



Manual

for installation and maintenance
solar photovoltaic systems

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1. INTRODUCTION

1.1. Purpose of the manual

This manual was written as part of the Renewable Energy Services in Education and Training RESET project, which is implemented by the Education Reform Initiative of South Eastern Europe (ERI SEE) Secretariat in cooperation with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), and is funded by the German Federal Ministry for Economic Cooperation and Development (BMZ). The manual is designed as a practical guide that enables students/students to acquire the necessary knowledge and skills for the installation, use and maintenance of solar photovoltaic systems. Through clearly explained theoretical foundations, users will understand the key principles of operation of solar photovoltaic systems, their components and the way they function, which is the basis for practical application.

The manual is primarily intended for high school students and participants of adult education programs and teachers in the field of renewable energy sources.

The manual can be used by relevant ministries and educational agencies, companies involved in practical education, training centers, private institutions working in the field of renewable energy sources, practical education instructors, and other interested parties. The material was agreed among experts in the field of renewable sources of electricity and education from six economies: Albania, Bosnia and Herzegovina, Montenegro, Kosovo*¹, North Macedonia and Serbia, involved in the implementation of the project.

The global energy transition towards sustainable energy sources has led to the rapid development of solar photovoltaic systems (SFNS), which are becoming the dominant source of renewable electricity. Thanks to the continuous reduction of technology costs, improvements in efficiency and the growing demand for energy independence, solar photovoltaic systems are today one of the most cost-effective solutions for electricity generation

With the transition to renewable energy sources a global priority, qualifications in the field of solar energy, especially in the photovoltaic sector, are becoming extremely sought after and valued. This industry is experiencing continuous growth, and the demand for experts is constantly increasing. According to the International Renewable Energy Agency (IRENA), the global solar energy industry employs more than 10 million people, with that number estimated to grow to over 14 million by 2030 and more than 24 million by 2050. Of these, the solar PV system sector makes up the largest and fastest growing part of the solar energy industry job market.

The aim of this manual is to train users to work with photovoltaic systems and enable them to:

- understand the key principles of operation of solar photovoltaic systems, including the mode of operation, components and connection of the system,
- install solar photovoltaic systems in accordance with technical and safety standards, thus ensuring safe and reliable operation,
- maintain and optimize the operation of solar photovoltaic systems, extending their service life and increasing efficiency,
- they recognize and eliminate possible malfunctions in order to ensure long-term and smooth operation of the system.

¹*This name is without prejudicing the status and is in accordance with the United Nations Security Council Resolution 1244/1999 and the Opinion of the International Court of Justice on the Declaration of Independence of Kosovo.

The manual combines theoretical knowledge and practical guidelines, providing users with security and confidence in working with solar technologies. Clearly structured material enables the acquisition of professional competences necessary for the installation, maintenance and improvement of solar photovoltaic systems.



Display of solar photovoltaic system

Finally, the handbook represents the basis for acquiring qualifications that are highly valued in the labor market.

Given the constant growth of the solar energy sector, the acquired skills enable professional development, opening up opportunities for employment and further training in one of today's most promising industries.

1.2. The importance and application of solar photovoltaic systems

Solar photovoltaic systems play a key role in the global transition to sustainable energy sources. The increasing demand for electricity, the instability of fossil fuel prices and the need to reduce harmful gas emissions make solar photovoltaic systems one of the most promising solutions for the future. Their application contributes to reducing carbon dioxide emissions in the power sector, increasing energy independence and stabilizing electricity prices.

According to data from the International Agency for Renewable Energy Sources (IRENA), at the end of 2023 the global installed capacity of solar PV systems reached an impressive 1,419 GW, with an annual growth of 32.2% during the same year. The growth trend for the period 2014 - 2023 is shown in the graphic. The continuous growth of the installed capacity of solar photovoltaic systems is clearly visible, with an accelerated increase in recent years.



By 2030, solar photovoltaic systems are expected to become the dominant source of electricity in many countries, thanks to decreasing technology costs, improved efficiency and growing awareness of the environmental and economic benefits of this form of electricity generation.

The key advantages of photovoltaic systems are:

- **inexhaustible potential**- Solar energy is an unlimited resource, and its daily capacity exceeds global energy needs many times over,
- **environmental sustainability**- solar photovoltaic systems produce electricity without the emission of CO₂ and other pollutants, which directly contribute to environmental protection and the fight against climate change,
- **decentralization of energy production**- solar photovoltaic systems enable the production of electricity at the point of consumption, reducing dependence on centralized power systems and increasing energy security,
- **economic viability**—thanks to the reduction of installation costs and the availability of financial incentives, solar photovoltaic systems represent one of the most cost-effective solutions for electricity production,
- **long life and low maintenance costs**- photovoltaic panels have a service life of more than 25 years, and with proper maintenance, their efficiency remains high for a long period of time.

Solar photovoltaic systems are widely used in various sectors, from small home systems to large solar photovoltaic power plants. The key areas of application are:

- Households and residential buildings - solar photovoltaic systems are used in individual houses and collective residential buildings in order to reduce energy costs, increase energy independence and the possibility of connecting to the grid with the delivery of excess electricity.
- Commercial, public and administrative facilities - solar photovoltaic systems are used in business and commercial buildings, educational and health institutions, sports facilities, public administrative buildings and administrative centers. These systems enable optimization of energy consumption, reduction of operating costs and increase of energy efficiency, and at the same time contribute to reliable supply of electricity.
- Industrial and agricultural sector - solar photovoltaic systems enable energy-efficient powering of production plants, warehouses and cooling systems in industry, while in agriculture they are used to power irrigation systems, farms and other energy-demanding processes. By using solar energy, electricity costs are reduced and it provides a more stable power supply in areas with limited access to the grid.
- Tourist and hospitality facilities - hotels, resorts, camps and wellness centers are increasingly using solar systems to reduce operating costs, increase business sustainability and ensure reliable electricity supply in tourist facilities, especially in remote and seasonal destinations.
- Traffic and infrastructure - solar photovoltaic systems are used to power charging stations for electric vehicles, lighting of parking areas and canopies, airports, railway and bus stations, bridges and tunnels. The integration of solar systems into the transport infrastructure contributes to the reduction of energy consumption from conventional sources and enables greater energy autonomy.
- Telecommunications and remote locations - solar photovoltaic systems enable reliable powering of base stations, repeaters and other telecommunications facilities, especially in rural and hard-to-reach areas where a stable power grid is not available. These systems enable uninterrupted functioning of telecommunication systems while reducing operation and maintenance costs.
- Large solar power plants - Photovoltaic parks are becoming an increasingly important part of power systems, enabling the production of electricity in large quantities and its distribution to consumers. The development of large solar power plants contributes to increasing the capacity of renewable energy sources in power grids and reducing reliance on fossil fuels.
- Smart grids and energy storage - solar photovoltaic systems play a key role in the development of smart power grids, enabling decentralized energy production and the integration of renewable sources into the grid system. Through advanced management systems and digital technologies, solar photovoltaic systems enable dynamic adjustment of consumption and production in real time, improve the efficiency of the network and reduce the load on traditional power sources. By integrating with battery systems, smart grids use solar PV systems to balance loads and increase system stability, thereby reducing energy losses and optimizing electricity supply.

With constant technological progress and ever-lower costs, solar photovoltaic systems are becoming a key element in the global energy transition. Their wide application and economic advantages make them one of the most promising sources of electricity in the future. It is expected that the further development of the market and new technologies will further increase the efficiency and availability of photovoltaic systems, enabling their even wider application in all sectors of the economy and society.

1.3. Manual structure

The Construction and Maintenance Manual for Solar Photovoltaic Systems is designed as a comprehensive guide covering all key aspects of installation, operation and maintenance. The presented material enables users to acquire basic theoretical and practical knowledge, equipping them for quality involvement in the work process. The manual is primarily intended for practical training, with the necessary theoretical foundations for the application of acquired knowledge in practice.

The Manual consists of an Introduction and six Chapters dedicated to the elaboration of the issues that are the subject of the Manual. At the end, the conclusion and recommendations, signs and abbreviations as well as literature and useful sources are given.

In the Introduction, the purpose and goals of the handbook are presented and the structure of the handbook is given, which shows the layout and subject matter of the chapters covered. At the end, the importance of solar photovoltaic systems is shown, with their most diverse application being indicated.

Chapter 2, Renewable energy sources, provides basic information about different forms of renewable energy sources.

Chapter 3, Safety at work and environmental protection, addresses the key safety measures and standards that must be followed during the installation and maintenance of solar photovoltaic systems, in order to ensure the protection of workers and the preservation of the environment.

Chapter 4, Solar Energy, from a theoretical aspect, deals with the types of solar photovoltaic systems, their working principle and elements.

Chapter 5, Construction of Solar Photovoltaic Systems, is a key chapter of the manual that elaborates in detail the procedures and methods for the practical realization of the construction of solar photovoltaic systems.

Chapter 6, Performing electrical installations of solar photovoltaic systems, deals with the practical aspects of all types of installations within solar photovoltaic systems, installation and maintenance of solar photovoltaic systems.

Chapter 7, Operation and Maintenance of Solar Photovoltaic Systems, gives a description of activities during operation and all types of maintenance of solar photovoltaic systems

Conclusion and recommendations, sublimates key conclusions based on previous information and provides guidelines for further work in this area.

At the end of the Handbook there is an overview of literature and useful sources with a list of used sources and additional materials that may be useful for a deeper understanding of the thematic areas of solar photovoltaic systems.

2. RENEWABLE ENERGY SOURCES

Energy is all around us. It moves all living beings. Everything in the environment is based on the use of energy. The bottom line is that energy is the ability to do some work. Energy depends on the conditions in which it is found. It determines all states in nature: motion and rest, thermal states, chemical processes, electromagnetic processes, propagation of light, bonds in atoms, etc.

The general definition of energy is: energy is the ability to do work. It is known that energy cannot be lost, but only transferred from one form to another (chemical to thermal, thermal to mechanical...).

Nowadays, energy has become a key element in the development of society. The development of the economy is directly conditioned by the use of various forms of energy.

Intensive use of existing and finding new sources of energy has a decisive influence on the speed of development and growth of the economy.

The basic characteristics of energy are:

- cannot come from nothing
- it is indestructible
- the ability to transform from one form to another or move from one body to another

In nature, energy appears in different forms:

- **Potential energy**– energy stored due to the position of the body in relation to other objects (eg water in the reservoir, spring under tension).
- **Kinetic energy**– energy of body movement. Everything that moves has kinetic energy (eg wind, moving car).
- **Chemical energy**– energy stored in chemical bonds between atoms (eg energy from food, fuel, batteries).
- **Electricity**– energy that arises due to the movement or distribution of electrical charges.
- **Thermal energy**- the energy that a body possesses due to its temperature, that is, the random movement and collision of its particles (eg heated metal, boiling water, air heated by solar radiation).
- **Nuclear energy**– energy released by changes in atomic nuclei, either by the splitting (fission) of heavy nuclei or by the fusion (fusion) of light nuclei (eg energy from nuclear power plants, reactions in the Sun).
- **Electromagnetic energy**- radiation energy that includes light, radio waves and other forms of electromagnetic radiation.

Throughout history, there have been conflicts over access to certain energy sources. The fact that industrial revolutions differed in the discoveries and application of new sources of energy speaks of the importance of energy. There is currently a revolution underway that emphasizes renewable sources and the development of energy-saving, "green" technologies.

Modern civilization is impossible to imagine without electricity. Electricity is used for lighting, heating, starting various machines, powering communication devices. Practically, there is no segment of human activity where electricity is not used.

The use of electricity has great advantages over other forms of energy:

- Sources of electricity may be far from the place of use of electricity;
- Electrical energy is transmitted with relatively low losses;
- By using the electricity transmission system, it is available to a large number of users;
- Electrical energy is simply transformed into other forms of energy (thermal, light, mechanical...).

In the professional literature, there are other divisions of energy, which depend on numerous criteria for division. Different forms of energy are divided, that is, grouped in several ways. The most common divisions with division criteria are shown in the table.

DIVISION	DIVISION CRITERIA
Accumulated and transitional	State and duration of existence
Primary, transformed and useful	Manifest form, form, i.e. possibility of use
Conventional and unconventional	Level of use, i.e. technical and economic profitability
Renewable and non-renewable	Natural renewable energy

Considering the natural renewability (time possibility of their depletion), primary energy can be divided into renewable energy and non-renewable energy.



The term non-renewable energy sources includes: fossil fuels, coal, oil and oil derivatives, natural gas, mineral deposits such as oil shale, as well as fission (nuclear) fuels.

The problem with non-renewable energy sources is their limited quantities and limited distribution. Fossil fuel supplies are limited and rapidly depleting.

Another problem is pollution of the human environment. The burning of fossil fuels, especially those based on oil and coal, is the most likely cause of global warming. Climate change is one of the most serious threats to the Earth's ecological system.

The application of nuclear energy represents a conditionally clean technology, but in the event of an accident, extremely large pollution can occur with enormous consequences for humans and the environment. Also, the disposal of radioactive waste is a big problem.

Renewable energy sources are resources that are renewed naturally and are not exhausted by their use. The name "renewable energy sources" comes from the fact that their reserves are continuously or cyclically renewed in nature, and the amount of energy used does not exceed the rate of its natural renewal.

The main types of renewable energy sources are:

- Solar radiation - the primary source of energy for almost all processes on Earth. Solar energy comes in the form of electromagnetic radiation, part of which reaches the surface of the planet, while the rest is absorbed or reflected in the atmosphere. The intensity of solar radiation depends on the geographical location, time of year and atmospheric conditions.
- Wind energy - arises as a result of uneven heating of the Earth's surface and the rotation of the planet, which creates pressure differences and leads to the movement of air masses. Wind speed and direction depend on geographical features and climatic conditions.
- Water power (hydropower) – water energy originating from the hydrological cycle, where solar radiation causes evaporation, condensation and precipitation, enabling the continuous flow of rivers and the renewal of water resources. The strength of the water flows depends on the altitude, the slope of the terrain and the amount of precipitation.
- Biomass – organic matter of plant and animal origin, which stores solar energy through photosynthesis. It covers a wide range of materials, including wood, agricultural residues, organic waste and specially grown energy plants.

- Geothermal energy – energy created by the decay of radioactive elements in the interior of the Earth and the heat left over from the period of its formation. Heat is transported through the Earth's crust to the surface, with sources most pronounced in volcanic and tectonically active areas.
- Sea and Ocean Energy - Includes tidal energy, energy from sea waves and temperature differences in the oceans. Tides are created under the influence of the gravitational force of the Moon and the Sun, while sea waves are created by the action of the wind on the surface of the water. The thermal energy of the sea comes from the temperature differences between the surface and deep layers of the ocean.

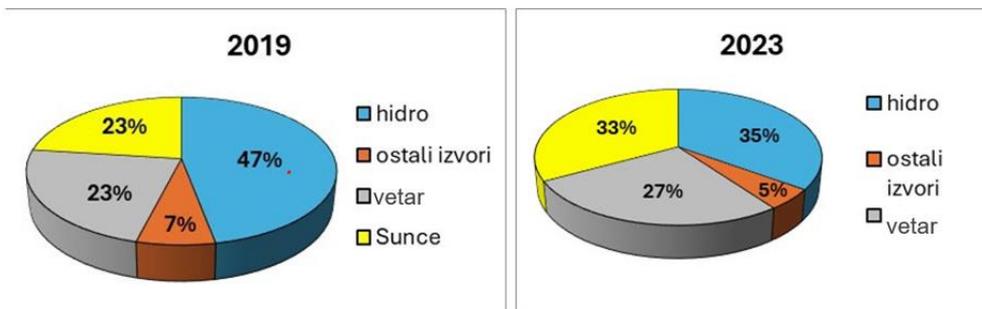
One of the main reasons for the accelerated development of renewable energy sources is their significantly lower negative impact on the environment compared to conventional sources.



Renewable energy sources

Renewable sources are recording accelerated growth in the power sector. According to the International Renewable Energy Agency (IRENA), the global capacity of renewable energy sources has reached about 3,064 GW by the end of 2023.

In 2024, investments in clean energy are almost double those in fossil fuels. Total investments in energy exceeded three trillion dollars, of which about two trillion were directed to clean technologies such as renewable energy sources, electric vehicles and nuclear energy.



Distribution of installed capacities of renewable energy sources

In the following, we will briefly refer to renewable energy sources, while a detailed analysis of wind - the key energy source for the technology of converting the kinetic energy of the wind into electricity - will be covered in the following chapters of this manual.

2.1 Solar energy

Solar power plants convert the sun's energy into electricity.

During one year, the solar energy that reaches the Earth is 20,000 times greater than the energy necessary to meet the needs of the entire population of the Earth.

In just three days, solar energy equivalent to the energy produced by all fossil sources and reserves on Earth reaches the surface of the Earth.

When passing through the atmosphere, part of the energy is consumed in complex processes, and part is reflected and re-emitted into space. That part amounts to about 1/3 of the energy that reached the edge of the atmosphere, so the energy flow to the Earth's surface is an average of 920 W/m².

There are two types of solar power plants namely:

- thermal solar power plants
- photovoltaic solar power plants

In thermal solar power plants, mirror systems direct the Sun's rays towards the tank containing the liquid that is being heated. The heated liquid goes into the heat exchanger, transferring the heat to the water or steam. The further process is identical to that in classic thermal power plants.

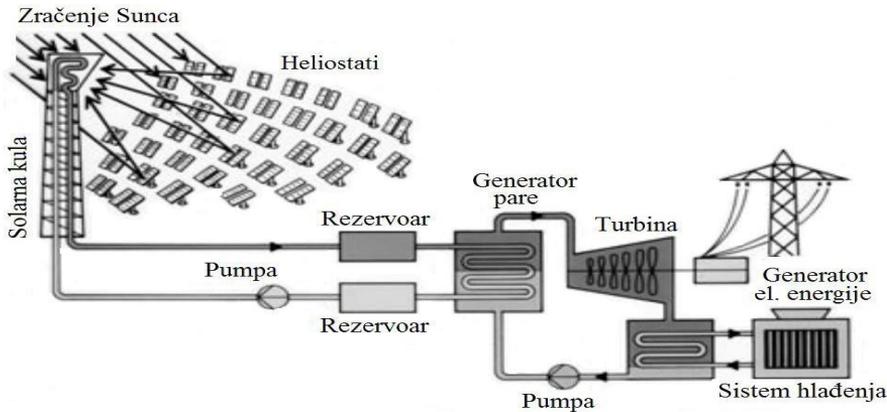


Solar power plant PS10 in Spain

The ability to store heat using thermal media (such as molten salt) is a key advantage of these systems, as it enables continuous production of electricity even in periods when direct solar radiation is not available.

