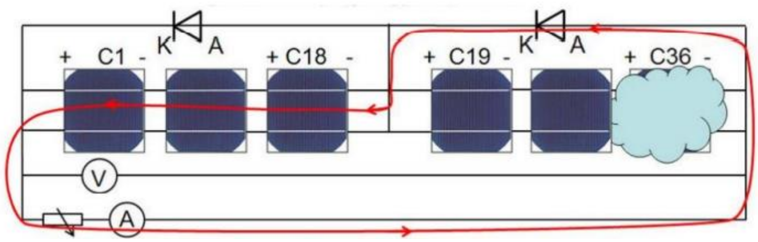


Image 17 Connecting a bypass diode to prevent damage to the photovoltaic module

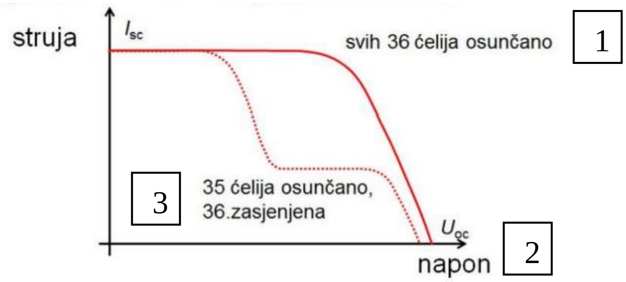


Image 18 Current - voltage characteristic of the photovoltaic module when shading one photovoltaic cell

1 – all 36 cells sunlit
2 – voltage
3 – 25 cells sunlit, 36. shaded

The ideal solution to the problem (by bridging diode) of shading of individual photovoltaic cells is that when manufacturing photovoltaic modules, each photovoltaic cell has its own bridging diode built in, but in practice this is a more expensive solution and is not carried out that way. It is economically justified to install one bypass diode for every 15 to 20 photovoltaic cells. Specifically, with today's photovoltaic modules that are present in practice of 36, 48, 60 or 72 photovoltaic cells, 3 bypass diodes are installed. That is why the current-voltage characteristic of the photovoltaic module shown for the described scenario has a significant reduction in the total current (photovoltaic cells from 19-36 are bridged), much greater than if only one photovoltaic cell was connected (because in that case the distortion of the current-voltage characteristic would be insignificant in relation to the nominal characteristic).

2.2 Regular periodic maintenance

In order for the operating condition of the photovoltaic system to be regular for as long as possible (all systems and equipment work without errors and electricity is produced), in addition to solving the shading problems during installation and installation, it is necessary to additionally maintain all installed components of the photovoltaic system, which includes all active components system. Due to the high quality and production technology of the system components, the scope of maintenance in practice is minimal, except for the accumulator batteries, which are the most sensitive component of the system, because the maintenance of the accumulator batteries depends on the type and charge/discharge cycles. The practice and obligation of the installer of the photovoltaic system is to provide the user with detailed instructions and maintenance recommendations according to the instructions of the manufacturer of the installed components of the photovoltaic system, which are in accordance with the applicable technical regulations and standards. The periodicity and scope of inspections, scope of servicing, testing and control measurements are most often prescribed. The basic actions that belong to the maintenance of such systems are:

- visual inspection of photovoltaic modules (breakage of glass, burning of the back panel, color change, formation of bubbles on the connection tracks between series and parallel connections, deformation of the distribution box with wiring of installations and connections)
- periodic cleaning of photovoltaic modules
- cleaning of filters on converter fans, charge regulators and distribution cabinets and cabinets with other equipment
- tightening of electrical connections and checking of electrical connections (recording with a thermal imaging camera of places that heat up)
- inspection of the DC distribution box (deformations, rust, leakage, damage on the outside)
- measurement of grounding resistance on all connections
- tightening of connections and checking of the mechanical connection between the equipment carrier and the frame of the photovoltaic modules
- inspection of all equipment and all joints from the aspect of corrosion
- inspection and renewal of various inscriptions
- tests of the complete electrical installation and replacement of consumable and damaged parts of the installation (integrity of conductors, insulation, crushing of conductors or mechanical damage)
- tabular collection and graphical presentation of key measured electrical quantities and parameters (measurement of produced electricity under conditions of the same solar intensity during the same periods or parts of the day, measurement of temperature, voltage, current)