Solar thermal power plants with a solar tower use a heliostat field.

Heliostatis a device that has an ordinary mirror that rotates so that throughout the day, it reflects the sunlight towards a specific target tower (helios derived from the Greek word for the sun, and stat derived from the English word stationary-non-moving).



Principle of operation of a solar thermal power plant with heliostats

Solar energy collectors (parabolic collectors) consist of parabolic mirrors that receive the heat energy of the Sun and refocus it on a tube located at the focal point of the parabola. There is a liquid in the tube, for example synthetic oil as a heat medium with an operating temperature of 400°C. The heated fluid circulates to the heat exchanger, where it transfers the heat to the water and turns it into saturated steam. The steam then drives a turbine connected to a generator that produces electricity.



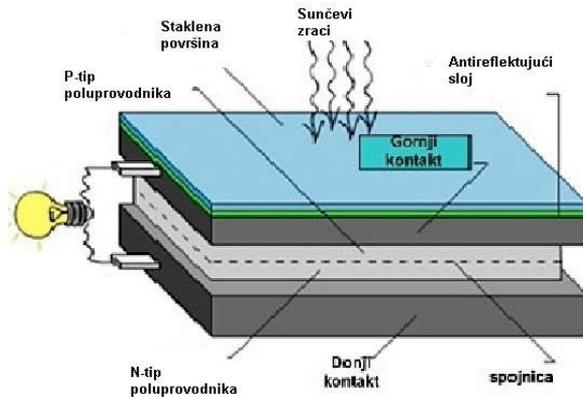
Parabolic collectors

Another type of solar power plant converts the sun's energy directly into electricity using semiconductor photovoltaic cells. The efficiency of these semiconductor converters is relatively small, so large areas of solar panels are needed to obtain a certain amount of electricity. The advantage of this plant is a long service life and easy handling, with minimal maintenance requirements, because the plant has no moving parts.

The downside of all solar power plants is that there is no continuity in energy production because at night, when there is no Sun, there is no electricity production.

When light particles (photons) fall on a silicon atom, electrons are ejected from the crystal lattice. Due to this, an excess of negative charge is created on one side of the semiconductor connection, and current flows on the other side of the positive charge.

Solar cells also have two metal grids, i.e. two electrical contacts. One is below the semiconductor material and the other is above. The upper network or contact collects electrons from the semiconductor and leads them to the external consumer. The electrical circuit is closed with the lower contact layer.



Photovoltaic cell array

2.2 Water power (hydropower)

The types of usable hydropower potential are reservoirs, watercourses of rivers and streams, tides, sea waves, underwater currents and the like, and the basic hydropower parameters are flow, drop height, water density, etc. Instruments for measuring hydroenergetic parameters are flow meter for flow, altimeters or laser altimeters for drop height and hydrometers or densitometers for water density.

Hydropower plants (HE) belong to facilities that use water as a renewable source of energy. They played a dominant role in the initial stage of the development of electrification in many countries.

Each hydroelectric power plant is designed separately, depending on:

- water quantities;
- meteorological conditions in the wider basin area;
- height of water fall;
- specifics of the terrain (geological conditions prevailing on the watercourse); as well as
- specific requirements (navigability of the river, irrigation, biological requirements for the watercourse...).

Considering the way water is used, there are the following types of hydropower plants:

- Flow-through HPPs in which water is used as it touches;
- Accumulation HPPs in which part of the water is accumulated, so that it can be used when the need arises.

Special types of hydropower plants are:

- Pumped storage or reversible hydropower plants
- Hydroelectric plants that use the energy of the sea (tides, wave energy, sea currents...).

When designing a HPP, not only energy use of water should be taken into account, but also the requirements of agriculture (irrigation, drainage), water supply, navigation...

The choice of HPP type depends on a number of factors that influence the rational and economical construction of the plant, so it is impossible to specify rigid rules for choosing the type of plant.

The principle of operation of a hydroelectric power plant:

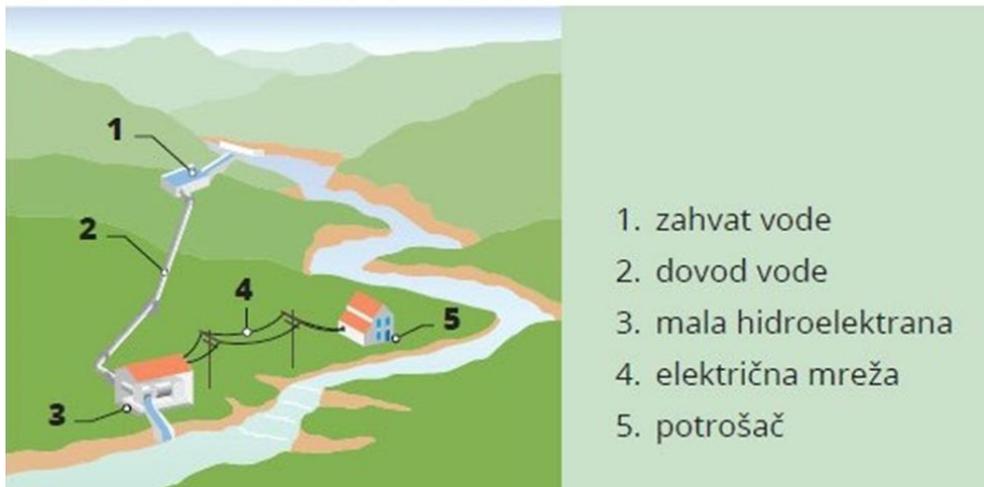
- Water from a river or lake comes through a system of canals or pipes to water turbines;
- Water turbines turn under the influence of water, and as the rotors of the turbine and the generator are mechanically connected, the rotor of the generator turns and electricity is produced;
- The produced electricity is delivered to consumers through a system of transformers and transmission lines.

Small hydropower plants (mHP) are hydropower systems of smaller power, mostly built on smaller watercourses, that is, on smaller rivers, streams, various canals, and even irrigation systems.

In them, the energy of these water streams is converted into useful energy, which ensures a relatively clean and reliable production of electricity.

Small hydropower plants are predominantly run-of-river power plants and therefore do not require significant earthworks and construction works and investments that are usually required by the construction of large dams and reservoirs. The main difference between large and small hydropower plants is in the installed power, with the power limit that divides these hydropower plants different from country to country. Regardless of the large deviations in certain countries, from the point of view of the upper limit of installed power (MHP from 1.5 MW to 30 MW), recently, the value of the total installed capacity of up to 10 MW (accepted in the EU - ESHA) is most often accepted as a standard.

A small hydro plant is not simply a scaled-down version of a large hydro plant. In order to satisfy the basic requirements that are put before it, specific equipment and devices are needed for its construction, primarily in terms of simplicity, the amount of investment and costs of operation and maintenance, the way of operation, maximum reliability and safety, as well as simple use and maintenance by persons who are not specialized for it. The principle scheme of a small hydroelectric power plant is shown in the picture.



The most common layout of the basic elements of a small hydroelectric power plant

1. zahvat vode
2. dovod vode
3. mala hidroelektrana
4. električna mreža
5. potrošač

2.3 Sea and ocean energy

Sea and ocean energy is a renewable source of energy that uses natural phenomena in the seas and oceans, such as tides, waves, sea currents and temperature differences between surface and deeper layers of water. These phenomena can be used to produce electricity using different technologies.

Sea and ocean energy utilization systems do not emit carbon dioxide during operation, which contributes to reducing pollution and mitigating climate change. Also, they can contribute to energy stability because they use natural processes that are constant and predictable, reducing dependence on fossil fuels. However, their wide application depends on the further development of technologies, reduction of construction and maintenance costs, and compliance with environmental protection regulations.

Seas and oceans contain huge amounts of energy that can be used to generate electricity. The main sources of this energy are: tidal energy, wave energy, ocean thermal energy (OTEC) and ocean current energy.

These sources differ in the mechanism of their formation and the technologies used for their exploitation.

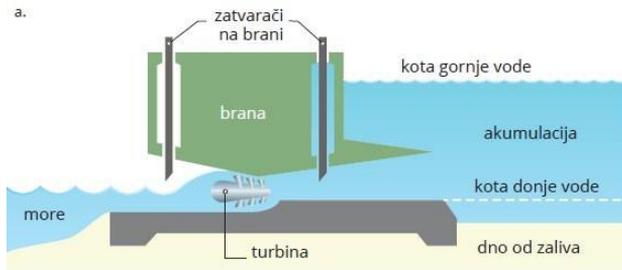
Power plants that use tidal energy (renewable energy source) to drive turbines are a special type of storage hydropower plants. Tides and ebbs (sea tides) occur under the influence of the Sun and the Moon on the water in the seas and oceans. Sea tides are the periodic rising (tides) and lowering (low tides) of the sea and ocean surface and the movement of large water masses caused by the gravitational force exerted by the Moon and the Sun on the water masses, in combination with the rotation of the Earth.

Because changes in tides cause fluid movement, i.e. of water mass (kinetic energy), it is possible to convert that energy into electricity using special power plants. These types of power plants are not common because their construction, maintenance and profitability currently require significant financial resources. Today, only highly developed and rich countries have developed several such power plants, although many countries have natural potential for their use.

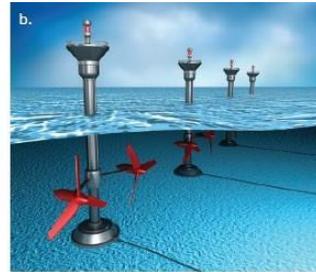
The technology used for the conversion is very similar to the technology used in conventional hydroelectric power plants. However, tidal power plants can never operate continuously, but only until the next tide occurs.

Today, there are mainly two possibilities of using tidal energy:

- by means of tidal dams (picture a) or
- using tidal currents (picture b).



a) Tidal dam



b) Tidal currents

With tidal dams, the dam serves to prevent water from entering the pool/reservoir and to collect and gradually release the water when the tide begins to recede. Electricity is produced by opening the shutter/lock and gradually allowing water to flow through the opening on the turbine. Energy can be produced in one or both directions.

Tidal currents are large amounts of water that flow through the oceans due to changes in the position of the water - the movement of tides. This effect is most often observed in shallow areas where there are natural constrictions where the water speed increases significantly. The technology for using this energy is similar to the technology for converting wind energy, with some important differences. Unfortunately, this technology is still in its infancy, it is quite expensive and is only available to developed countries.

The areas of the east coast of Canada as well as the west coast of France and Great Britain are areas of pronounced tides. The largest measured difference between high and low tides of 16 meters was measured in Canada.



Example of height difference between high and low tides



La Rance Power Plant

The most famous and at the same time the largest such power plant was built in 1966 in France. It is located at the confluence of the La Rance river with the sea. In that area, the average high tide is 8m, and the maximum is 13.5m. The power of the power plant is 240MW.

2.4 Energy of ocean currents

The power plant generates electricity using sea currents - it works like a kind of underwater windmill. Such a test plant has already been installed off the south-west coast of England. To be able to use the currents in both directions, the rotor blades can be rotated by 180°.

The power plant consists of three main components: a 50-meter high tower that serves as a pillar on which the plant is mounted, i.e. the "drive room" which contains the control system of the connection to the electricity transmission network, the hydraulic system for raising and lowering the plant, as well as the rotor which is attached to the tower and which forms the heart of the plant.



Strangford Lough Power Station

2.5 Wave energy

Sea wave power plants are those that use wave energy (renewable energy source) to produce electricity. The main cause of the generation of wave energy is the action of the wind (a consequence of the action of the Sun) on the surface of the sea and ocean. Since wave power differs from daily tides and constant circular ocean currents, a favorable location must be selected for its use where waves are sufficiently frequent and of sufficient strength.

Wave power is defined per unit area normal to the direction of wave movement. It can be as much as 10kW/m², but it can also be around zero. For example, for the North Atlantic area, in the open sea between Scotland and Iceland, 50 percent of the time, the wave power is 3.9kW/m² or higher.

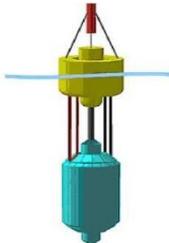
Wave energy can be harnessed through surface and underwater devices, as well as reservoirs.

Surface devices (floating systems)- These devices are moved up and down by the waves on the surface of the ocean and thus transfer energy to them.

Floating float

Connecting rods

Submerged cylinder



Power transmission



Oscillating Water Column (OWC) -Structures that use water oscillations in chambers to create pressure that drives turbines. The air in the chambers is pushed by the waves and thus drives the generator. Example: Limpet in Scotland.



Wave serpentine devices (surface attenuators)– Long floating structures that bend under the influence of waves and generate electricity. These technologies mimic the way a snake moves in water and use mechanical connections to convert energy. Example: Pelamis Wave Energy Converter technology (Pelamis WEC).



Pelamis WEC

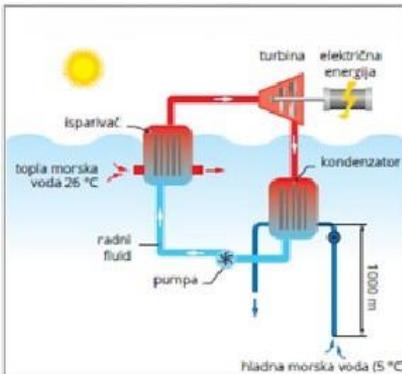
Underwater devices– They range from balloon objects attached to the bottom of the ocean to long tubes that stretch a great length. When waves cause them to oscillate, they drive a turbine and generate electricity.



Underwater devices

2.6 Ocean Thermal Energy Conversion (OTEC - Ocean Thermal Energy Conversion)

OTEC uses the temperature difference between the warm surface waters and the cold deep waters of the tropical oceans to generate electricity. A larger temperature difference enables more efficient energy conversion. Near the equator, the temperature difference between surface and deep water can reach up to 25 °C, which makes this energy source a significant potential. OTEC power plants can operate 24 hours a day throughout the year, using the thermal energy that the tropical seas constantly accumulate.



Schematic diagram of the OTEC system



Floating OTEC plant

There are three basic technologies in the OTEC system:

- **Closed cycle**– Use a working fluid with a low boiling point, such as ammonia. Warm seawater passes through a heat exchanger and transfers energy to the working fluid, which evaporates. The resulting gas drives a turbine connected to an electricity generator. After that, the gas is cooled and condensed with the help of cold deep water, returning to the liquid state and closing the cycle.
- **Open cycle**- Seawater from the warm surface layers is introduced into a chamber with reduced pressure, where part of the water evaporates due to the low pressure. The resulting steam drives the turbine, after which it is cooled by contact with cold deep water and condenses again into a liquid.
- **Hybrid cycle** –It combines elements of closed and open cycle to increase efficiency. Hot water evaporates the working fluid as in a closed cycle, while at the same time, part of the water in an open cycle evaporates directly under low pressure

2.7 Geothermal energy

Geothermal energy is a renewable source of energy that originates from the interior of the Earth and arises as a result of the high temperature of its deep layers, which ranges between 4000°C and 7000°C. This heat is the result of the natural decay of radioactive elements such as uranium, thorium and potassium, as well as the remains of thermal energy generated during the formation of the planet.

The temperature of the Earth's interior increases with depth - at 80 to 100 km, the temperature of the rocks reaches 600°C to 1200°C. This heat constantly flows towards the surface and can be used for electricity generation, heating of buildings and industrial processes.

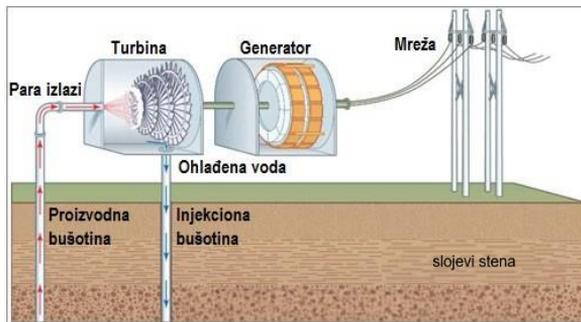
Geothermal energy has a wide range of applications, from direct heating of space and industrial plants to the production of electricity in geothermal power plants.

Geothermal power plants

Geothermal power plants they use thermal energy from the Earth's interior to produce electricity. Steam or hot water from deep layers is fed to turbines that drive generators, which produce electricity. After passing through the turbine, the steam is condensed and the cooled water is returned to the underground source so that the process can be repeated.

There are three basic types of geothermal power plants:

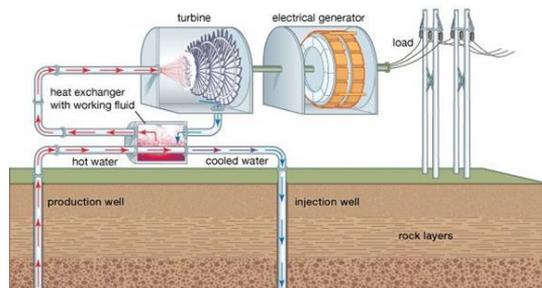
Dry steam power plants- they use the oldest way of converting geothermal energy into electricity. Steam from the Earth's interior is fed directly to a turbine, which drives a generator. This type of power plant was first used in 1904 in Tuscany, Italy. Today, they are rarely used due to the specific geological conditions required for their functioning.



Schematic representation of a dry steam power plant

Flash steam power plants- they use underground water under high pressure, which, upon reaching the surface, suddenly turns into steam and drives the turbine. In this type of power plant, hot water is pumped under high pressure to a low-pressure reservoir where it is turned into steam that drives a turbine. In this process, the steam cools, condenses back into water, and returns to the Earth's interior to be reheated and used. Most geothermal power plants are of this type.

Power plants with binary cycle– In binary cycle power plants, hot water from inside the earth is used to heat another liquid to its boiling point, when it turns into steam and drives a turbine. These power plants are particularly suitable for areas with moderate geothermal resources, as they enable the efficient use of lower temperatures. Also, they have a closed system, which reduces gas emissions and contributes to energy sustainability.



Schematic representation of a power plant with a binary cycle

Direct application of geothermal energy

In addition to the production of electricity, geothermal energy is directly used for heating and other practical applications, enabling the efficient and environmentally friendly use of thermal energy for:

- **Heating of buildings-** Geothermal water is used for district heating of settlements and cities. In Iceland, more than 90% of households use geothermal energy for heating.
- **Agriculture and aquaculture-** Enables the heating of the greenhouse, which extends the vegetation period, as well as the controlled cultivation of fish and shellfish in warmer waters.
- **Industrial application-** It is used for drying agricultural products, pasteurizing milk and other processes that require heat.
- **Geothermal heat pumps-** This technology uses shallow geothermal sources to heat and cool buildings, increasing energy efficiency with low operating costs.

Although geothermal energy is considered a virtually inexhaustible resource, its widespread application depends on geological conditions, exploration and drilling costs, and technical challenges such as pipeline corrosion and mineral deposition in equipment.