Photovoltaic modules are relatively easy to maintain because the installed equipment does not contain moving parts, which significantly affects the intensity and number of repairs on the equipment itself. A key aspect of maintenance is periodic cleaning so that the amount of electricity produced is close to the nominal values with regard to the installed power of the installed photovoltaic modules, minus minimal losses. In addition to reaching the desired amount of electricity produced, maintenance aims to preserve the installed components in order to reach the guaranteed service life. As a rule, cleaning is carried out once a year in order to remove accumulated dust, bird droppings, soot, leaves and various other accumulated substances that can prevent the sun's rays from entering the photovoltaic module, while instructing the system user to monitor the characteristics and amount of electricity produced. Experience shows that the mentioned external disturbances can interfere with the installed power of the photovoltaic module by up to 20%. Cleaning can be done more often, and it is best to do it in the spring period (at the beginning of spring) in order to best prepare

the photovoltaic modules for the new season, i.e. the period of the highest solar radiation. The best part of the day in the spring period is the morning part or the night part in order to carry out the cleaning when the photovoltaic modules are not excessively heated.

It can be said that natural influences such as rain, dew and wind can contribute to the cleaning of the mentioned impurities, but they are by no means sufficient for efficient cleaning of the module. During the winter period (regardless of the naturally reduced utility during the production of electricity due to the position of the Sun, the production process is still carried out partially), snow removal is not carried out if a large amount of snow attacks, but the recommendation of the photovoltaic module manufacturer is to wait for the natural melting of the snow. At the same time, natural cleaning of previously accumulated impurities is also achieved.

Image 19 An example of removing a small amount of snow

If an unpredictable major weather event occurs, such as hail, the protective glass that protects the cells of the photovoltaic module may be damaged, and in such cases the entire photovoltaic module must be replaced because partial repair is impossible. The photovoltaic module can partially work with minor damage to the glass, but the size of the damage is correlated with the lower production of electricity.

1

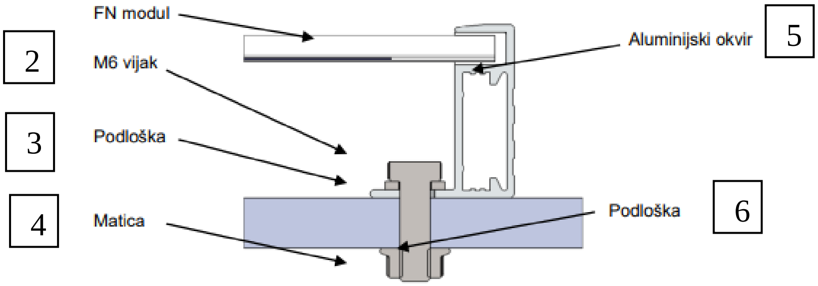


Image 20 Attaching the photovoltaic module support to the load-bearing structure (mechanical check during regular maintenance)

1 – FN module
2 – M6 screw
3 - washer
4 - nut
5 – aluminum frame
6 - washer

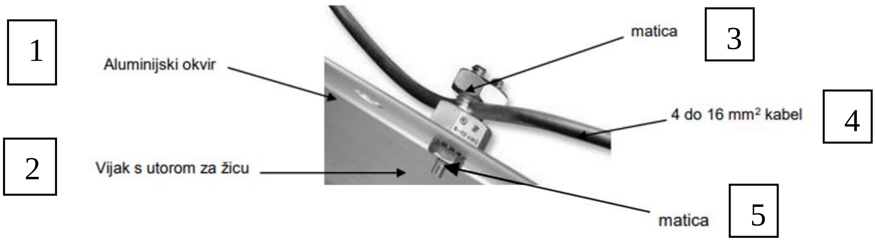


Image 21 Detail of attaching the grounding of the photovoltaic module to the load-bearing structure (mechanical check of connections during regular maintenance, and measurement of grounding resistance)

1 – aluminium frame
2 - wire slot screw
3 - washer
4 – 4 to 16mm^2 cable
5 – washer

All frames of photovoltaic modules and load-bearing structures for mounting must be properly grounded in accordance with regulations. Proper grounding is achieved by interconnecting all metal parts using a suitable grounding conductor with a grounding device or a suitable grounding electrode. The grounding conductor may be copper, copper alloy, or other material acceptable for use as an electrical conductor.

2.3 Maintenance documentation management

For each plant or system, it is necessary to maintain the prescribed operating documentation, which includes the storage and transmission of information about the system, the repairs performed and the method of repair. In maintenance, different documentation is used, which according to its content and form can be:

- Construction documentation (assembly or assembly drawings, workshop drawings of individual parts, schemes of electrical and other installations, kinematic schemes)
- Technological documentation (daily, weekly, monthly, seasonal and annual diagrams of electricity production, instructions on current maintenance, catalog of components, list of preventive inspections, technological procedure of preventive inspections, technological procedure of repair and replacement of parts)
- work documentation (defect report, work order, release form, work sheet, other documents characteristic of a particular plant).

The application of the maintenance strategy is of a managerial nature, and in addition to tasks related to business organization, there are also two key things from the aspect of a technical-technological nature. The first aspect is determining the optimal inspection interval of the entire system and equipment. In our case, that aspect is not a problem due to the nature of the photovoltaic system alone, which does not produce electricity 24/7. Another aspect is optimizing the content of preventive maintenance procedures. We have already mentioned that it is necessary to follow the manufacturer's instructions and recommendations, but manufacturers usually recommend more work with greater frequency, which usually increases the cost of maintenance itself. In view of the above, the orderly keeping of all records comes to the fore here, which can statistically contribute to the maintenance of regular operating conditions and the greatest possible usefulness for the owner of the photovoltaic system.

APPLICATION ACTIVITY

Process steps	Suggestions
Find online and analyse basic elements of maintenance documentation	
List and describe three situations in which the shading effect occurs	

CONTROL LIST

Evaluate yourself by putting an (X) mark in the "Yes" box for the skills you have gained from the behaviors listed below, and the skills you have not gained by placing a "No" box within the scope of this activity.

Evaluation Criteria	YES	NO
1. Can you explain what a shading effect is?		
2. Can you describe what regular periodic maintenance includes?		
3. Can you list and describe maintenance documentation used?		

EVALUATION

At the end of the evaluation, review your answers as “No”. If you do not think you are proficient, repeat the learning activity. If all your answers are “Yes”, proceed to “Assessment and Evaluation”.

MEASUREMENT AND EVALUATION

1. What is the shading of the photovoltaic cell?

2. How can the shadowing effect be prevented during the production of photovoltaic modules?

3. What are the key aspects of regular maintenance of photovoltaic modules?

4. Should operating documentation be maintained for a photovoltaic system as an energy plant and which one?

EVALUATION

Compare your answers with the answer key. Return to the activity and repeat the topics related to the questions that you gave wrong answers or hesitated to answer. If all your answers are correct, proceed to the next learning activity.

LEARNING ACTIVITY–3

PURPOSE

You will learn about the monitoring of the regular operating conditions of the installed photovoltaaic system, regular periodic maintenance and maintenance documentation.

RESEARCH

- Research about the main reasons for deteoration of photovoltage panels in your local area
- Share the findings with your colleagues.

3. MONITORING OF THE REGULAR OPERATING CONDITION OF THE INSTALLED PHOTOVOLTAIC SYSTEM

As we have already mentioned, regular maintenance is prescribed by the instructions of the manufacturer of the installed components of the photovoltaic system and it guarantees regular operating conditions and the planned or estimated production of electricity with regard to the installed power of the photovoltaic system and the number of hours of sunshine during certain months of the year (if the user adheres to the periodicity and scope of inspection, servicing, testing and control measurements). The normal operating state, i.e. the reduction of the amount of electricity production, can be affected by external unplanned disturbances, which should be monitored in

order to detect the current disturbance with the aim of eliminating it as quickly as possible and establishing the regular operating state (shadowing by throwing an object on the photovoltaic module, equipment damage due to weather accident, in short all unplanned disruptions caused by mechanical impact). As soon as an irregular operating condition is detected, the system maintenance operator should be called. Disturbances that cannot be influenced and are difficult to predict are correlated with meteorological changes, but on an annual basis they are not significant and should not be reacted to, if the meteorological forecast is followed.

When a new photovoltaic system is installed, for the location of the installation and nominal data of the system, an assessment and calculation of electricity production is carried out by a computer program that takes into account the statistical data of sunny days in the area of installation. These data (they may deviate within the permitted limits from the real ones due to the influence of unplanned meteorological conditions) become the input parameters of the system for data processing and monitoring of the operational status and the desired amount of electricity produced. Most often, they are also displayed graphically to make it easier for the user to analyze the data.