Advantages of geothermal energy:

- Geothermal energy is a renewable source of energy if the tank with hot water is properly managed, ie. if the speed of energy extraction is not higher than the speed of natural tank filling.
- Geothermal energy is clean, closed type and does not contribute to the creation of the greenhouse effect.
- It is economically profitable. Direct use of geothermal energy is much cheaper than energy obtained using fossil fuels.
- Energy generation is constant and does not depend on weather conditions
- Geothermal power plants require less space than thermal power plants, solar power plants or wind power plants.

2.8 Biomass

Biomass is a fuel that is obtained from organic matter, it is created from renewable and sustainable energy sources and can be used to generate electricity or heat energy.

Some examples of materials that make up biomass are - waste wood, forest residues, certain crops, fertilizer and some types of waste.

With a constant supply of waste - from construction works and land clearing, to wood not used in paper production, to solid municipal waste, the production of green energy can continue indefinitely.

Biomass is a renewable fuel source for energy production because residues will always exist - waste wood, forest resources and mill residues.

Biomass energy is produced from renewable organic waste that is otherwise disposed of in landfills or burned.

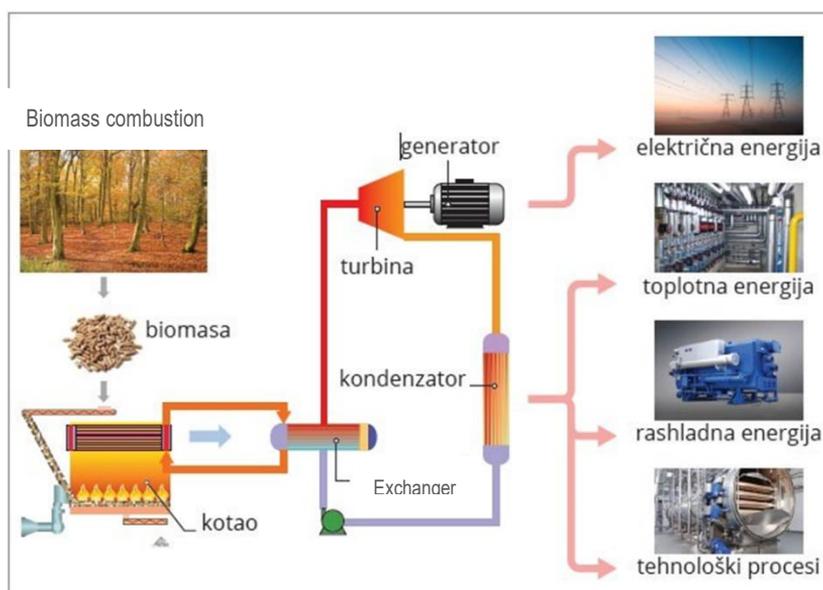
When burned, biomass energy is released in the form of heat. If you have a fireplace, you are already participating in the use of biomass, because the wood that burns is actually biomass.

In biomass power plants, waste wood or other waste is burned to produce steam that drives a turbine to produce electricity or that provides heat for industry or households.

Biomass is a rich resource: organic matter surrounds us, from forests and farmland to waste and landfills. All biomass initially receives energy from the Sun through photosynthesis. Biomass resources regenerate in a relatively short period of time compared to fossil fuel resources that take hundreds of millions of years to replenish. This means that we will certainly not run out of biomass for energy production.

Diverting waste to biomass power plants instead of landfills not only helps reduce the size of landfills and mitigates these risks, but also uses materials that would otherwise be unused.

- **Principle of operation of biomass power plants** it is basically based on the thermodynamic Rankine cycle, which uses the heat generated by burning biomass to produce steam or by heating a special working fluid. Steam at high temperature and pressure drives a turbine connected to an electric generator, which produces electricity. After expansion, the steam cools in the condenser, changes to a liquid state and is returned to the boiler by means of a pump, which closes the cycle. At the same time, part of the heat can be used for heating water and various technological processes, which ensures more efficient use of available energy.
- **Biomass cogeneration plants** simultaneously produce electrical and thermal energy. Heat that would be lost through condensers in classic power plants is used here for space heating, hot water preparation or industrial processes. In this way, with minimal losses, the efficiency of the plant is significantly increased and the utilization of biomass as a primary energy source is optimized.
- **Organic Rankine Cycle (ORC)** is an increasingly prevalent technology in biomass cogeneration plants. The specificity of this technology is reflected in the use of an organic fluid with a lower evaporation point, which enables more efficient heat conversion from lower temperature sources and often facilitates the operation of smaller, decentralized systems. In this way, compared to classic water-steam plants, ORC achieves better utilization of energy from biomass, especially when dealing with lower combustion temperatures or limited amounts of heat.



Schematic representation of the biomass ORC system

Apart from the initial costs to start up the plant, there are additional costs associated with extracting, transporting and storing the biomass before generating electricity. This is an additional cost that other renewable technologies do not have to take into account, as they rely on free on-site resources such as tides, sun, wind for fuel.

Total costs depend to a large extent on the type of biomass and how it is converted into electricity. However, although biomass is often more expensive than alternative renewable energy sources, the most expensive types of bioenergy are still equal to or cheaper than fossil fuels. Bioenergy does not require drilling in the ground, which leads to a large reduction in monetary costs and an increase in the purity of extraction.

2.9 Wind farms

Wind power plants are systems consisting of several wind turbines connected into a single unit. They can be smaller, with a few generators for local consumption, or large, with dozens or even hundreds of wind generators placed in suitable locations. According to the position, they are divided into:

- **Onshore wind farms-** they are placed on land, on plains or hilly areas with favorable winds. They are characterized by easier construction and maintenance, but also lower average wind intensity compared to offshore wind farms.
- **Offshore wind farms-** they are built on seas and oceans, most often on shallow coastal areas, where the winds are stronger and more stable. Although they enable greater energy production, their construction and maintenance are technically more demanding and expensive.
- **Wind farms on mountain passes-** they are placed on elevated terrain, where the wind accelerates due to orographic effects, which enables more efficient use of energy.
- **Wind farms in deserts-** they use stable, dry climatic conditions with constant winds, although the problem is sand erosion and specific protective equipment



Examples of different types of wind farms

2.10 Hybrid wind farms

Hybrid wind farms combine wind energy with other energy sources, most often solar energy, diesel generators or battery systems. These systems are particularly important in isolated locations, such as islands, remote settlements and research stations, where power stability is essential without relying on a centralized grid. Hybrid systems are often used on modern sailing ships with integrated propulsion solutions, which increases energy efficiency and reduces fuel consumption.

The development of wind energy systems has significantly improved the utilization of wind energy in various sectors. Wind turbines, wind power plants and wind turbines for special purposes enable the wider application of this renewable energy source, thus contributing to energy stability and reducing negative impacts on the environment.



A hybrid power plant that uses wave, wind and solar energy. The so-called Hybrid Energy Converter (HEC)

Although today new energy sources are used to produce only a small part of the total energy needed by the world, due to the numerous advantages of their use, this share should be significantly increased in the near future.

Some of their most important advantages:

- These energy sources play a very important role in reducing the emission of carbon dioxide (CO₂) into the atmosphere, which is strongly emphasized in the energy policy of the European Union.
- Increasing the share of renewable energy sources increases the energy sustainability of a country's system, as well as its economic and state independence. At the same time, it helps to improve the security of energy supply and thus reduces the dependence on the import of energy raw materials, fuel and electricity.
- In due time, most renewable energy sources are expected to become economically competitive with conventional energy sources.

For greater use of energy from renewable sources, the developed ecological awareness of the population is very important, as well as the political will to invest in plants for the production of the so-called clean or green energy.



EXERCISE

Research work - Analysis of energy plants in the region:

Small hydroelectric power plants
Solar photovoltaic power plants
Biomass power plants
Geothermal



QUIZ

Quiz 1: Renewable energy sources:

<https://forms.office.com/e/YZ1j2ZSCB0>

3. SAFETY AT WORK AND PROTECTION OF THE ENVIRONMENT

3.1. Possible hazards to the health and safety of workers when working on solar plants/photovoltaic systems

Working in the environment of solar photovoltaic systems implies exposure to various factors of the working environment that can negatively affect the health and safety of workers.

Factors of the working environment: extreme temperatures (high and low), relative humidity, wind, sunlight, noise, vibrations, poor surface, work at heights, heavy loads, long-term incorrect body position, presence of dangerous voltages, atmospheric overvoltages, pollution, presence of dangerous substances and chemicals, etc.

Extreme temperatures, both high and low, can cause serious health problems if workers are not adequately protected. High temperatures, combined with direct exposure to sunlight, can lead to heatstroke, dehydration and burns, while low temperatures increase the risk of frostbite and hypothermia.



Extremely high temperatures



Heavy lifting Weather adversity



Extremely high temperatures

The relative humidity of the air additionally affects the feeling of temperature and can make the body's thermoregulation more difficult. Workers installing and maintaining solar panels are often exposed to long-term direct solar radiation, which can cause skin burns and an increased risk of long-term health problems such as vision impairment and skin diseases.

In addition to physical hazards, the presence of electricity in the work environment poses a serious risk.

Possible sources of danger from high voltage: direct contact with live parts, approaching high voltage device parts, too high contact and step voltage, electric arc, induced voltage, residual voltage, static electricity, influence of electric and magnetic fields, atmospheric overvoltages, etc.

Direct contact with live parts can cause serious injury or death, while approaching high-voltage installations without proper protection carries the risk of induced voltage. High contact and step voltages can cause serious burns and internal tissue injuries, and electric arcs can cause thermal damage to the skin and eyes. The regulations set the limit value of contact voltage that is dangerous to human life and health, and it is 50 V for alternating current (for 50 Hz) or 120 V for

direct current. Higher values of touch voltage increase the risk of electric shock, heart fibrillation and thermal tissue damage, depending on the duration of exposure and the electrical resistance of the body. Induced and residual voltages represent additional sources of danger, especially during the maintenance of systems that are temporarily switched off, while static electricity can cause unpredictable power incidents. The effect of electric and magnetic fields on the human body is still a subject of research, but it is believed that long-term exposure can cause health problems. The presence of atmospheric surges, especially during storms, further increases the risk of lightning strikes and damage to electrical equipment.



VIDEO

Step and touch voltage:

<https://www.youtube.com/watch?v=8sPp8G8a48E>

The effects of electric current on the human body can be thermal, mechanical, electrochemical and biological. Thermal effects are manifested through burns and tissue destruction due to the high temperatures that occur during an electric shock. Mechanical effects include muscle spasm, which can lead to loss of control of movement and serious injury. Electrochemical effects are reflected in changes in blood composition and damage to the nervous system, while biological effects include disturbances in the work of the heart, which can result in cardiac arrest.

The picture shows the action of electric current on the human body, where the effects that occur and depend on the strength of the current are given.



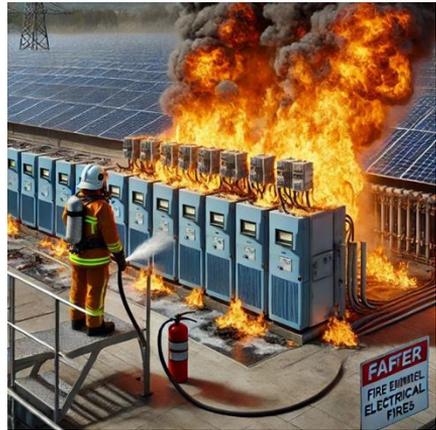
Effect of electric current on the human body

In addition to electrical hazards, the presence of dangerous substances and chemicals in the work environment can cause poisoning, skin and eye irritation, and respiratory problems. In certain segments of work on solar photovoltaic systems, different chemical preparations are used, such as cleaning agents for solar panels, cooling fluids in inverters and protective coatings for electrical connections. If not stored and handled properly, these preparations can cause serious health effects to workers, including chemical burns and long-term respiratory problems.

The presence of pollution in the air, especially in the form of dust and small particles generated during drilling, cutting and installation of solar panel supports, can cause long-term lung damage and increase the risk of occupational respiratory diseases. Workers are often exposed to inorganic dust during assembly on roofs and other open spaces, which can cause respiratory irritation and allergic reactions.

Another important aspect is the risk of fire. Fires represent an additional threat to the safety of workers, because in photovoltaic systems they can occur due to short circuits, overloads or faulty electrical components. Inadequate equipment maintenance, poorly executed electrical connections, faulty electrical components, cable damage and inadequate equipment maintenance can increase the risk of fire outbreaks.

Also, some solar panels contain flammable materials in the insulation layers, which can increase the risk of fire in the event of an electric arc or overheating of the system. The increased temperature of the components can cause self-ignition, especially if the cooling systems of the inverter are not functioning properly.



Fire hazard

Battery systems used for energy storage also pose a fire risk due to the potential for overheating and uncontrolled chemical reactions in the batteries.

In the event of an accident, quick and proper first aid can be crucial in saving lives. Knowledge of basic resuscitation procedures, providing assistance in case of burns, fractures and electric shocks enables workers to respond adequately in emergency situations. Evacuation plans and training for emergency situations play a key role in minimizing the consequences of accidents and protecting the health of employees. There is a constant risk of electric shock in all working and auxiliary rooms, as well as on construction sites with electrical installations and devices. The consequences can be harmless or fatal, depending on a number of factors. Electric shock can cause mild or severe health damage, depending on the circumstances of the accident.

The procedure for rescuing the victim depends on whether it is low or high voltage. The first step is to turn off the voltage in the part of the plant or installation with which the victim is in contact. In the case of low voltage, the voltage is switched off with a switch, by removing the plug or fuse, and if this is not possible, the victim is separated with insulating objects such as hooks, poles or pliers adapted to that voltage. The rescuer must stand on a dry surface and avoid contact with walls or other persons. In no case should the casualty be touched directly.

In the case of high voltage, disconnection can only be performed by a professionally qualified person. Before disconnection, the casualty must not be approached or touched, even with isolated means. After disconnection, disconnected parts must be earthed before assistance is provided.

After the rescue, it is necessary to check the condition of the victim - breathing, pulse and possible bleeding. If it is bleeding, the bleeding should be stopped first. In case of cessation of breathing or heartbeat, immediately start:

- artificial respiration,
- external heart massage,
- combined methods of resuscitation in case of apparent death.



Immediately notify the health care facility of any accident.

The safety of workers in solar photovoltaic systems depends on the correct application of the prescribed safety measures at work, the use of appropriate protective equipment and continuous training.

Awareness of potential hazards and compliance with preventive measures are key factors in preventing accidents and ensuring a safe working environment. Proper risk assessment, use of appropriate personal and collective protective equipment, as well as adherence to prescribed procedures during assembly, maintenance and work with electrical components, are essential for worker protection.

Given that work in solar photovoltaic systems often involves exposure to solar radiation, working at heights and contact with electrical installations, it is necessary to ensure regular training for workers to reduce the risks of injuries and accidents. The application of adequate safety measures, such as the correct use of protective helmets, gloves, safety glasses and safety belts, significantly contributes to safety during the performance of all works.

3.2. Application of safety and protection measures at work during the performance of solar works photovoltaic systems

When carrying out work on solar photovoltaic systems, it is crucial to apply safety and occupational protection measures to reduce the risks of injuries and accidents. The methods of work in relation to the presence of voltage are divided into works in a de-energized state, works near voltage and works under voltage.

Works in a voltage-free state imply a complete shutdown of the power supply of the photovoltaic system with the implementation of prescribed protection measures to prevent unintentional reactivation.

Working near live voltage requires additional precautions, including the use of protective barriers, safety distances, and suitable insulated tools to reduce the risk of electric shock.

Live work is carried out with special technical and organizational measures, including the use of specialized equipment, isolation tools and adherence to strict safety procedures.

Protective means and equipment are divided into personal and collective.

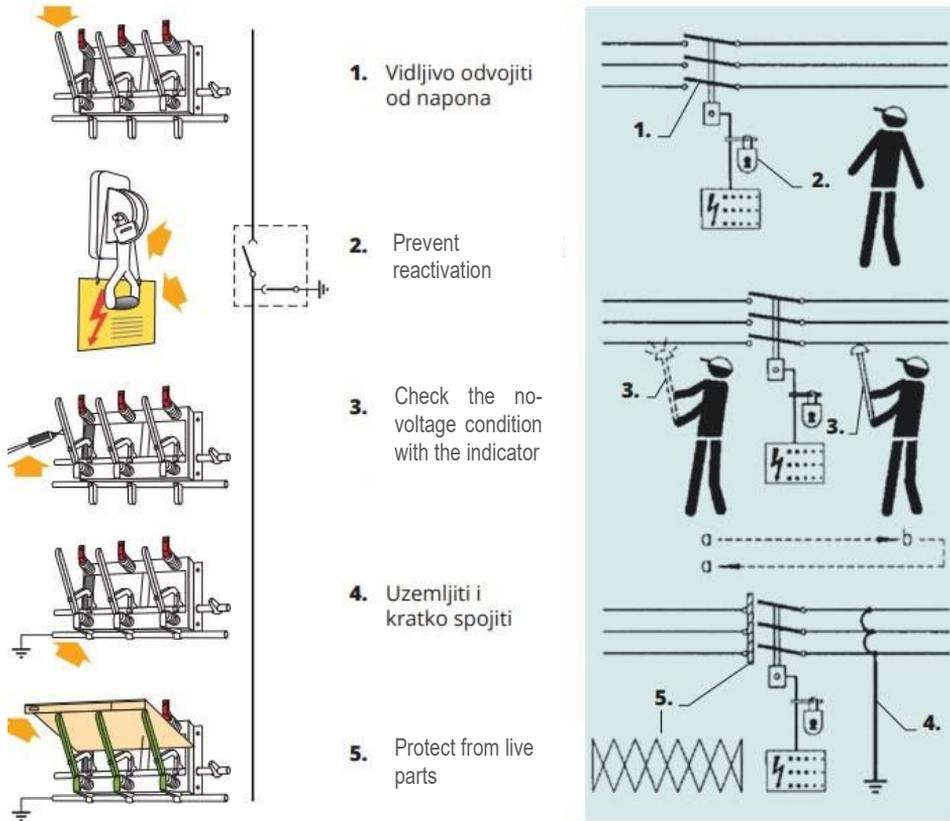
- Personal protective equipment includes helmets, goggles, visors, gloves, protective clothing and footwear, safety belts and equipment for working at height.
- Collective protective means include isolation barriers, protective partitions, warning signs and means for securing the working space.

The correct choice and use of protective equipment are key to minimizing risks when working on solar systems.