Of the series of data that can be collected and analyzed, the most important is to highlight:

- the influence of temperature change on the characteristics of the photovoltaic panel (current-voltage I-U, power-voltage P-U)

- the influence of changes in solar radiation on the characteristics of the photovoltaic panel (current-voltage, power-voltage)

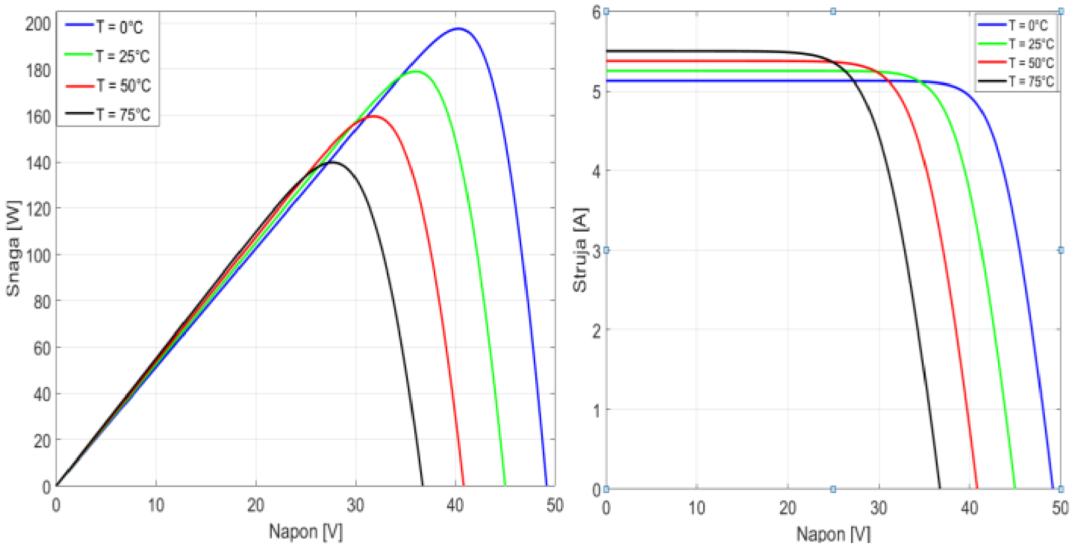


Image 22 P-U and I-U characteristics, the influence of temperature changes on the characteristics of the photovoltaic panel

Increasing the temperature of the photovoltaic panel increases the short-circuit current and reduces the no-load voltage. The decrease in voltage is much more sensitive than the increase in short-circuit current, therefore the total produced power is also significantly reduced. We can see that a significant increase in temperature affects the amount of power, and therefore the amount of electricity produced.

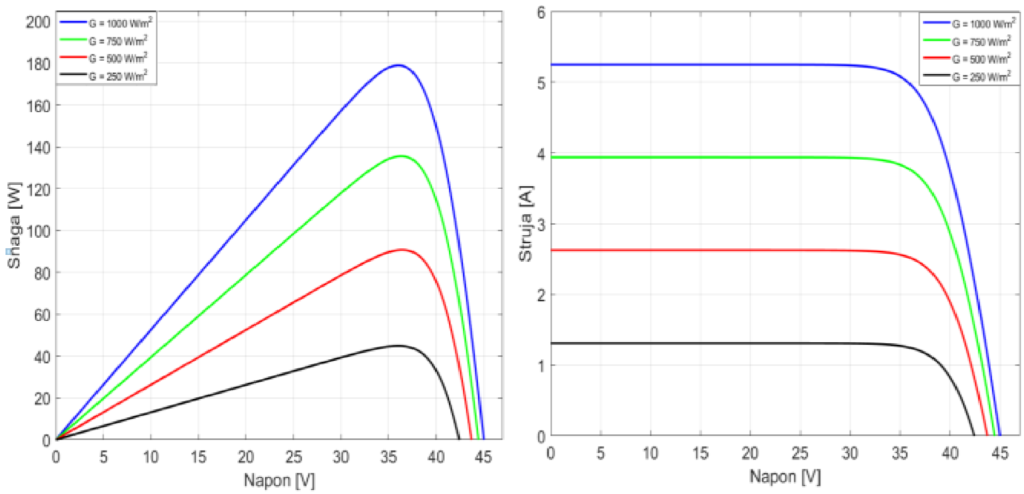


Image 23 P-U and I-U characteristics, influence of changing solar radiation on the characteristics of the photovoltaic panel

The reduction of solar radiation significantly reduces the short-circuit current as well as the power of the photovoltaic panel.

The point of maximum power changes depending on temperature and solar radiation. In order to produce maximum power, it is necessary to continuously maintain the panel at the operating point of maximum power, because then the system is the most productive, with the desired operating temperature (as low as possible) and the highest possible illumination. When modeling each system, two marginal modes of operation are always observed, i.e. idling and short circuit. The actual working area is determined between them.