Safety measures at work are based on the application of the "five golden rules" of safety, which include disconnecting the voltage, securing against reconnection, checking the absence of voltage, grounding and short-circuiting, and fencing and marking the work area. In addition, it is important to use insulating guards, plates and covers to prevent accidental contact with live parts. Installation of fences, tapes and warning signs additionally contributes to the safety of the work area.

Safety measures:

- "five golden rules";
- installation of insulating protective partitions, plates, covers;
- installation of fences and warning signs, fencing of workplaces, etc.;
- prohibition of working under voltage, etc.



Five golden rules

Before starting the work, it is necessary to check the correctness of protective means and equipment. Every protective helmet, glove, belt or other element must be technically correct and meet the prescribed standards. In addition, it is mandatory to install means for marking and securing the work area, including protective fences, tapes for marking works and temporary traffic signals.



Personal protective equipment

3.3. Implementation of safety measures and personal protection measures when working at height in solar plants/photovoltaic systems

When performing work at height in solar photovoltaic systems, workplaces include various locations, such as building roofs, access platforms, panel supports and specially designed mounting systems. These locations require special attention due to specific hazards, as workers often work at great heights, in adverse weather conditions and on surfaces that may be slippery, steep or inadequately prepared.

Locations of work at height: building roofs (sloped and flat), building facades, column structures, towers, parking canopies, etc.



Equipment required for work at height

When performing work at height, it is necessary to thoroughly record the factors of the working environment. For example, when installing solar panels on the roof of the building, workers should pay attention to weather conditions - wind speed and direction, temperature, possibility of precipitation and slippery surface - as well as to the stability of the roof, the safety of access platforms and any obstacles that may affect safety. Detailed recording of these factors enables potential risks to be recognized in time and adequate protection measures to be taken.

The implementation of safety measures for the safe performance of work at height implies the implementation of all prescribed safety procedures. This includes:

- Installation of protective fences and barriers at workplaces.
- Use of fall protection systems, including safety belts, ropes and anchor points.
- Securing workplaces using specialized equipment for working at height.
- Regular reviews and maintenance of access systems to ensure they are stable and secure.

Also, it is extremely important to ensure constant communication between workers through radio links or other means of communication in order to enable coordination and immediate response in the event of an accident. Evacuation procedures must be clearly defined, and all workers trained for quick and efficient response in emergency situations.

The use of personal protective equipment when working at height is a key protection measure. Workers must be equipped with protective helmets, safety belts, specialized equipment for working at height and other personal protective equipment necessary to prevent injuries.



QUIZ

QUIZ 2: Application of safety and protection measures at work during the construction of solar photovoltaic systems:

<https://forms.office.com/e/J2vYyMiPED>.



VIDEO

Working at height: <https://www.youtube.com/watch?v=FqEOvrBnE58>. need and characteristics of parts of personal protective equipment:

<https://www.youtube.com/watch?v=nA9oC--tq50>.



PRACTICAL EXERCISE

Task 1: Evacuation simulation

Material and tools:

- Safety belt with buckles;
- Carabiner clips;
- Anchor points;
- Communication equipment (radio or mobile device);
- Simulation protective equipment.

Procedure:

1. Preparation of safety equipment

- Install the seat belt and fasten it properly according to the manufacturer's instructions.
- Check that all seat belts are properly adjusted and secured before starting the simulation.
- Attach the safety belt to the anchor point using the appropriate carabiner clip.
- Ensure that the anchor point is stable and can support the load.

2. Evacuation planning

- Communicate with team members and establish an evacuation plan.
- Determine the roles: one person in charge of communication with the base, another for checking the equipment.

3. Emergency simulation

- According to the instruction of the instructor, simulate an emergency situation (a fall or the need for evacuation).
- Follow the evacuation plan in a coordinated manner:
- Notify the team.
- Secure the evacuation site.
- Carry out the procedure of lowering or extracting workers.

4. Simulation analysis

- After completing the exercise, analyze the evacuation procedure.
- Identify possible mistakes or areas for improvement.
- Discuss with the instructor and the team to improve the speed and efficiency of the reaction.



PRACTICAL EXERCISE

Task 2: Simulation of rescue from height

Material and tools:

- Safety net;
- Rescue system (ropes, pulleys, carabiners);
- Safety belts;
- Communication equipment;
- First aid.

Procedure:

1. Preparation of the rescue system

- Review the safety net and rescue system.
- Check the condition of the net and fastening elements.
- Ensure that the net is placed stably.

2. Emergency simulation

- Simulate the fall of a worker from a height.
- Demonstrate the correct team response.

3. Performing a rescue

- Communicate with the team and ensure the stability of all work platforms and safety equipment.
- Using the lowering or lifting system, apply the appropriate technique for evacuating the injured worker.
- Properly fasten the rescued worker's safety harness and secure him until the team lowers him to safety.

4. Analysis of the rescue procedure

- Discuss any challenges during the simulation.
- Evaluate the effectiveness of the response and the safety of all involved team members.

3.4. Implementation of measures to reduce the negative impact of solar photovoltaic systems on the environment

Preservation of the environment is one of the key aspects in the construction and exploitation of solar photovoltaic systems. Given the fact that renewable energy sources play a significant role in reducing greenhouse gas emissions, it is also important to recognize and control the possible negative impacts of these plants on the ecosystem. Sustainable management of natural resources, protection of biodiversity and proper disposal of waste represent the basic principles of responsible business in the field of renewable energy sources.

Solar photovoltaic systems can have certain negative impacts on the environment. First of all, the construction of solar farms can lead to land degradation, especially when natural vegetation and trees are removed to install the panels. This change in landscape can affect plant and animal life, especially in ecologically sensitive areas.

Waste management procedure: waste identification, waste sorting, waste packaging, waste labeling, waste transportation, waste storage, recycling, etc.

In California, solar panels are installed on building roofs and abandoned industrial sites instead of agricultural land, thus reducing the negative impact on natural ecosystems.

Also, the reflective surface of solar panels can cause optical interference and disturb birds and other animal species. Studies have shown that birds can misperceive solar panels as bodies of water, which can lead to unwanted collisions.

Japanese scientists have developed a coating inspired by the eyes of moths, which significantly reduces the reflection of solar panels, thereby reducing optical interference and increasing their efficiency.

Noise generated during installation and maintenance of solar systems, as well as electromagnetic interference produced by inverters and other electrical components, can have a minor but measurable impact on the environment and communication systems.



Reducing the reflection of solar panels

In order to minimize the negative impacts of solar photovoltaic systems on the environment, it is necessary to implement a series of measures:

- Proper planning of solar farm sites to minimize impact on habitats and ecological corridors.
- Implementation of technologies to reduce the reflection of solar panels to reduce disturbance to birds and other animal species.
- Preservation of natural vegetation around solar power plants in order to maintain ecosystems and reduce soil degradation.

- Proper disposal of solar panels at the end of their useful life and recycling of materials to reduce the amount of waste.

The European Union implements mandatory solar panel recycling programs through the WEEE Directive (Waste Electrical and Electronic Equipment), which requires manufacturers to be responsible for the disposal of panels at the end of their useful life.

Recycling of solar panels and other equipment of solar photovoltaic systems after the end of their useful life

Recycling of solar panels and other equipment of solar photovoltaic systems is essential to reduce waste and protect natural resources. The implementation of the circular economy in the sector of renewable energy sources contributes to reducing the ecological footprint and optimizing resources.

It is estimated that by 2050, millions of tons of solar panels will reach the end of their life, making them a key issue for e-waste management. Although solar panels are designed to last 25–30 years, many are already reaching the end of their life cycle, which poses challenges for proper disposal and recycling.

Most solar panels consist of an aluminum frame, glass, silicon cells, copper and silver connectors, and polymer protective layers. Over 80% of solar panel materials can be recycled, including glass, aluminum and silicon. However, the removal and processing of plastic layers and thin semiconductor layers represent a technical challenge.

Currently, many defective solar panels are disposed of in landfills, which is not sustainable. Some countries are already introducing regulations that require mandatory recycling of panels in order to reduce the negative impact on the environment.



Solar panels for recycling

Key methods of recycling solar panels include:

- **Mechanical grinding**– Solar panels are crushed to separate the glass, metal parts and silicon.
- **Heat treatment**– A heating process that removes plastic layers, allowing glass and metal to be reused.
- **Chemical treatment**– Using chemical solutions to break down and extract valuable materials, including silver and silicon.

New technologies are developing methods of more efficient separation of solar panel layers and reuse of materials in the production of new cells. The European Union already implements mandatory recycling programs through the Waste Electronic Directives (WEEE), while other countries are gradually adopting similar regulations.

First Solar has developed a closed recycling system in which 95% of the material from thin-film solar panels can be reused in the production of new cells, thereby reducing the need to exploit natural resources. French company Veolia has opened Europe's first factory specialized in solar panel recycling, which can process 4,000 tons of panels per year, extracting silicon, glass and metals for reuse.

It is necessary to continue developing solutions that will ensure a sustainable future for solar energy and reduce the environmental footprint of the industry.



PRACTICAL EXERCISE

Task 1: Waste management in solar photovoltaic systems

Material and tools:

- Containers for different types of waste (plastic, metal, paper, electronic waste, hazardous waste);
- Labels for categorizing waste;
- Waste bags and containers for chemicals;
- Regulations on ecological waste disposal;
- Gloves and protective equipment.

Procedure:

1. Waste identification

- Inspect the area of the power plant and identify the types of waste generated during operation and maintenance.
- Categorize waste into general, electronic, hazardous and recyclable waste.

2. Waste sorting

- Sort waste according to environmental standards and regulations.
- Mark the containers according to the type of waste (eg paper, metal, plastic, electrical and electronic waste, hazardous waste).

3. Packaging and labeling of waste

- Properly pack waste using adequate bags and containers.
- Label each container according to the type of waste and disposal instructions.

4. Storage and recycling

- Properly store waste until it is taken over by authorized services.
- Determine the possibilities for recycling and reuse of certain materials (metal and electrical waste, plastic).

Final check:

- Check that all waste is properly sorted and labeled.
- Inspect the storage area and ensure that environmental regulations are followed.
- Discuss the possibilities of improving the process of recycling and reuse of materials.



PRACTICAL EXERCISE

Task 2: Application of protective equipment during the implementation of environmental protection measures

Material and tools:

- Personal protective equipment (gloves, masks, protective suits, footwear);
- Hazardous waste containers;
- Labels for chemicals and hazardous materials;
- Standard procedures for handling waste materials.

Procedure:

1. Preparation of protective equipment

- Choose appropriate protective equipment according to the type of waste being handled.
- Check the correctness and functionality of the equipment before use.

2. Proper handling of waste and chemicals

- Identify hazardous materials and chemicals according to labels.
- Use protective gloves and masks when handling chemicals.
- Close and store chemical containers properly to prevent leakage or contamination.

3. Packaging and transportation of hazardous waste

- Properly package and label hazardous waste according to prescribed standards.
- Use appropriate containers and labels for hazardous materials.
- Transport waste in accordance with safety procedures and environmental standards.

Final check:

- Check the correct application of protective equipment during the performance of tasks.
- Ensure that waste materials are properly packaged and labeled prior to storage or transport.
- Discuss potential risks and ways to improve environmental and safety procedures in solar power plants.

4. SUN ENERGY

Solar energy is the primary source of energy on Earth and can be directly used to produce heat and electricity through solar technologies. Solar systems are based on the use of solar radiation, which is available everywhere and represents an inexhaustible and environmentally friendly energy resource. The strength, availability, and characteristics of solar radiation depend on several factors, including geographic location, atmospheric conditions, orientation of surfaces receiving radiation, and measurement of its parameters. Understanding these factors and precise measurement of solar radiation parameters are necessary for proper design and optimization of solar systems.

Characteristics and parameters of solar radiation

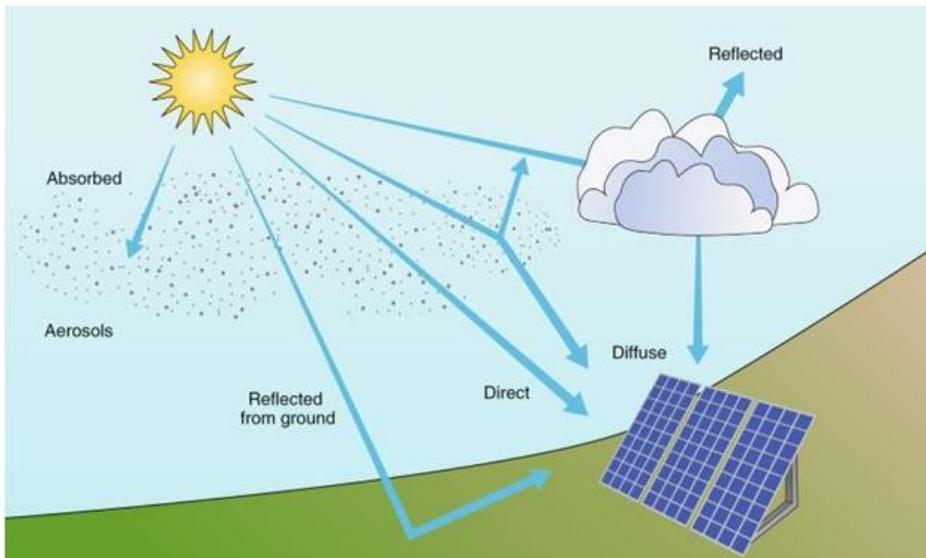
Solar radiation is electromagnetic energy emitted by the Sun in the form of light and heat. This energy reaches the Earth and enables all forms of life, while simultaneously serving as a source of renewable energy for solar technologies.

Types of Solar Radiation

Solar radiation can be divided into several types depending on how it reaches the Earth's surface:

- **Direct radiation**– Sunlight that comes directly from the Sun and can be directed at solar devices without reflection or scattering.
- **Diffuse radiation**- Part of the solar radiation that is scattered in the atmosphere due to the interaction with air molecules, dust particles and clouds.
- **Reflected radiation**- Part of the radiation that is reflected from the ground, buildings, vegetation and other surfaces.

Total solar radiation reaching a certain surface is the sum of direct, diffuse and reflected radiation.



Types of Solar Radiation

Key parameters of solar radiation

Several parameters define the intensity and quality of solar radiation:

- **Solar constant**– the average value of the energy that the Sun emits in the form of electromagnetic radiation to the outside of the atmosphere (approximately 1361 W/m²).
- **Solar radiation spectrum**– includes ultraviolet (UV), visible and infrared (IR) radiation.
- **Radiation intensity**– is measured in W/m² and depends on the time of day, season and location on Earth.
- **Azimuth and elevation angle of the Sun**– parameters that describe the position of the Sun in relation to the horizontal surface.
- **Surface albedo**– the amount of solar radiation that is reflected from the ground.

Variations of solar radiation

Solar radiation varies depending on several factors:

- **Latitude**- areas closer to the equator receive more solar energy during the year.
- **Time of day**- the maximum radiation intensity is reached at noon when the Sun is at its highest point.
- **Season**– due to the tilt of the Earth's axis, radiation varies between summer and winter months.
- **Weather conditions**- cloudiness, fog and atmospheric particles reduce the intensity of radiation.
- **Altitude**- at higher altitudes, the absorption and scattering of radiation decreases.

Map of solar radiation by region

For designing photovoltaic systems, a solar radiation map is used, which shows the average annual values of solar energy in different geographical areas. This data enables:

- **Dimensioning of photovoltaic systems**- Accurate assessment of the required number of solar panels and their surface area.
- **Energy production estimation**- Realistic calculation of the amount of electricity produced at a specific location.
- **Optimization of panel orientation and tilt**– Placing the panels at an appropriate angle for maximum efficiency.
- **Analysis of seasonal variations**- Planning of energy storage capacity in areas with pronounced winter insolation.

By using accurate solar radiation data, investors and engineers can make optimal decisions that increase the energy efficiency and economic profitability of solar power plants. One of the sites that can be used for this purpose is <https://globalsolaratlas.info/map>.

Influential factors of solar radiation

Several factors affect the use of solar radiation in solar systems:

- **Atmospheric absorption**- water vapor, carbon dioxide and ozone absorb part of the solar radiation.
- **Aerosols and pollution**- reduce direct solar radiation and increase the diffuse component.
- **Tilt and orientation of solar panels**- properly adjusted panels maximize the collection of solar energy.
- **Surface reflectivity**- materials with high reflectivity increase the amount of reflected radiation.

Measurement of solar radiation parameters

Accurate measurement of solar radiation is crucial for designing and optimizing solar energy systems. Different methods and instruments are used:

- Pyranometer – measures global radiation (direct + diffuse) on a horizontal surface.



- Pyroheliometer - measures only direct solar radiation.



- Actinometer - Used to measure the total amount of solar radiation at a specific location.



- Sun tracking systems - enable precise tracking of the Sun's path for increased efficiency.



- Spectral analyzers – analyze the spectrum of solar radiation.
- Networks of meteorological stations - enable continuous monitoring of solar parameters at different locations.

These measurements enable the optimization of solar energy systems and their adaptation to specific climatic conditions.

Methods of measuring solar radiation

Measurement of solar radiation can be direct or indirect, depending on the accuracy of the data.

Direct measurement:

- It measures the intensity of solar radiation at a specific location.
- Pyreliometers and pyranometers measure direct (DNI) and global (GHI) radiation in real time.
- Key to designing solar systems, optimizing and validating data from satellite models.

Indirect measurement:

- It uses satellites and mathematical models to estimate radiation.
- Satellites collect atmospheric data that are used in models to calculate radiation on Earth.
- GIS (Geographic Information Systems) systems help visualize solar resources and plan solar projects.



Geographic information systems

Accurate measurement is important for evaluating solar potential and optimizing solar systems.

4.1. Solar energy systems and their application

Solar energy systems use the sun's energy to produce electricity and heat and can be divided into three basic categories:

- Solar photovoltaic systems (SFNS),
- Solar collector systems (SKS),
- Concentrated solar systems (CSP - Concentrated Solar Power).

Solar photovoltaic systems (SFNS) convert sunlight directly into electricity using photovoltaic cells. This technology is based on the photoelectric effect, in which photons of sunlight release electrons in a semiconductor material, creating an electric current.

Photovoltaic systems can have different capacities and purposes - from small autonomous systems for powering individual buildings to large solar parks, which produce electricity for the power system.

Solar photovoltaic systems are covered in detail in the following chapters, as the main subject of study in this manual.

4.2. Solar collector systems (SKS)

Solar collector systems (SKS) are technologies that use the energy of the Sun to heat a fluid, which is then used for space heating, preparation of sanitary hot water or industrial processes. These systems work on the principle of collecting solar radiation using collectors, which transfer heat to the working fluid.