When the nominal data of the installed photovoltaic system and its characteristics are known, during operation data from the actual plant can be collected by measuring key quantities, which are then compared using the method of comparison (depending on which quantities are measured, and which are calculated on the basis of the measured data - current, voltage, intensity solar radiation, temperature, amount of electricity produced) are compared with the expected values. While the comparison result is close to zero or within the permissible limits, the operating condition is considered normal. If the result significantly deviates from the expected, an irregular operating condition is alarmed and the operator on duty for the maintenance of the photovoltaic system is notified in order to return the operation to a regular condition in the shortest possible time with the aim of achieving the plan in the production of electricity. Sensors, i.e. measuring devices and equipment are most often connected by wire or wireless to the equipment and the computer that monitors, collects and processes data. The collected and processed information can then be sent wirelessly to the system user or to the on-duty power dispatcher who runs the facility if it is a larger system, to a cell phone, laptop or similar.

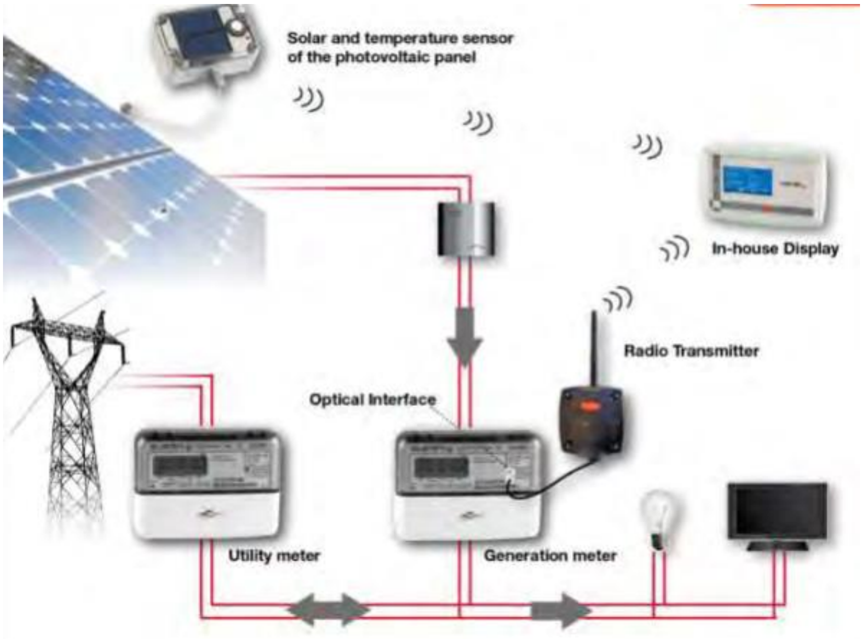


Image 24 Photovoltaic system equipped with sensors for measuring temperature and intensity of solar radiation

The key equipment for monitoring, collecting, processing and sending data from the photovoltaic system is a remote terminal intended for the purposes of remote measurement, protection, monitoring and management of the connection of the photovoltaic system to the distribution network. The basic element of the remote terminal is the control signal terminal (UST) or field terminal (TP). In addition to monitoring and control functions, it also provides functions of overcurrent protection (overload, short circuit, earth connection), undervoltage, overvoltage, underfrequency and overfrequency protection. A voltage relay can be used for the functions of voltage and frequency protection and islanding detection in smaller photovoltaic systems. From the measurement of electrical quantities that are important for monitoring, we can highlight the measurement of current, voltage, power, electric energy, power factor cosφ and voltage quality, which is controlled according to valid standards.

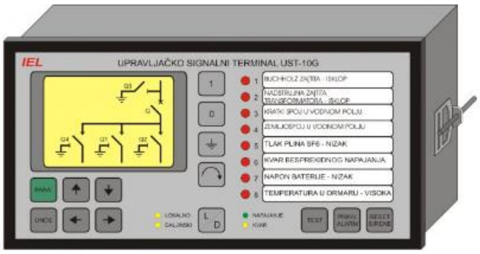


Image 25 Control signal terminal (one of various manufacturers and types)

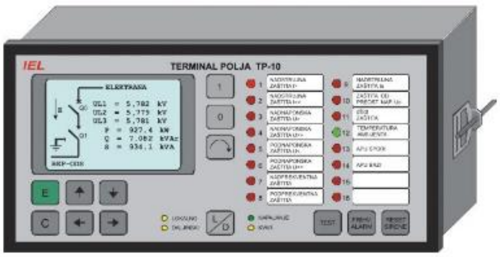


Image 26 Field terminal (one of various manufacturers and types)