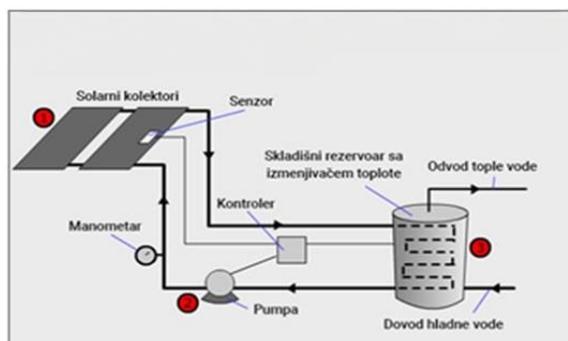
Solar collector systems are the most widespread application of solar thermal technology, especially in residential, commercial and industrial facilities, where they contribute to savings in electricity consumption and reduction in the use of fossil fuels. Unlike solar photovoltaic technology, which directly converts sunlight into electricity, and solar thermal power plants, which use concentrated solar energy to produce electricity using a steam turbine, solar collector systems do not produce electricity. They are used exclusively for heating fluids and distributing heat to end users.

Principle of operation and components of solar collector systems

The operation process of solar collector systems takes place through three basic phases:

- **Absorption of solar radiation**– Sunlight falls on the surface of the collector, where it is absorbed and converted into the heat of the working fluid.
- **Heat transfer to the working fluid**– The heated absorption plate of the collector transfers heat to the working fluid, which circulates through the system.
- **Heat distribution or storage**– Heated fluid transfers heat to consumers or is stored in storage tanks for later use.

In closed systems, the working fluid (antifreeze or thermal oil) takes the heat and transfers it through the heat exchanger to the tank. Fluid circulation is enabled by means of a pump, which ensures continuous flow through the system or by natural convection flow. Control systems automatically regulate fluid flow and pump operation depending on the fluid temperature in the collectors and storage tank.



Components of solar collector systems

Solar collector systems consist of several components that enable efficient reception, transmission, storage and distribution of thermal energy.

- **Solar collectors**- the basic element of the system that absorbs solar energy and converts it into heat.
- **Working fluid**- transfers heat from the collector to the end user (boiler, heating, industrial processes). It can be water, antifreeze or thermal oil.
- **Pipeline**– a system of pipes through which the working fluid circulates, made of materials resistant to high temperatures and corrosion (copper, stainless steel, special plastics).
- **Circulation pumps**- enable the flow of the working fluid through the system, ensuring continuous heat transfer.
- **Storage (accumulation) tank**- enables the storage of heat for later use.
- **Heat exchanger**– transfers heat between the working fluid and consumer water.
- **Control system**- enables automatic regulation of system operation, which optimizes efficiency and reduces energy losses.

Types of solar collectors

- **Flat plate collectors**- the most commonly used, simple and reliable, but with higher heat losses due to exposure to the surrounding air.
- **Vacuum tube collectors**- more advanced collectors with better insulation, which increases efficiency and reduces heat losses.
- **Concentration collectors** –they use mirrors or lenses to focus sunlight, enabling high temperatures to be achieved and are suitable for industrial use.



Flat plate collectors installed on the roof of a residential building



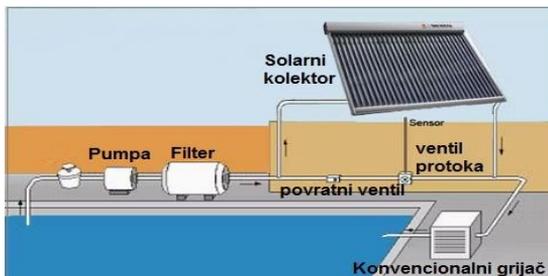
Vacuum tube collectors

Each type of solar collector has its own specific application, depending on the climatic conditions and the needs of the user. Flat plate collectors are the most affordable and widespread in households, while vacuum collectors are more efficient in regions with lower temperatures. Concentration collectors are used in large solar power plants and industry. Proper collector selection is crucial for the efficiency and long-term profitability of solar thermal systems.

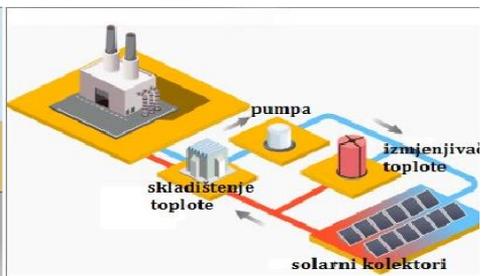
Application of solar collector systems

Solar collector systems (SKS) have a wide range of applications:

- **In residential buildings**- for preparing sanitary hot water and supporting heating systems.
- **In commercial and public facilities**- hotels, hospitals, schools, sports centers use SKS to reduce energy costs.
- **In industry**- used for pasteurization, sterilization, drying and other processes.
- **In district heating**- integration of solar collector systems with centralized heating systems in urban areas.
- **In isolated areas**- for supplying hot water and heating facilities in rural and remote regions.



Schematic representation of the use of collectors for heating water in the swimming pool



Schematic representation of the use of collectors in industry

Advantages and challenges of solar collector systems

Advantages:

- Free and renewable source of energy.
- Reduction of water and space heating costs.
- Environmentally friendly system with reduced CO₂ emissions.
- Long lifespan of 20 to 30 years.
- The possibility of combining with other energy systems.

Challenges:

- High initial installation costs.
- Dependent on the amount of solar radiation.
- Additional installation space required.
- Necessary maintenance for long-term efficiency.

Solar collector systems are one of the most efficient applications of solar thermal energy for water and space heating, as well as for supporting industrial processes. Their simplicity, reliability and long-term profitability make them an attractive solution in many sectors.

4.3. Concentrated solar systems (solar thermal power plants)

Concentrated solar power systems (Concentrated Solar Power - CSP systems) are advanced thermal systems that use solar energy to generate heat through optical devices, such as parabolic mirrors, solar plates or heliostats. This heat can have various applications - from industrial processes to heating, but it is most often used to start thermodynamic cycles in order to produce electricity.

Solar thermal power plants are the basic type of concentrated solar system intended for the production of electricity. They use concentrated solar energy to heat the working fluid, which transfers the heat to the steam generator. The steam created under pressure drives a turbine connected to a generator, which produces electricity.

One of the main advantages of solar thermal power plants is the ability to store heat, which enables continuous production of electricity even when there is no solar radiation, such as at night or on cloudy days. In this way, solar thermal power plants ensure a stable and reliable supply of electricity, contributing to energy security and reducing reliance on fossil fuels.

Technologies and principles of operation of solar thermal power plants

In solar thermal power plants, as well as in concentrated solar systems in general, four basic technologies are used to convert solar energy into thermal energy:

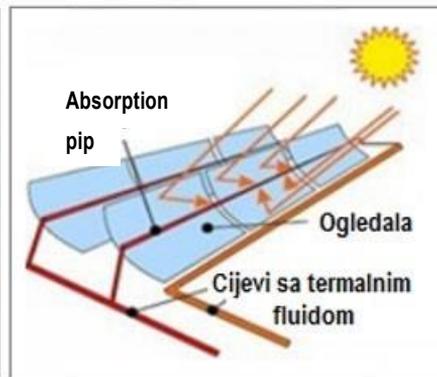
1. Parabolic trough collectors

Parabolic collectors use long parabolic mirrors that precisely focus the Sun's rays onto an absorption tube placed in the focus of the parabolic mirrors. This configuration allows the energy to be directed evenly along the pipe, thus increasing the efficiency of heat absorption. The system uses single-axis tracking of the Sun to achieve maximum effect.

The heated working fluid, usually thermal oil or molten salt, circulates to the heat exchanger, where it transfers the heat to the water and turns it into saturated steam. The steam then drives a turbine connected to a generator that produces electricity. After giving up the heat, the working fluid is cooled and returned to the collectors, where it is reheated and a new cycle begins.



Parabolic trough collectors - actual appearance



Parabolic collectors - schematic view

This technology is most often used in large solar thermal power plants, especially in sunny and flat areas, where they can occupy large areas and efficiently use available solar radiation.

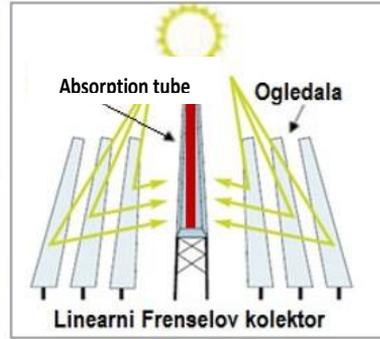
2. Linear Fresnel reflectors

Linear Fresnel collectors are a more economical version of parabolic collectors. They use a series of flat or slightly curved mirrors that reflect the Sun's rays to a fixed absorption tube placed above them. This design reduces the required area and simplifies installation.

The technology works by the fact that the mirrors direct the solar radiation towards the absorption tube through which the working fluid flows. The heated fluid transfers the heat to the exchanger, where it heats the water and turns it into steam. This steam drives a turbine, which is connected to a generator that produces electricity.



Linear Fresnel collectors collectors - actual appearance



Linear Fresnel collectors collectors - schematic view

Linear Fresnel collectors are suitable for smaller solar thermal power plants and industrial processes that require high temperatures, but are less efficient in producing electricity compared to parabolic collectors.

3. Solar plates (Dish-Stirling or Dish Collector)

Solar panels use deeply curved dish mirrors that focus the Sun's rays to a single point where the energy conversion unit is located. This unit consists of an absorption receiver, a Stirling engine and a generator.



Solar dish - real life



Solar plate - schematic view

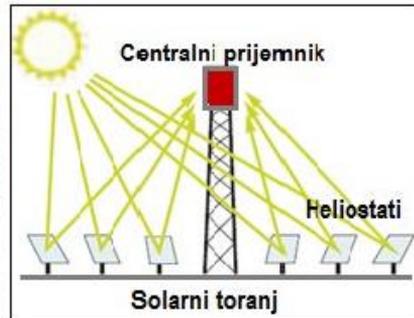
Solar plate technology provides the highest efficiency among concentrated solar systems, but due to its high complexity and costs, it has rarely been used for large thermal power plants.

4. Solar towers (Power Tower System)

Solar towers use a network of movable mirrors (heliostats) that reflect the Sun's rays to a receiver located at the top of the tower. Inside the receiver is a working fluid, usually molten salt or high-pressure air, which absorbs heat and is heated to a temperature between 500 and 1000 °C.



Actual application of the solar tower



Schematic representation of the solar tower

The main advantage of a solar tower is the ability to store heat, which enables continuous production of electricity even after sunset.

Advantages and disadvantages of concentrated solar systems

Advantages:

- The ability to store heat enables the production of electricity even during the night.
- High efficiency of converting solar energy into electricity.
- Reduced greenhouse gas emissions.
- Long working life, often over 30 years.

Disadvantages:

- High initial construction and maintenance costs.
- A large area of land is required to install the mirror.
- Dependence on direct solar radiation.

Concentrated solar systems represent an advanced technology for the production of clean energy with great potential, especially in areas with strong solar radiation. Further development of technology and improvement of energy storage systems can make them even more competitive in the global energy transition.



QUIZ

Quiz 3: SKS and CSP technologies and their applications:

<https://forms.office.com/e/K8RJQZTQPU>.

Quiz 4: Solar Collector Systems (SCS) and Concentrated Solar Systems (CSP):

<https://forms.office.com/e/6KyGAFYrMc>.

4.4. Basic components of solar photovoltaic systems

Photovoltaic cells

Photovoltaic cells (photovoltaic cells or FN cells - Photovoltaic cells) are the basic unit of photovoltaic panels. They enable the direct conversion of the energy of solar radiation (visible light) into electrical energy through the photovoltaic effect.



Photovoltaic cell

Structure and principle of operation of a photovoltaic cell

The structure of photovoltaic cells consists of different layers of materials, each of which has its own specific role in converting sunlight into electricity. These layers include:

- **Protective glass**- Provides mechanical protection to the cell and allows the passage of light.
- **Anti-reflective coating**- Reduces sunlight reflection and increases energy absorption.
- **Front contact**(conductive metal layer) – Collects electrons and enables the conduction of electric current. It is the negative terminal of the photovoltaic cell.
- **PN junction (semiconductor layer)**- The key part of the cell that enables the conversion of light energy into electricity:
 - **P-type silicon**– Doped with boron, contains an excess of positive carriers (cavity).
 - **N-type silicon**- Doped with phosphorus, it contains an excess of negative carriers (electrons).
- **Last contact**- Enables the closing of the electrical circuit and the return of electrons to the cell.
- **Protective layer on the back**- Provides additional resistance to moisture and mechanical damage.

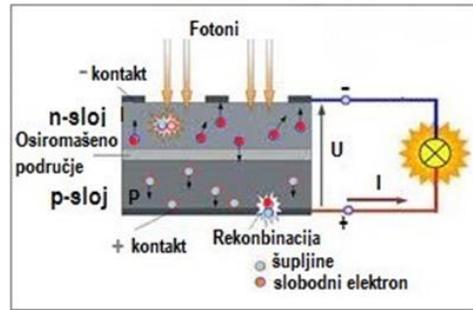


Structure of the FN cell

A potential difference is created between the contacts (photovoltaic cell connections), i.e. the voltage of the photovoltaic cell is generated.

The principle of operation of a photovoltaic cell:

When the Sun's photons hit a photovoltaic cell, they transfer energy to electrons, freeing them from their atomic bonds. The released electrons migrate to the N-layer, while the holes remain in the P-layer. An electric field is created at the PN junction, which prevents the spontaneous recombination of electrons and holes. When a cell is connected to an external electrical circuit, electrons flow through that circuit, creating an electric current.



Schematic representation of a PN cell

Types of photovoltaic cells

There are several types of photovoltaic cells, which differ in the materials from which they are made, the method of production and efficiency. Each type has its advantages and disadvantages, and the choice depends on the specific needs for energy production.

The main types of photovoltaic cells are:

- **Monocrystalline photovoltaic cells**– High efficiency (17-22%), long service life (over 25 years), high production costs.
- **Polycrystalline photovoltaic cells**– Lower efficiency (15-18%), but more favorable production price.
- **Thin-film photovoltaic cells**: These cells do not have a crystalline structure, which makes them easier to manufacture. In addition to the low price, their advantage is flexibility.
 - Amorphous Silicon (a-Si) – Flexible, but with low efficiency (~10%).
 - Cadmium Telluride (CdTe) – Relatively high efficiency (~15%), but environmental challenges (use of potentially toxic materials such as cadmium).
 - CIGS cells (copper-indium-gallium-selenide) – Flexible, efficiency 16-20%. Disadvantages are higher price compared to amorphous and polycrystalline cells and limited availability on the market.



Monocrystalline cell



Polycrystalline cell



Amorphous cell

Comparison table of photovoltaic cells

Cell type	Solar irradiation (W/m ²)	Efficiency (%)	Average lifespan (years)	Approximate price (€/W)	Advantages
Monocrystalline	140	17-22	25	0.35	Highest efficiency, long service life
Polycrystalline	130	15-17	20	0.3	Lower price, good performance balance
Thin-film	50	10-13	15	0.25	Flexibility, better in diffused light

In addition to the mentioned types of cells, there are also new technologies with increased efficiency and reduced production costs that are still in the development phase:

- **Perovskite cells**- are made from a combination of organic and inorganic materials. They show high efficiency, which in laboratory conditions reached a value of 25%.
- **Bifacial cells** - they are designed to absorb light from both sides of the panel, which allows them to produce up to 30% more energy. They are particularly effective in areas with high light reflection.

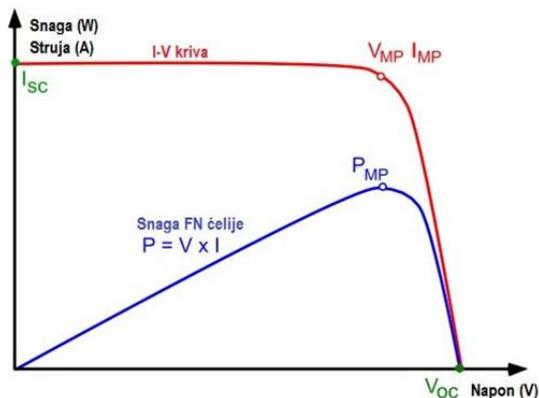
Advanced technologies, such as Gallium Arsenide and Cadmium Telluride cells, offer high efficiency, but are expensive or have environmental limitations.

The choice of the type of photovoltaic cell depends on specific needs, such as efficiency, cost, available installation space and expected lifetime of the system. When choosing solar panels, it is more important to pay attention to the manufacturer, the warranty period and the quality of the installation, than only to the type of cells.

Electrical characteristics of photovoltaic cells

The electrical characteristics of photovoltaic cells define their ability to generate electricity from sunlight. Knowing these characteristics is crucial for proper sizing and optimization of photovoltaic systems

- **Open circuit voltage (V_{oc})**– Maximum voltage when there is no load. V_{oc} for a monocrystalline silicon cell is from 0.5 V to 0.7 V.
- **Short circuit current (I_{sc})**– Maximum current in case of a short circuit (I_{sc} of a standard cell with a surface of 0.1 m² is about 5 A at a radiation of 1000 W/m²).
- **Maximum power (P_{max})**– The highest output power of a photovoltaic cell.
- **Cell efficiency**– Ratio of output power to solar energy. It shows what percentage of the solar energy the cell can convert into electricity.
- **IV characteristic (current-voltage characteristic)** – Shows the relationship between current and voltage.
- **PV characteristic**– Shows the dependence of power on voltage.



IV and PV characteristics of the N cell

Understanding the structure, types and basic electrical characteristics of photovoltaic cells is crucial for proper design, installation and maintenance of solar systems, as well as for achieving maximum operational efficiency.

Photovoltaic panels

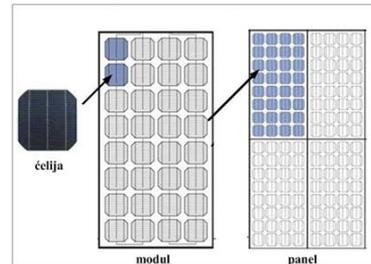
Photovoltaic panels are a key component of solar energy systems, as they enable the direct conversion of sunlight into electricity. They consist of several interconnected photovoltaic cells which, with proper construction and proper positioning, ensure stable and efficient energy production.



Photovoltaic panels

Formation of photovoltaic panels

The electrical values of individual photovoltaic cells, such as voltage, current and power, have extremely small values and are not suitable for practical application. For example, one silicon cell produces a voltage of about 0.5 to 0.7 V and with a current density of about several tens of mA/cm², depending on the strength of the solar radiation, but also on the radiation spectrum.

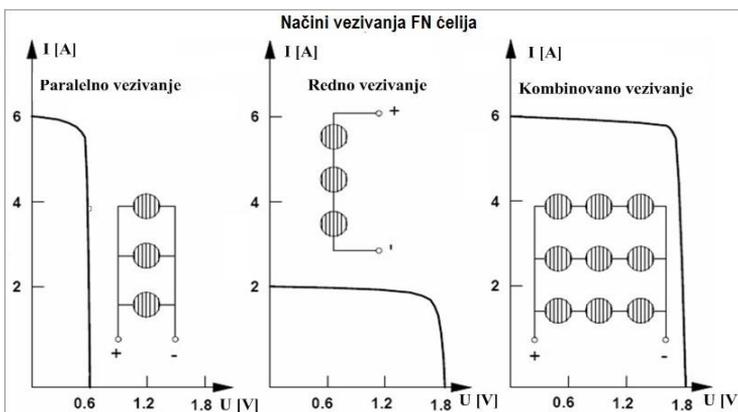


Connection: cell-module-panel

Therefore, to obtain electrical values that can be used practically, cells are connected into modules, and modules into panels, which are the basic component of solar energy systems.

The process of forming photovoltaic panels takes place through several key steps:

- **Connecting photovoltaic cells into modules-** is the basic step in the formation of the panel. The cells are connected in series, parallel or mixed, depending on the system requirements and the values of the electrical characteristics. There are three ways of binding:
 - **Series connection** –It increases the voltage while the current remains the same.
 - **Parallel connection**– Increases the current, while the voltage remains the same.
 - **Mixed compound**– Combines series and parallel connection to optimize parameters.



Characteristics and method of attaching photovoltaic cells



VIDEO

Solar photovoltaic panel structure:

<https://www.youtube.com/watch?v=TZTUefOjNI8>.

- Module formation - is realized by first connecting the photovoltaic cells in the desired configuration (serial, parallel or mixed). After that, they are placed between protective layers that protect them from mechanical damage, moisture and UV radiation, and ensure their long-term and stable operation. The module layers are:
 - Top layer (glass) – Protects cells from damage.
 - Middle layer (encapsulation material) – Ensures cell stability.
 - Backsheet – Protects against moisture and mechanical influences.
 - Aluminum frame – Ensures the strength of the panel.
 - Junction box – Contains bypass diodes to protect against shading. The box must be hermetically sealed to protect the electrical connections from moisture and dirt.
- Testing and quality control - Upon completion of assembly, the panels undergo testing to verify their functionality and resistance to external influences. Tests are performed under standard conditions and include checking maximum strength, resistance to moisture, UV radiation and mechanical loads caused by wind, snow or hail.

At the end of the formation process, the panels are ready for installation in the solar energy system, as compact, functional and reliable units.



Photovoltaic panels

Indicated electrical characteristics of photovoltaic panels

For photovoltaic panels, a number of electrical characteristics are specified on the technical plate and in the technical documentation. These characteristics are crucial for the correct selection, sizing and connection of panels in solar energy systems. Data are provided for standard test conditions (Standard Test Conditions - STC), which include:

- Radiation: 1000 W/m²;
- Cell temperature: 25 °C;
- Spectral distribution: AM1.5 (Air Mass 1.5).

The technical plate of the panel lists the following electrical characteristics:

- **Rated power (Pmax)**– Maximum power under standard conditions. It represents an estimate of electricity production.
- **Open circuit voltage (Voc)**– No-load voltage. This value is important for determining the maximum system voltage.
- **Short circuit current (Isc)**– Short circuit current. It is used for sizing cables, protective devices and inverters.
- **Voltage at maximum power, Vmp**- The voltage that the panel achieves at the point of maximum power. This value is important for setting up the inverter and optimizing system performance.
- **Current at maximum power, Imp**- The current produced by the panel at the point of maximum power. It is used to determine the required capacity of cables and other system components.
- **Panel efficiency**- What percentage of solar energy is converted into electricity.
- **Temperature coefficients**– They show the effect of temperature on panel performance.
- **Maximum system voltage**- The highest voltage at which the panel can safely operate. This value is important to determine the maximum number of panels that can be connected in series.
- **Maximum fuse current**- The highest current that the panel can withstand without damage. It is used when determining the value of protective devices in the system.

In addition to the mentioned electrical characteristics, other relevant panel characteristics are given on the technical plate, such as:

- **Panel type**;
- **Panel manufacturer and model**– manufacturer's name, model name and serial number that enables identification of the product;
- **Panel dimensions and weight**- data on the length, width, thickness and weight of the panel, which is important for assembly planning and mechanical stability of the structure;
- **Standards and certificates**– markings of standards according to which the panel has been tested (eg IEC 61215 for performance, IEC 61730 for safety) and possible special certifications (eg for resistance to moisture, hail or fire);
- **Protection class**- designation of the degree of protection against external influences, usually IP65 or IP67 for panel connection boxes.

These additional features allow users to more easily recognize the panel, check its compliance with the technical requirements of the system, and ensure proper installation and safe operation in various conditions of exploitation.

Electrical data from the technical plate for the specific photovoltaic panel

The indicated electrical characteristics of the SunTech Mono 400W FN panel

Rated power (Pmax): 400 W
 Open circuit voltage (Voc): 40.5 V
 Short circuit current (Isc): 10.2 A
 Voltage at maximum power (Vmp): 33.6 V
 Current at maximum power (Imp): 9.5 A
 Panel efficiency (η): 20.5%
 Temp. coef. voltage (β): -0.3 %/°C
 Temp. coef. current (α): +0.04 %/°C
 Temp. coef. strength (γ): -0.4 %/°C
 Maximum system voltage: 1000 V
 Maximum fuse current: 15 A
 Type: monocrystalline Si

4.5. Characteristics and types of solar photovoltaic systems

Solar photovoltaic systems (SFNS) are power plants (Solar photovoltaic power plants - SFNE) with a very wide range of applications - from small, home systems with a power of 1-10 kW, through commercial and industrial plants from 100 kW to several MW, and up to large power plants (solar photovoltaic parks), with a power of more than 100 MW. These systems are increasingly becoming an irreplaceable source of electricity within the framework of modern smart power systems and EES.

In the context of solar photovoltaic systems, electricity storage systems and the development of smart power grids will be of particular importance in the future. Storage systems enable the use of produced energy even in periods when solar radiation is not available. Smart grids integrate solar photovoltaic systems as decentralized energy sources, enabling more stable power supply, better control of consumption and reducing the load on centralized capacities.

The application and development of solar photovoltaic systems contributes to increasing energy security, reducing the emission of harmful gases and more efficient and intensive use of renewable energy sources.

Basic characteristics of solar photovoltaic systems

The performance of solar PV systems depends on a number of factors, including PV cell technology, installation location and meteorological conditions. Key features include:

- **Installed power** – It refers to the total maximum power that a power plant can produce under optimal conditions. It can vary from a few kilowatts (kW) for small systems to hundreds of megawatts (MW) for large solar power plants.
- **Efficiency** – Represents the percentage of solar energy that is converted into electricity. The efficiency of the system depends on the type of photovoltaic cells, whereby monocrystalline cells have a higher efficiency (15-22%) compared to polycrystalline and thin-film cells.
- **Annual production of electricity** – It refers to the amount of electricity produced during one year, depending on the climatic conditions, geographical location and the tilt of the panels.
- **Storage capacity** – If the system includes energy storage batteries, the storage capacity determines the amount of energy that can be stored for later use, which is especially important for off-grid and hybrid systems.
- **Durability and maintenance** – The expected lifespan of photovoltaic panels is 25-30 years with minimal maintenance, while other components, such as inverters and batteries, have a shorter lifespan and require regular servicing.
- **Environmental impact** – Solar power plants do not emit harmful gases during operation, but their production and recycling can have an environmental impact that is tried to be minimized by using sustainable materials and recycling methods.

Understanding the characteristics of solar PV systems is essential for efficient system design and operation.

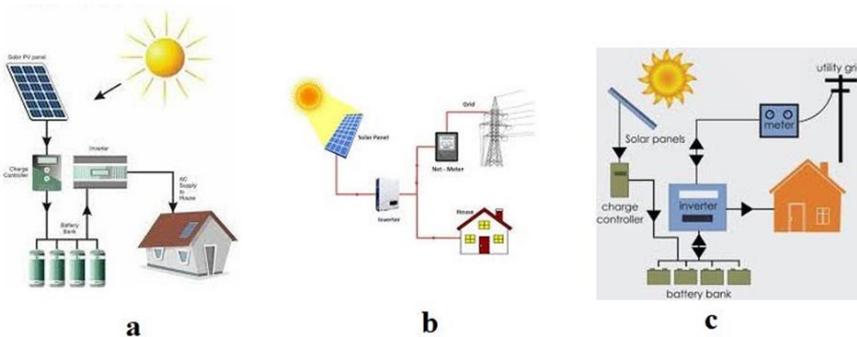
Division of solar photovoltaic systems according to different criteria

Solar photovoltaic systems can be classified according to various parameters, including the mode of operation, the installation location, the size of the system and the type of photovoltaic cells used.

Division according to work autonomy

- **Independent (off-grid) power plants** – They function independently of the power grid and usually include battery systems for energy storage. They are used in remote areas, campsites, mountain houses and other facilities without access to the network.
- **On-grid power plants** – They are connected to the power grid and use an inverter system to convert the produced direct current (DC) into alternating current (AC). Excess energy can be delivered to the grid through a net metering system.

- **Hybrid power plants**- They combine photovoltaic panels with other energy sources, such as batteries, wind farms or diesel generators, thus ensuring a reliable supply of electricity even in periods of reduced solar radiation.



Schematic representation of power plant autonomy: a) off grid; b) on the grid; c) hybrid

Division by location

- **On construction sites (rooftop power plants)**- Installed on the roofs of houses, industrial and commercial buildings. They optimize the use of available space and reduce the need for additional infrastructure.
- **On the ground (solar farms)**- Large solar power plants installed on large areas with optimal orientation towards the Sun, intended for the production of electricity for the grid system.
- **On water surfaces (floating power plants)**- Installations on lakes, artificial reservoirs or seas, where the occupation of land space is reduced and the efficiency of the panels is increased due to water cooling.
- **On moving objects**- Solar systems integrated on vehicles, ships and planes, enabling powering electrical systems and reducing fuel consumption.

Division by system size

- **Micro solar power plants**- Small power plants up to a few kilowatts, mainly for individual needs of households or smaller buildings.
- **Small solar power plants**- With a capacity of up to several tens of kilowatts, they are often used for commercial and industrial facilities.
- **Medium-sized solar power plants**- Powers from several hundred kilowatts to several megawatts serve as a significant source of energy for large business facilities and industrial plants.
- **Large solar power plants**- Installed capacity in megawatts (MW), used to power the power grid and supply electricity to a large number of users.

Division according to panel technology

- **Power plants with monocrystalline photovoltaic panels**- They use high-efficiency monocrystalline silicon cells with an efficiency of 18-22%.
- **Power plants with polycrystalline photovoltaic panels**- They have a slightly lower efficiency (15-18%) and lower production costs.
- **Power plants with thin film photovoltaic panels**- Flexible and light, but with lower efficiency, suitable for specific applications.
- **Power plants with organic photovoltaic panels (OPV)**- Light, environmentally friendly panels with lower efficiency, in the development phase.
- **Power plants with perovskite photovoltaic panels**- Advanced technology with high potential for the future due to lower production costs and higher efficiency.

Independent (Off-Grid) solar photovoltaic systems

Off-grid solar photovoltaic systems are energy systems that operate independently of the power grid, enabling users to produce and use electricity in areas where access to the grid is unavailable or unreliable. These systems are ideal for rural and isolated facilities, mountain houses, campsites, ships, vehicles and research stations.

Stand-alone solar photovoltaic systems can be classified according to structure, energy storage capacity and method of use.

Off-grid Solar photovoltaic systems without energy storage

These systems directly supply consumers with electricity produced from solar panels, without the possibility of storing excess energy. Main features include:

- **Advantages:** Simple design, lower costs, minimal maintenance.
- **Disadvantages:** The system only works as long as there is sunlight; no power at night or in cloudy conditions.
- **Application:** System for direct power supply of water pumps, fans, lighting in greenhouses, simple electrical devices.

Off-grid Solar photovoltaic systems with battery energy storage

These systems contain batteries that store excess energy produced during the day and enable powering consumers during the night or during periods of low solar radiation. The main features are:

- **Advantages:** Uninterrupted supply of electricity, stable operation of the system.
- **Disadvantages:** Higher costs due to the battery system, the need for battery maintenance.
- **Application:** Power supply for households, remote farms, tourist camps, mountain facilities, signaling and communication systems.

Portable off-grid solar photovoltaic systems

Portable (mobile) solar power plants are designed for easy relocation and quick installation. These systems are often integrated into compact modules and used in special applications.

- **Advantages:** Mobility, easy installation and use.
- **Disadvantages:** Limited capacity, dependent on weather conditions.
- **Application:** Humanitarian missions, camping, emergencies and emergency services, military and research expeditions.

Structure and principle of operation of independent (off-grid) solar photovoltaic power plants

Off-grid solar power plants consist of several interconnected components that enable the production, regulation, storage and distribution of electricity.

Photovoltaic panels with supporting structure

- **Photovoltaic panels**– They generate electricity by converting sunlight into direct current (DC).
- **Supporting structure**- Ensures proper placement of panels at an optimal angle to maximize solar radiation.

DC components

- **DC cables**- They transfer the electricity generated from the photovoltaic panels to the charge controller.
- **Charge controller**– A regulatory device that controls the charging of batteries and prevents them from being overcharged or deeply discharged.
- **Battery system**- Stores excess energy produced during the day and enables the use of electricity when there is no sunlight.
- **DC distribution cabinet**- Contains protection and switching equipment for regulation and protection of direct current circuits.

AC components

- **Inverter**– Converts direct current (DC) from batteries into alternating current (AC) suitable for standard consumers.
- **AC cables** –They connect the inverter to electrical devices and enable the distribution of electrical energy.
- **AC distribution cabinet**– Contains protective switches, fuses and measuring equipment (optional) for power regulation.

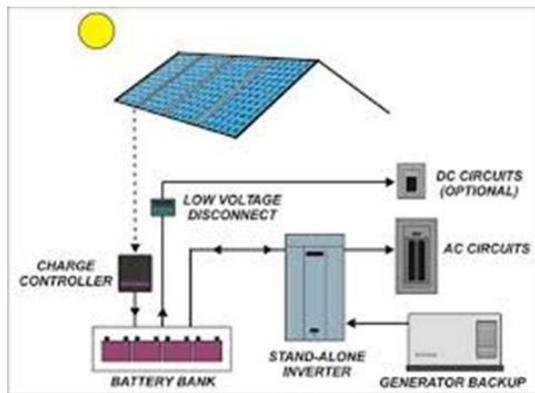
Consumer connection

- It connects the system to end consumers, including electrical appliances, lighting, heating and air conditioning systems, pumps, communication systems, etc.

Grounding and lightning protection system

- It ensures protection of the system from lightning strikes and stabilizes the voltage in the system, thus increasing the safety and longevity of the components.

Schematic diagram of off-grid solar PV systems: This diagram shows the basic components of the system and their interconnections, including the PV panels, charge controller, batteries and inverter.



Schematic diagram of an off-grid solar photovoltaic system



VIDEO

Principle of operation of off-grid solar photovoltaic power plants:

https://www.youtube.com/watch?v=i_4rJS35GF4.

On-grid solar photovoltaic systems

On-grid solar photovoltaic systems are systems that are directly connected to the public power grid. These systems allow users to produce electricity for their own needs, and any excess energy produced is transferred to the grid. This approach contributes to reducing electricity bills and enables more efficient use of renewable energy sources.

Types and characteristics of on-grid solar photovoltaic power plants

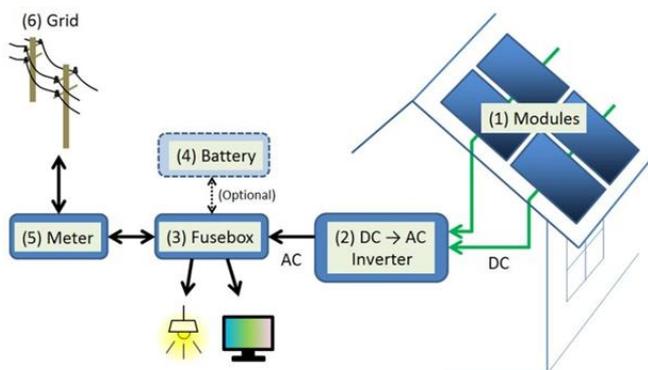
Grid solar photovoltaic systems can be classified according to the method of connection to the power grid:

- **Solar photovoltaic systems** connected to the network through the home installation: These systems are installed on residential or commercial buildings and are connected to the internal electrical installation of the building. The produced energy is first used for the needs of the facility, while the excess energy is transferred to the public grid.
- **Solar photovoltaic systems** directly connected to the grid: These systems are usually larger and are intended exclusively for the production of electricity that is directly supplied to the power grid, without local consumption.

Structure and principle of operation of on-grid solar photovoltaic power plants

On-grid solar photovoltaic systems are systems that enable the direct conversion of solar energy into electricity, where they are connected to the public power grid. These systems allow users to produce electricity for their own needs, and any excess energy is transferred to the grid. This reduces electricity costs and contributes to the sustainable use of renewable sources.

The structure of these systems includes several key components that together enable the efficient production and distribution of electricity:



Schematic structural view of the on-grid system

1. Photovoltaic panels with supporting structure

Photovoltaic (PV) panels are the basic elements of a system that converts sunlight into direct current (DC) electricity. These panels consist of multiple solar cells made of semiconductor materials, most often silicon. The supporting structure ensures stability and the optimal position of the panels in relation to the Sun, which is crucial for the maximum efficiency of the system.

DC components

- **DC cables:** They transmit the direct current produced in the panels to the inverter. Quality cables are necessary to minimize energy losses and ensure the longevity of the system.
- **DC distribution cabinet with protection and switching equipment:** This cabinet contains circuit breaker and protection devices, such as fuses and circuit breakers, which protect the system from overvoltages, short circuits, and other electrical anomalies.

AC components

- **Inverter:** A key component that converts direct current from the panel into alternating current (AC), compatible with the public grid and home appliances. Modern inverters also provide system performance monitoring and may have built-in protection mechanisms.

- **AC cables:** They transmit alternating current from the inverter to the main distribution cabinet of the facility or directly to the mains connection.
- **AC distribution cabinet with protection,** switching and measuring equipment: This cabinet contains equipment for distribution of electrical energy, protection against overload and short circuits, as well as measuring equipment for monitoring energy consumption and production.

Network connection

It represents the connection point of the system with the public power grid. Through this connection, excess produced energy can be delivered to the grid, and in periods when production is insufficient, energy can be taken from the grid.

Grounding and lightning protection system

This system provides protection against electric shocks and surges caused by lightning or other disturbances. Proper grounding and lightning protection are essential for user safety and equipment longevity.