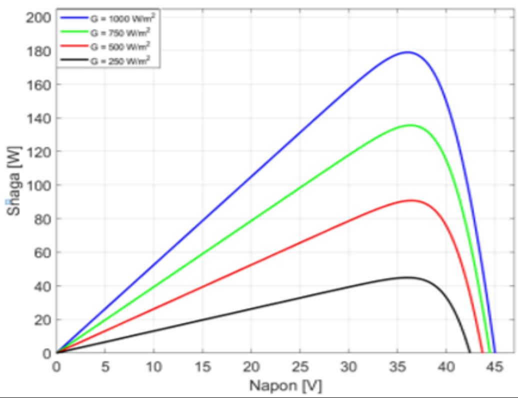
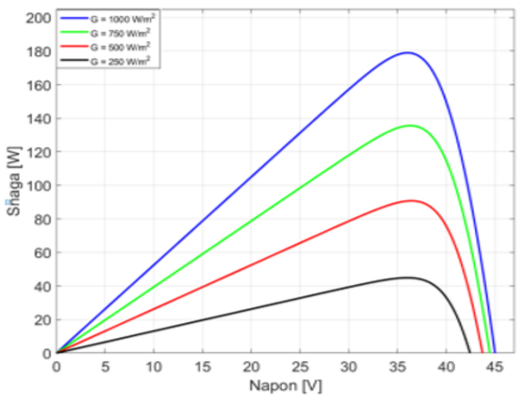
Image 27 Measuring terminal (one of various manufacturers and types)

A GPRS modem is used to establish a remote communication connection, which is the basic element of the system for connecting measurement, monitoring and control equipment to a remote monitoring and control dispatch center via a GPRS connection. The modem offers the possibility of connecting equipment at the plant level via a serial or Ethernet interface. An optical cable can also be used to establish a local communication connection at the plant level, which represents a certain security at the local level of monitoring and management in the event of a wireless connection interruption.

The connection of process control equipment in the remote control center with GPRS modems is realized through a concentrator, which connects the local network with system of our own VPN network, data transmission takes place according to the IEC 60870-5-104 protocol.

Image 28 GPRS modem (one of various manufacturers and types)

APPLICATION ACTIVITY

Process steps	Suggestions
On the P-U characteristic from the picture, read the maximum power value for a voltage of U=35V, amount of solar radiation G=750 W/m2. 	Analyze carefully at the graphic representation
On the P-U characteristic from the picture, read the amount of solar radiation G=750 W/m2. 	Analyze carefully at the graphic representation
What is the current of the photovoltaic module in that case	Check the calculation result on the I-U characteristic and circle the specified point.

CONTROL LIST

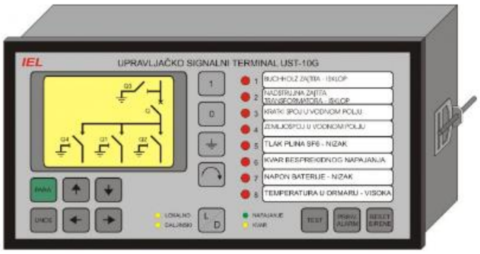
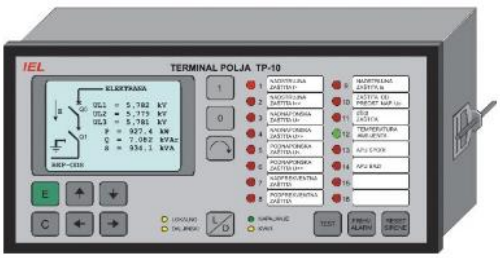
Evaluate yourself by putting an (X) mark in the "Yes" box for the skills you have gained from the behaviors listed below, and the skills you have not gained by placing a "No" box within the scope of this activity.

Evaluation Criteria	Yes	No
Can you name the most important Of the series of data that can be collected and analyzed as part of monitoring of the regular operating condition of the installed photovoltaic system		
Do you know what should be done as soon as an irregular operating condition is detected?		
Can you describe the function and purpose of the GPRS modem?		

EVALUATION

At the end of the evaluation, review your answers as “No”. If you do not think you are proficient, repeat the learning activity. If all your answers are “Yes”, proceed to “Assessment and Evaluation”.

Connect the image with the correct description

 1.	A) GPRS modem
 2.	B) Field terminal
 3.	C) Control signal terminal
 4.	D) Measuring terminal

1. ________
2. ________
3. ________
4. ________

EVALUATION

Compare your answers with the answer key. Return to the activity and repeat the topics related to the questions that you gave wrong answers or hesitated to answer. If all your answers are correct, proceed to the next learning activity.

MODULE EVALUATION

In the bracket next to the statement number, write the letter T if you think the statement is true, or the letter F if you think the statement is false.

1. ( ) The photovoltaic cell is the basic component in the architecture of the photovoltaic module but the construction, use and properties of the photovoltaic cell do not characterize the operation of the photovoltaic system.
2. ( ) The first silicon photovoltaic cell was discovered in 1941 by Russell Ohl, and its efficiency was above 17%, which significantly accelerated the further development of newer generations photovoltaic cells.
3. ( ) The key phenomenon for the production of electricity from the energy of the Sun is photovoltaic effect, and it can be characterized by the generation of voltage (or the corresponding electric currents) in a material after exposure to sunlight.
4. ( ) Produced electrical energy or current using the photovoltaic module is alternating and can be used for various purposes, i.e. powering various appliances.
5. ( ) The encapsulant serves as protection of the photovoltaic cell from external influences, but also as the connection of the upper layer, the cell and the lower layer of the photovoltaic module.
6. ( ) The principle of operation of a photovoltaic cell can best be explained by a substitute scheme on which the photovoltaic cell can be viewed as a current source to which it is light diode connected in parallel.

Answer the following questions:

1. How do the current and voltage of the series connection of photovoltaic cells behave?
2. How do the current and voltage of the parallel connection of photovoltaic cells behave?
3. Which combination of photovoltaic cells is used to make a photovoltaic module?
4. List at least 2 more elements of the photovoltaic system that, in addition to the photovoltaic modules, are essential for the functioning of the system.
5. When can the photovoltaic system also power AC consumers?
6. What is the basic task of the voltage regulator?

In the bracket next to the statement number, write the letter T if you think the statement is true, or the letter F if you think the statement is false.

1. ( ) Shading of a photovoltaic cell can be defined as the effect when one cell in serie is not exposed to the same intensity of solar radiation as the remaining cells in photovoltaic module.
2. ( ) Shading of one photovoltaic cell is a problem for the whole to the photovoltaic module because that particular cell will have a lower current than other non-shaded cells.
3. ( ) The key task of the protective bypass diode is to prevent the occurrence of destructive reverse voltage on the shaded cell, i.e. prevention of leakage in total produced electrical currents of the photovoltaic module through the shaded photovoltaic the cell.
4. ( ) As protection against shading of photovoltaic cells in the photovoltaic module, economically it is justified to install one bypass diode on each photovoltaic cell, which in the production of photovoltaic modules and practices.
5. ( ) In order to maintain the regular operating condition of the photovoltaic system for as long as possible while using the system itself (all parts and equipment work without errors and electricity is produced), for the purpose of saving on maintenance, it is not necessary maintain all installed components but only the most essential ones such as photovoltaic modules.
6. ( ) The practice and obligation of the photovoltaic system installer is to follow the instructions the manufacturer of the installed components of the photovoltaic system delivers to the user detailed instructions and recommendations for maintenance that are in accordance with the valid technical regulations and norms.

Answer the following questions:

1. What is the key aspect of maintaining photovoltaic modules in order to maintain the amount of electricity produced close to the nominal values with respect to the installed power?
2. Which season and which segment of the day in that period are most suitable for cleaning photovoltaic modules?
3. What should be done if an unforeseeable major weather event occurs (e.g. hail), which results in damage to the protective glass that protects the cells of the photovoltaic module?
4. How is proper grounding of all photovoltaic module frames and load-bearing constructions for assembly achieved?
5. What are the two key influences that can affect the characteristics of a photovoltaic system?

6. How does a significant increase in the temperature of a photovoltaic module manifest itself?

In the bracket next to the statement number, write the letter T if you think the statement is true, or the letter F if you think the statement is false

1. ( ) Key equipment for monitoring, collecting, processing and sending photovoltaic data system is a remote terminal intended for the needs of remote measurement, protection, monitoring and management of the connection of the photovoltaic system to the distribution network.
2. ( ) In addition to monitoring and control functions, the remote terminal also provides overcurrent functions undervoltage and overvoltage protection, but not underfrequency and overfrequency protection because the frequency of the system is always 50 Hz.
3. ( ) To realize a remote communication connection of the photovoltaic system and remote dispatch center for the purpose of monitoring and management via GPRS connection, GPRS is used modem, which is the basic element of the system for connecting equipment.
4. ( ) It is not necessary to keep a prescribed operating record for each plant or system documentation, because information about occasional repairs and methods repairs are not important because there are not many repairs.