Monitoring and management system

Modern on-grid systems are often equipped with software solutions that enable monitoring of system performance in real time, detection of potential problems and optimization of operation. These systems can be accessed through web platforms or mobile applications, providing users with detailed insight into energy production and consumption.

The integration of all these components enables the efficient operation of grid solar photovoltaic power plants, providing users with a reliable and sustainable source of electricity.

The principle of operation of these systems is based on the conversion of solar energy into electricity through photovoltaic panels. The direct current produced is transmitted via DC cables to the inverter, which converts it into alternating current. This energy is then supplied via AC cables and distribution cabinets to the power grid or used for the needs of the facility.

On-grid solar systems are designed to produce electricity from sunlight and connect it directly to the public power grid. These systems allow users to reduce their electricity bills and potentially generate income by selling the excess energy produced back into the grid.

The principle of operation of the on-grid system:

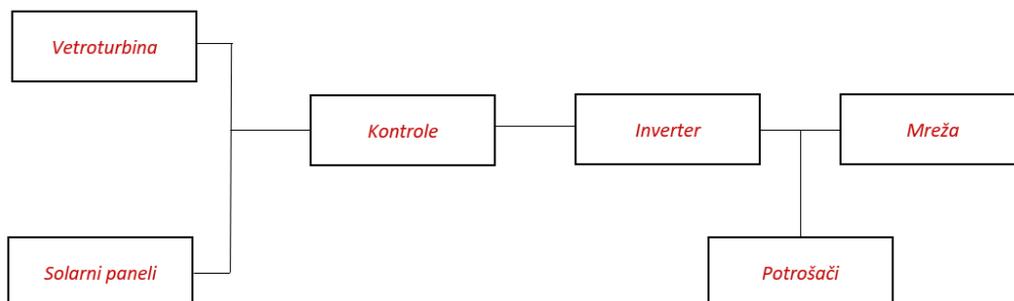
- **Production of electricity:** Photovoltaic (FN) panels, mounted on roofs or open areas, absorb sunlight and convert it into direct current (DC) electricity. This process is based on the photovoltaic effect, where photons from sunlight release electrons in the semiconductor material of the panel, creating an electric current.
- **Conversion of DC to AC current:** The direct current produced is transferred to an inverter, a device that converts it into alternating current (AC). This conversion is necessary because most household appliances and the power grid use alternating current.
- **Energy distribution:** After conversion, alternating current is distributed through the facility's electrical installation to power various devices. If the system produces more energy than is currently needed, the excess is automatically sent to the public grid. In cases where production is less than consumption, the lack of energy is compensated by taking it from the grid.
- **Measurement and calculation:** Special two-way meters monitor the amount of energy that is delivered to the network and that which is taken from it. Based on this data, users can realize savings on electricity bills, and in some cases, income from the sale of excess energy, depending on local regulations and tariffs.

It is important to note that on-grid systems do not function during a power outage, as they are designed to shut down automatically for the safety of workers repairing the grid. To provide power during such periods, hybrid systems incorporating energy storage batteries should be considered.

By integrating on-grid solar systems, users can efficiently use renewable energy sources, reduce their electricity costs, and contribute to the reduction of harmful gas emissions.

Hybrid solar photovoltaic systems

Hybrid solar photovoltaic systems combine the characteristics of grid (on-grid) and autonomous (off-grid) systems, allowing users to use energy from multiple sources and provide continuous power even in the event of a power outage. These systems integrate different energy sources and storage to optimize the production and consumption of electricity.



Block diagram of the hybrid system

Types of hybrid solar photovoltaic power plants with battery energy storage

These systems use batteries to store excess energy produced during the day. The stored energy is used during the night or during periods of reduced solar activity, providing a stable power supply. The advantage of this system is the possibility of using its own energy even during a power outage from the network.

With generator (diesel, petrol)

In this type of hybrid system, solar panels are combined with a fossil fuel generator. The generator is automatically switched on when the solar energy production and the energy from the batteries are not enough to meet the consumption. This ensures a reliable power supply even during long periods without sunlight.

With a wind turbine

These systems combine solar panels with wind turbines, using both solar and wind energy to produce electricity. This combination allows greater flexibility and stability in energy production, especially in areas where both sunlight and wind are available during different periods.

With a small hydroelectric power plant

In this case, solar panels are integrated with small hydroelectric plants, using the energy of flowing water as an additional source. Such systems are suitable for areas with available water streams, enabling constant energy production regardless of weather conditions.

By integrating different sources of energy and storage, hybrid solar photovoltaic systems provide flexibility and security in the supply of electricity, reducing dependence on a single source and ensuring continuous power even in the event of an interruption in the public grid.



EXERCISE

Research paper/PPT presentation "Comparative analysis of advantages and challenges of off-grid, on-grid and hybrid solar power plants".



QUIZ

Quiz 5: Division of solar photovoltaic power plants into off-grid, on-grid and hybrid power plants>

<https://forms.office.com/e/77hGTsPQV>.

Elements of solar photovoltaic systems, function and assembly principle

Solar photovoltaic systems consist of a number of key components that enable the conversion of solar energy into electricity, its storage and distribution to end users. Each component has a specific function and requires proper installation to make the system efficient, safe and long-lasting.

Supporting constructions of photovoltaic panels

Supporting structures play a key role in ensuring the mechanical stability of photovoltaic panels and their optimal positioning towards sunlight. The correct selection of the structure depends on the location of the installation, climatic conditions and the way the system is used.

Types of supporting structures and assembly procedure

- **Structures for mounting on the ground**

These structures are used when photovoltaic panels are installed in open areas, such as solar farms or private land.

- Fixed constructions imply placing the panels at an optimal angle for the region in which they are located. Assembly is done by attaching the panels to solid metal or aluminum supports that are previously buried in the ground or attached to concrete foundations. These supports provide system stability and resistance to winds and other weather conditions.
- Systems with tracking the position of the Sun can be uniaxial (move the panels in the horizontal plane) or biaxial (track the Sun both horizontally and vertically). These systems have electric motors and sensors that automatically adjust the tilt of the panels throughout the day to maximize energy production. Assembly includes installation of the load-bearing structure, installation of the electric motor and connection to the control system.

- **Constructions for installation on objects**

When photovoltaic panels are installed on buildings, different fastening systems are used:

- Integrated roof structures imply that the panels become an integral part of the roof. This system requires specialized supports and joints that replace traditional roof coverings.

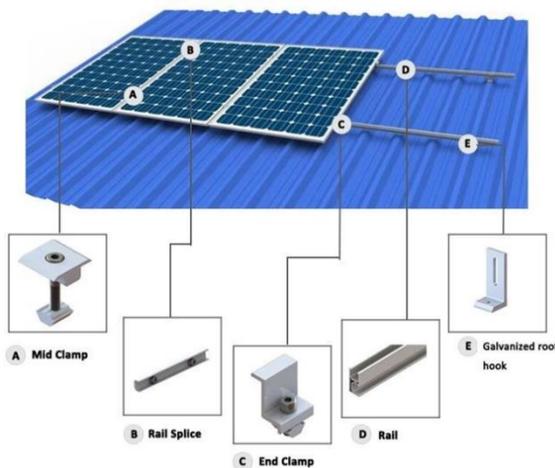
- Installation on facades and flat roofs involves the use of fixed steel or aluminum brackets on facade walls or concrete slabs. Procedure it involves drilling, anchoring the supports, attaching the panels to the rails and connecting them to the distribution cabinet.
- Solar canopies and pergolas are a popular solution that combines sun protection with electricity production. Assembly is done by attaching the panels to steel or aluminum frames that are installed as the canopy roof.

Components of supporting structures

- Roof Hooks and Anchors – Used to attach panels to roof beams.
- Brackets and guides - Horizontal and vertical brackets allow for stability and adjustability of the panel.
- Frames and Substructure – Ensures weather resistance and allows for secure attachment of panels.
- Fasteners - Screws, screws and fasteners ensure the strength of the joints.
- Solar tracking systems - Motorized mechanisms that enable optimal positioning of the panels during the day.



Various types of holders for PV panels



Elements for mounting PV panels on roofs with profiled sheets



Elements for mounting PV panels on tiled roofs

Electrical energy storage systems

Battery systems enable the storage of excess electricity produced for later use, which is especially important for off-grid and hybrid solar power plants.

Characteristics of battery systems

- Battery capacity (Ah or kWh) – Defines the amount of energy the battery can store.
- Rated voltage (V) – Standard values are 12V, 24V and 48V.
- Depth of Discharge (DoD) – Measures how much battery capacity can be used without damage.
- Storage efficiency and cycle life - Determines the longevity of the battery.

Assembly procedure of battery systems

- Placement of battery cabinets - Batteries are placed in specialized cabinets with ventilation to prevent overheating.
- Cable connection – Cables are connected in series or in parallel, depending on the required system voltage.
- Connection with charge controller and inverter - Ensures proper management of battery charging and discharging.

Charge controllers

The charge controller controls the flow of electricity from the panels to the batteries and prevents them from being overcharged or overdischarged.

Charging regulator mounting procedure

- Mounting the regulator on the wall or inside the distribution cabinet - It is placed in an easily accessible place.
- Connection to panels, batteries and consumers - Ensures optimal energy flow.
- System configuration – Setting the charging mode depending on the type of batteries.

Inverters

Inverters convert direct current (DC) to alternating current (AC), enabling the use of electricity in standard home and industrial systems.

- Inverter installation procedure
- Placing the inverter on the wall or in a cabinet - Allows ventilation and cooling of the device.
- Connection with solar panels and batteries - Ensures the conversion and distribution of energy.
- Connection to the power grid (for on-grid systems) - Enables the delivery of excess energy to the distribution system.

Electrical installations and protection systems

Properly designed electrical installations ensure reliable and safe operation of solar photovoltaic power plants.

Installation procedure of electrical components

- Laying of DC and AC cables – Protective channels and cable supports are used.
- Installation of distribution cabinets - They are mounted in protected locations to ensure the smooth operation of protective devices.
- Grounding and Lightning Protection - Necessary to reduce the risk of electric shock.

Monitoring and management system

Monitoring systems enable remote monitoring and optimization of the operation of solar photovoltaic power plants.

Elements of the surveillance system

- Sensors and Controllers – Monitor key system parameters.
- Work Monitoring Software - Enables remote monitoring.
- Alarms and safety devices - Warn of possible malfunctions.



Mounting elements for connecting PV panels



Solar charger 5.5 kW, inverter 12 V AC 220 V, battery charger 20 A and inverter 48 V 6000 W



QUIZ

Quiz 6: Elements of solar photovoltaic systems, function and assembly principles:

<https://forms.office.com/e/qNGbXtUMhy>.

4.6. Technical documentation and technical regulation of solar photovoltaic systems

Technical documentation and regulations play a key role in the design, installation, operation and maintenance of solar photovoltaic power plants. It includes all necessary information about system design, equipment characteristics, safety requirements and legislative frameworks that regulate the operation of solar plants. Proper access to technical documentation and regulations ensures efficiency, safety and compliance with regulations.

Types of technical documentation and their purpose

Technical documentation represents a set of design, technical and legal documents that are used in all phases of the life cycle of a solar power plant - from conceptual design to implementation and maintenance. There are different types of technical documentation, and the basic ones are:

- **Project documentation-** Contains all the necessary data for the design and implementation of the solar photovoltaic system. Includes:
 - Project Terms of Reference – Defines the basic requirements and objectives of the project.
 - Conceptual solution - Shows the concept of system operation and basic technical characteristics.
 - Conceptual project - Detailed overview of technical solutions and feasibility assessment.
 - Main project – Document with precise technical parameters, schemes, situational background from the geodetic administration and calculations required for performing the installation.
 - Project of the executed state - It is compiled after the implementation of the project and shows the actual executed solution.
- **Equipment manufacturer's documentation–** Includes technical specifications, instructions for use and maintenance, as well as certificates and test protocols for equipment such as photovoltaic panels, inverters and protective components.
- **Studies and expert findings-** They contain site analysis studies, environmental impact assessment and technical-economic analyses.
- **Test protocols and certificates-** Document system component testing results, display functional tests, protection settings and measurements of connection line insulation resistance and earthing resistance, performance verification and compliance with standards.

Types of technical regulations and their application

Technical regulations include a series of regulations, norms and guidelines that ensure the safety, efficiency and reliability of solar photovoltaic systems. Basic categories of technical regulation include:

- **Standards–** Technical documents defining the minimum technical requirements for the design, installation and maintenance of solar photovoltaic systems (eg IEC, ISO, EN standards).
- **Technical regulations–** National and international laws and regulations that regulate the construction and operation of solar photovoltaic systems.
- **Regulations-** Specific documents that regulate certain segments of the system, such as connection to the electrical distribution network, safety standards and occupational safety measures.
- **Recommendations and instructions-** Guidelines for designing, optimizing and integrating solar systems into the power system.

Interpretation of project documentation of solar photovoltaic systems

Project documentation is a key resource for contractors, investors and regulatory authorities. Studying and understanding project plans enables proper implementation of the system, prevention of technical problems and optimization of performance.

Some of the most important elements of project documentation include:

- **Principle diagrams**- They show the basic way the system functions and the interconnections of the components.
- **Block diagrams**- Illustrate the interaction of different parts of the system (panels, batteries, inverter, network).
- **Single-pole schemes**- Precise electrical representations of all system components and their interconnections.

Electrical symbols of elements of solar photovoltaic systems

Solar photovoltaic systems contain a large number of electrical components, each of which has its own technical symbol in electrical diagrams. Knowledge and correct interpretation of these symbols enables the understanding of project documentation and the realization of correct electrical connections.

Danger signs and warnings in technical regulations and documentation

Safety is a key aspect when working with solar photovoltaic systems. Technical documentation and regulations include various warning signs that inform about potential risks. Among them are:

- **High voltage markings**- They warn of the presence of dangerous voltage in the system.
- **Signs of danger of electric shock**- They inform about zones with an increased risk of electric shock.
- **Protective equipment labels**- Indicates the mandatory use of protective equipment, such as insulated gloves, safety glasses and footwear.

Interpretation of the safety plan at work in the solar photovoltaic system

The safety plan at work in the solar photovoltaic system defines all necessary measures and procedures for safe work with solar systems. This plan includes:

- **Measures to protect against electric shock**- Application of adequate insulation materials, protective devices and grounding systems.
- **Procedures in case of emergency situations**- Fire prevention measures, evacuation routes and procedures for extinguishing fires caused by electrical installations.
- **Weather protection**- Includes safety measures for working at height, protection against lightning strikes and resistance of equipment to extreme climatic conditions.

4.7. Material, tools, equipment and devices for work on the construction and maintenance of solar photovoltaic systems

For high-quality and safe construction, assembly and maintenance of solar photovoltaic systems, it is necessary to use appropriate materials, tools, equipment and devices. Each component of this system contributes to the efficiency and safety of work, enabling the correct execution of all operations.

Material: wiring conductors and cables, clamps, connectors, splitters, insulating tapes and other insulating material, PV pipes and boxes, lubricants, rust removers, corrosion protection agents (anti-corrosive paints, coatings, mastics), sealing materials, screws and nuts, marking and signaling material, construction material, etc.

Examples of power cables



PP00



PP40

Usage: For energy distribution in city networks, industrial plants. They are laid in cable ducts, closed rooms and in the ground with the application of additional protection.



PP 45-A

Usage: For energy distribution in city networks, industrial plants and in places where mechanical damage is expected. They are laid in the ground, in cable channels and in open space. It is suitable for vertical and oblique laying, as well as on slippery surfaces.



Control and signal cables

Usage: For connecting signal and command devices in industry, thermal power, hydroelectric power plants, wind and solar power plants, traffic, etc. They are laid in cable ducts in closed rooms and in the ground with the application of additional protection.



The MC-4 connector is the most common in practice



Various types of cable lugs



Various types of coupling sleeves



PVC installation pipes

Tool: insulating pliers, compression pliers, wire cutters, metal saws, screwdrivers, wrenches, files, hammers, electrical locksmith tools, manual lifting equipment, insulation shears and knives, sheet metal shears, saws, brazing tools, sheet metal bending tools, profile bending tools, punching tools, cutting tools, cutting tools, threading tools, measuring and control tools, tools and accessories for welding, spirit level, etc.



Tools for crimping, stripping insulation, measuring instruments

Equipment and devices: portable grounder, insulating pole, portable transformer, portable generator, drill, grinder, high-voltage voltage indicators, multimeters, instrument for recording UI characteristics of solar panels, diagnostic and testing devices, megohmmeter, temporary structures and facilities (scaffolding, working platforms, shelters, etc.), lifting hooks, brackets, anchors, crane with isolation platform, etc.



Measuring instruments



Power quality analyzer



Solar multimeter



Installation multifunction tester

Specialized machines and vehicles:For the construction and maintenance of solar photovoltaic systems, specialized machines and vehicles adapted to work in difficult conditions are often used. These include large-capacity telescopic cranes, all-terrain vehicles for transporting equipment and materials over inaccessible terrain, self-propelled scaffolding and platforms for working at height, as well as specialized drilling rigs. These vehicles and machines enable the safe and efficient execution of all construction and electrical works on solar photovoltaic systems.



Specialized vehicles

These materials, tools, equipment and devices are extremely important for efficient and safe work on the construction and maintenance of solar photovoltaic power plants, enabling quality performance of all necessary operations and tasks.



PRACTICAL EXERCISE

Task 1. Identification and analysis of materials for work in solar photovoltaic systems

Material and tools:

- Samples of different types of materials (copper and aluminum conductors, insulating materials, plastic and metal pipes, protective sheaths);
- Technical documentation and manufacturer's catalogs;
- Measuring tools (micrometer, crimping pliers, insulation stripping knife);
- Protective equipment (gloves, safety glasses).

Execution procedure:

1. Overview of available materials
 - Sort samples of conductors and insulating materials.
 - Identify materials based on color, flexibility, markings and standards.
2. Comparison of material properties
 - Measure the thickness of the conductor and insulation.
 - Compare the mechanical strength of different materials.
 - Analyze the advantages and disadvantages of using copper in relation to aluminum in electrical installations.
3. Discussion on the application of the material
 - Identify what materials are used for different types of installations.
 - Assess which material is most suitable for specific working conditions (moisture, high temperature, mechanical stress).
4. Group tasks
 - Divide into groups and analyze the technical specifications of a particular material.
 - Show conclusions about the choice of materials for specific applications.

Final check:

- Present the analysis and conclusions about the use of materials in specific working conditions.
- Explain the reasons for choosing a particular material based on technical data.
- Check the accuracy of the data in the technical documentation.