EVALUATION

Compare your answers with the answer key. Return to the activity and repeat the topics related to the questions that you gave wrong answers or hesitated to answer. If all your answers are correct, proceed to the next performance test..

CONTROL LIST

Evaluate yourself by placing a check mark (X) in the Yes box for the skills you have gained from the behaviors listed below within the scope of this module, and No for the skills you have not gained.

Evaluation Criteria	Yes	No
1. Can you describe the photovoltaic cell and its purpose?		
2. Can you name parts and layers of a photovoltaic cell?		
3. Can you describe the functioning of a photovoltaic cell?		
4. Can you explain how a photovoltaic mdule is made?		
5. Can you list and explain the purpose of other important parts of the photovoltaic system?		
6. Can you describe what the shading effect is and give examples for it?		

7. Can you describe the elements of regular periodic maintenance?		
8. Can you explain the importance and basic types of maintenance documentation?		
9. Can you explain the importance of monıtorıng of the regular operatıng condıtıon of the ınstalled photovoltaıc system		
10. Can you name and describe different types of		

EVALUATION

At the end of the evaluation, review your answers as "No". If you do not think you are proficient, repeat the learning activity. If all your answers are "Yes", contact your teacher to move on to the next module.

ANSWER KEYS

ANSWER KEY TO LEARNING ACTIVITY-1

1	Shading of a photovoltaic cell can be defined as the effect when one cell in a row is not exposed to the same intensity of solar radiation as the remaining cells in the photovoltaic module.
2	It can be prevented by using a bypass diode. In this case, practically no electric current flows through the shaded photovoltaic cell, and there is no increased heating, so ultimately there is no risk of breakdown.
3	The key aspect of maintenance is periodic cleaning so that the amount of electricity produced is close to the nominal values with regard to the installed power of the installed photovoltaic modules.
4	It is necessary to keep operational documentation. Construction documentation, technological documentation and work documentation.

ANSWER KEY TO LEARNING ACTIVITY-2

1	An effect which occurs when one cell in a row is not exposed to the same intensity of solar radiation as the remaining cells in the photovoltaic module. This phenomenon can also occur when one photovoltaic module is partially or completely shaded, but the shading of only one photovoltaic cell represents a problem for the entire photovoltaic module because that specific cell will have a lower current than the other non-shaded cells, and therefore a whole row of cells will have less current. The above results in a limitation of the total current of the entire photovoltaic module
2	By improving production procedures and installing additional protective components
3	- visual inspection of photovoltaic modules - periodic cleaning of photovoltaic modules - cleaning of filters on converter fans, charge regulators and distribution cabinets and cabinets with other equipment - tightening of electrical connections and checking of electrical connections - inspection of the DC distribution box - measurement of grounding resistance on all connections

	- tightening of connections and checking of the mechanical connection between the equipment carrier and the frame of the photovoltaic modules - inspection of all equipment and all joints from the aspect of corrosion - inspection and renewal of various inscriptions - tests of the complete electrical installation and replacement of consumable and damaged parts of the installation - tabular collection and graphical presentation of key measured electrical quantities and parameters
4	For each plant or system, it is necessary to maintain the prescribed operating documentation, which includes the storage and transmission of information about the system, the repairs performed and the method of repair: -Construction documentation -Technological documentation

ANSWER KEY TO LEARNING ACTIVITY-3

1	C
2	D
3	A
4	B

ANSWER KEY TO MODULE EVALUATION

1.

1.	N
2.	N
3.	T
4.	N
5.	T
6.	T

2.

1.	**The current is the same throughout the whole series, the total voltage of the series is equal to the sum of the voltages of individual cells**
2.	**The voltage is the same on all cells, the total current is equal to the sum of the**

	currents through individual cells
3.	**Mixed (combination of serial and parallel)**
4.	**Accumulator batteries, DC/AC converter, charging regulator**
5.	**When the converter is connected to it**
6.	**To control the charging of the battery, making sure that it is not overcharged or completely discharged**

3.

1.	T
2.	T
3.	T
4.	N
5.	N
6.	T

4.

1.	periodic cleaning
2.	spring, morning
3.	it is necessary to replace the entire photovoltaic module
4.	by interconnecting all metal parts using a suitable grounding conductor with a grounding device or a suitable grounding electrode
5.	temperature change and solar radiation change
6.	the power of the photovoltaic module decreases, and thus the amount of electricity produced

5.

1.	T
2.	N
3.	T
4.	N

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