PRACTICAL EXERCISE

Task 2: Using hand and power tools

Material and tools:

- Basic hand tools (pliers, screwdrivers, scalpels, knives for removing insulation);
- Electric tools (drill, grinder, soldering iron, hot air gun);
- Testers and measuring instruments (multimeter, voltage tester, ammeter);
- Safety equipment (protective gloves, safety glasses, work clothes)

Execution procedure:

1. Demonstration of the use of tools
 - Familiarize yourself with the basic functions of hand and power tools.
 - Review the technical characteristics of the tool and how to use it.
 - Adjust the tool correctly before use.
2. Practical application of tools
 - Uses pliers and screwdrivers to process conductors and connect electrical elements.
 - Try power tools for drilling, cutting and shaping materials.
 - Apply the correctness test electrical installations.
3. Analysis of work efficiency and safety
 - Check the correctness of the tool before and after use.
 - Compare the speed and accuracy of hand and power tools in different tasks.
 - Discuss about safety rules when working with electric tools.

Final check:

- Demonstrate the correct and safe use of each tool.
- Present the correct application of power tools through practical tasks.
- Identify possible errors in using the tool and suggest improvements.

5. CONSTRUCTION OF SOLAR PHOTOVOLTAGE SYSTEMS

5.1. Preparatory works on the construction of solar photovoltaic power plants

Performing preparatory work on the construction of solar photovoltaic systems is a key stage in the system implementation process. This phase ensures that all conditions are adequately met for the successful installation of solar modules and associated equipment. Preparatory works include technical analysis, site assessment, organization of materials and tools, as well as the application of appropriate security measures.

Interpretation of technical documentation

Before starting the practical works, it is necessary to study the technical documentation in detail in order to gain an insight into the project specifications and installation conditions. Technical documentation includes design drawings, manufacturer's instructions and technical characteristics of system components. The key elements of the documentation to be analyzed are:

- Orientation and tilt of solar panels for maximum efficiency.
- Type and dimensions of the supporting structure.
- Electrical specifications of the system, including inverter power, cable type and connection method.
- Safety requirements and installation standards.

Delivery of equipment, materials and tools

One of the basic preparatory tasks is the proper organization of equipment and materials needed for assembly. Solar panels, supporting structures, cables, inverters and protective equipment must be delivered and stored in a way that prevents their damage. It is important to ensure that all elements are available at the construction site in accordance with the assembly plan in order to avoid work delays.

When organizing tools, it is necessary to prepare:

- Manual and electric assembly tools (drills, screwdrivers, wrenches, cable cutters, etc.).
- Protective equipment for working at height (belts, helmets, gloves, glasses).
- Measuring instruments (digital level, multimeter, solar analyzer).

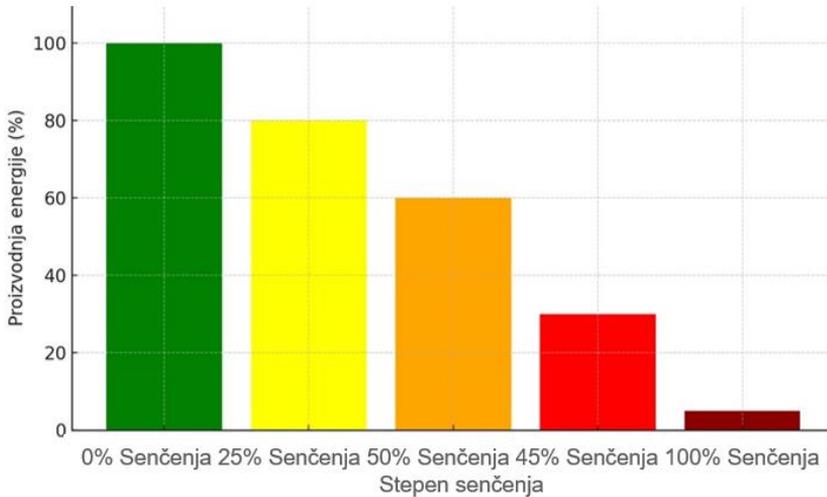
Checking the mounting surface

The quality and stability of the base on which the solar power plant will be placed are key factors for the safe and long-term operation of the system. Depending on whether the installation is carried out on the roof or on the ground, the approach to the evaluation of the substrate differs:

- **Roof inspection:** The material and load capacity of the roof are analyzed. For example, when mounting on sheet metal roofs, it is necessary to provide additional brackets to reduce the load. With concrete roofs, the possibilities of drilling and fixing the supports should be checked.
- **Soil testing:** When installing solar panels on the ground, an analysis of the soil's bearing capacity is carried out. In case of weak soil, additional foundations or concrete bases may be required to stabilize the structure. A table with a check list of the sequence of works is used.

Identification and removal of shading sources

Shading is one of the key factors that can reduce the efficiency of solar PV systems. Therefore, it is necessary to identify the sources of shading and take appropriate measures. Common sources of shading include trees, tall buildings, chimneys, and other objects that can block sunlight.



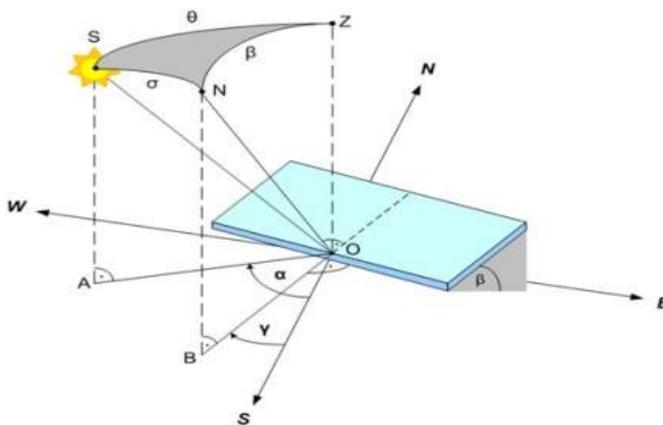
The influence of shading on the production of solar photovoltaic systems

Shading analysis uses tools such as solar analyzers and software tools to simulate the path of the Sun. If shading is a significant problem, it is possible to adjust the tilt and position of the solar panels to reduce losses.

Checking the orientation and slope of the surface

The correct orientation and tilt of the solar panels are crucial for achieving maximum electricity production. In general, for the northern hemisphere, the recommended orientation is toward the south, while for the southern hemisphere, solar panels are oriented toward the north.

The optimal tilt depends on the geographical location and the angular height of the Sun during the year. The slope that corresponds to the geographical latitude of the location is most often used, but it can be adjusted depending on the seasonal energy demand.



The position of the photovoltaic panels and the position of the Sun

The type and position of the roof will define the angle of inclination (β) and the azimuth angle (γ) of the photovoltaic panels (picture above), on which, among other things, the production of electricity will depend.

Cleaning and preparation of the mounting surface

Before installing the brackets and solar panels, the surface must be cleared of dirt, leaves, snow or other obstacles that may interfere with the installation. On roofs, it is important to check the stability of the materials and make the necessary repairs to ensure the safe operation of the installation.

Marking and provision of work space

For the safe execution of works, it is necessary to place appropriate safety signs, barriers and ensure access only to authorized persons. It is especially important to install safety equipment for work at height, such as safety ropes, safety belts and safety nets.



PRACTICAL EXERCISE

Task 1: Site assessment for a solar power plant

Correctly measure the slope and orientation of the roof/ground using measuring instruments, to ensure optimal efficiency of the solar power plant.

Material and tools

- Technical documentation
- Inclinometer
- Compass
- Solar analyzer
- Work protective equipment (gloves, safety glasses)

Procedure:

1. Preparing the workspace

- Ensure a safe environment for performing measurements.
- Interpretation of technical documentation
- Prepare the necessary measuring instruments.

2. Running the simulation

- Measuring the slope of the roof or ground using an inclinometer.
- Analyzing the influence of surrounding objects (trees, buildings, chimneys) on the efficiency of the system.
- Use a compass to determine the orientation to the south.
- Compare the obtained data with technical guidelines for optimal energy production.

Final check

- Compare the measured values with the recommended parameters for the solar installation.
- Discuss possible challenges in measurement and suggestions for improvement.



PRACTICAL EXERCISE

Task 2: Preparation of assembly equipment and tools

Proper organization of the necessary material and installation of safety measures before the installation of solar panels.

Material and tools

- Set of assembly tools (wrench, screwdriver, drill);
- Protective equipment (gloves, helmet, safety belt);
- Signaling for securing the work space;
- Elements of prefabricated construction.

Procedure

1. Preparing the workspace

- Ensure all materials and tools are available and organized.
- Check the safety measures at the work location (protective equipment, barriers, signaling).

2. Running the simulation

- Arrange and organize materials according to assembly stages.
- Check the correctness of assembly equipment and safety systems.
- Install temporary protective measures before starting work.

Final check

- Check that equipment and tools are properly prepared.
- Discuss possible improvements in the organization of assembly works.

5.2. Installation of supporting structures and photovoltaic panels

The installation of supporting structures and photovoltaic panels is a key step in the construction of solar photovoltaic systems. This process includes selecting and preparing the site, placing a stable and secure base for the panels, their precise orientation and ensuring optimal system performance. Correct installation of the structure and panels directly affects the durability, safety and efficiency of the operation of the solar power plant.

Determining the location and preparing the terrain

Before installing the solar photovoltaic system, it is necessary to perform a site analysis and prepare the ground for installation. Key factors in site selection include insolation, topography, slope and orientation, shading, and soil or roof bearing capacity.

Insolation refers to the amount of solar radiation available at a particular location during the year. By analyzing the insolation, the annual energy production can be estimated and a decision can be made about the optimal position of the panels.

The topography of the terrain plays an important role in determining the method of installation of solar panels. Flat terrains are preferred because they allow for easier installation and reduce the need for ground leveling, while uneven terrains require additional processing and adjustment of the supports.

Tilt and orientation directly affect the efficiency of a solar power plant. The panels are placed to face south (in the northern hemisphere) or north (in the southern hemisphere) to receive maximum solar radiation during the day. The slope of the panel depends on the geographical latitude of the location and is adjusted according to the recommended values for optimal electricity production.

Shading can significantly reduce system efficiency. Obstacles that can cast shadows on the panels, such as buildings, trees, poles and other objects, must be avoided. It is also necessary to pay attention to the placement of panels in order to avoid mutual shading. Shading analysis is done using specialized software or physical measurements during different parts of the day and year.

The bearing capacity of the ground or roof must be evaluated to ensure the stability of the installation. For installation on the ground, it is necessary to analyze the structure of the soil and select the appropriate type of foundation, while for roof installations, an assessment of the statics of the building is carried out to determine whether the roof can bear the additional load of the panels and supports.

After the location is selected, the terrain is prepared by removing vegetation and leveling the ground, if necessary. In the case of installation on the roof, the statics of the building are checked and the appropriate structure is chosen for mounting the panels. These steps ensure long-term, safe and efficient operation of solar photovoltaic systems.

Creation of the foundation for the supporting structure

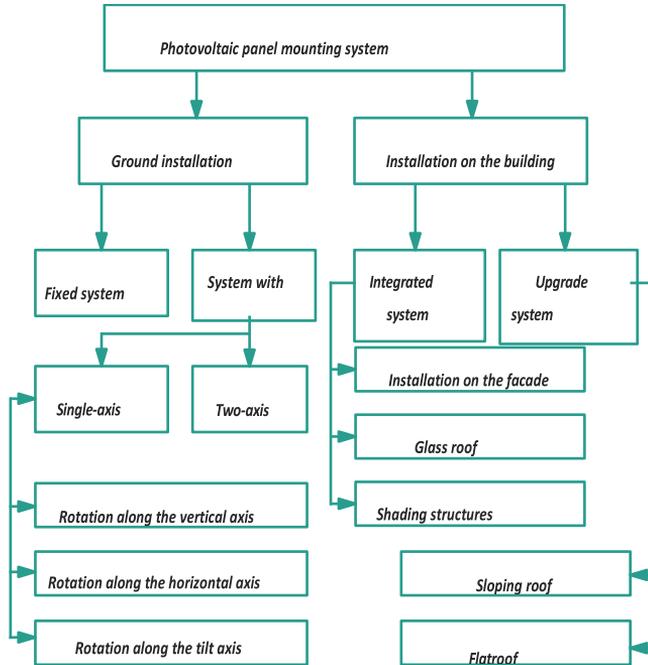
Laying the foundation for the supporting structure depends on the type of terrain and the load that the structure has to bear. When mounting on the ground, three basic types of foundations are used:

- Concrete foundations – the most stable solution, especially for large solar power plants. Pits are dug, reinforcing mesh is placed in them and concrete is poured.
- Screw foundations - are used for lighter constructions and in areas where it is not desirable to do concrete work.
- Steel columns grounded directly in the ground - they are placed using special machines that enable fast and firm anchoring.

In the case of roof installations, instead of foundations, special supports adapted to the type of roof are used. Flat roofs require mounting brackets that ensure stability and optimal tilt of the panels.

Installation of the supporting structure for photovoltaic panels

The supporting structure serves to fix the photovoltaic panels on the roofs or the ground, enabling optimal positioning according to the solar radiation. The installation differs depending on the installation location - on the roof or on the ground.



Types of systems for mounting photovoltaic panels

Installation of supporting structure elements for photovoltaic panels on the roof/on the ground

Mounting of supports and guides begins with fixing the basic structure according to the technical specifications of the project. In roof installations, roof hooks or anchors are first installed, to which horizontal and vertical guides are then attached. Screws and clamps are used to securely fasten the panels, paying special attention to proper load distribution to prevent mechanical stress.

When mounting on the ground, first the terrain is prepared and foundations or steel columns are placed, pull out tests are performed, after which horizontal and vertical guides are mounted. The panels are fastened with end and middle clamps, while screws and connecting material are used to firmly connect the elements. In addition, in systems with sun tracking, actuators are installed that allow adjusting the tilt of the panels during the day.

After installation, it is necessary to check the stability of the structure, the strength of the joints and the resistance to weather conditions before proceeding with the installation of the photovoltaic panels. The stability check includes testing the strength of the mounting brackets and guides, ensuring that all screws and fasteners are properly positioned and tightened, and testing resistance to loads such as high winds and vibrations. In addition, a final inspection of the structure should be performed to ensure that there are no unwanted movements or deformations that could compromise the longevity of the system.

Elements of the supporting structure for photovoltaic panels on the roof:

- Roof hooks or anchors - attach the structure to the roof surface and ensure stability.
- Brackets/guides (horizontal and vertical) - used for placing and attaching panels to the structure.
- End clamps and intermediate clamps – hold the panels in place and ensure their strength.
- Fastening material (bolts, screws) – used to fasten all structural elements.
- Roof screws for metal roofs – special screws for secure fastening of supports on metal roofs.

- Brackets for flat roofs - allow the installation of panels at a suitable slope.
- Substructure – additional elements that improve stability on specific types of roofs.

Elements of the supporting structure for photovoltaic panels on the ground:

- Foundations and base plates - ensure the stability of the structure on the ground.
- Brackets/guides (horizontal and vertical) - allow fixing of panels.
- End clamps and middle clamps – fasten the panels to the structure.
- Connecting material (bolts, screws) - connects the construction elements.
- Tilting structures - adjust the panel at the optimal angle towards the Sun.
- Solar tracking systems - allow automatic adjustment of the panels to maximize the use of solar energy.

Orientation and inclination of the supporting structure of the photovoltaic panels

The mounting of the support structure for the photovoltaic panels differs depending on the location because the installation on the roof or on the ground requires different approaches and specific methods of ensuring the stability and efficiency of the system.

In the case of roof mounting, the structure is attached directly to the load-bearing surface of the roof using roof hooks, anchors or brackets. These elements enable secure fixing of the panels with minimal damage to the roof structure. Special supports with ballast are used on flat roofs, which ensure stability without the need to drill holes in the roof. Additional challenges with roof installations include the slope and static load capacity of the building, so before installation it is necessary to carry out a load analysis



Installation on the ground or on flat roofs



Installation of panels on a flat roof

When mounting on the ground, the structure is placed on foundations or screw posts that enable stability and long-term operation of the system. Placing it on the ground allows greater flexibility in terms of panel orientation and tilt, as the supports can be precisely adjusted to the optimal angle of incidence of the Sun's rays. Additionally, solar tracking systems are often integrated with such installations to increase energy production.



Systems for installing panels on water (floating systems)

For installations on the ground, photovoltaic panels can be installed on fixed systems, where they are constantly at a certain angle, or on tracking systems, which follow the movement of the Sun for better efficiency. Systems with tracking can be single-axis (rotation along a vertical, horizontal or tilt axis) or two-axis, where the panels follow the Sun in both directions, which allows for maximum energy production.



Installation of solar panels on the ground

In installations on buildings, photovoltaic panels can be part of an integrated system, where they replace building elements (facades, glass roofs), or an upgrade system, where they are subsequently mounted on existing structures. The panels can be installed on sloping or flat roofs. In the case of sloping roofs, the panels are attached using special supports, which enable safe installation without disturbing the roof structure. On flat roofs, special brackets or ballast brackets are used to ensure stability without the need to drill the roof. Panels on flat roofs can be installed at a fixed angle or with an adjustable pitch, to optimize energy production depending on the geographical location.



Solar panels on the roofs of residential buildings

Solar panel mounted on the balcony fence

Installation of photovoltaic panels on flat roofs and use of ballast

The installation of solar panels on flat roofs covered with insulating membranes requires a special approach in order to ensure the mechanical stability of the system, the durability of the roof structure and optimal energy production. Key challenges include:

- **Preservation of waterproofing of the roof-** breaking through the roof membrane can lead to leakage and damage to the building.
- **Resistance to wind and other weather influences-** it is necessary to ensure that winds do not destabilize the system.
- **Optimal panel inclination-** in order to achieve maximum efficiency in electricity production.

Use of ballast in installation on flat roofs

Due to the need to preserve the waterproofing of the roof, the installation is done without fixed anchoring, and instead a ballast construction is used. This means:

- Placement of concrete blocks as a load that holds the structure in place.

- Proper placement of ballast to ensure even load-bearing capacity and prevent panel movement due to wind.
- The use of tilt-adjustable mounting systems, which allow the panels to be set at the optimal angle to maximize energy production.

Software analysis of bearing capacity dimensioning

When designing the system, software analysis is used, which takes into account the following parameters:

- **Wind rose**- analysis of dominant directions and wind speeds at the location.
- **Height of the object**- larger buildings are exposed to stronger winds and require additional stabilization measures.
- **Geographic location**- climatic conditions, snowfall and temperature affect the choice of assembly system.
- **Microclimate**– specific conditions on the roof (winds, shading, reflection) are analyzed in order to optimize the installation.

Advantages of ballast systems

- **Minimal impact on the roof**- does not damage the waterproofing layer.
- **Flexibility in installation**- easily adapts to different roof surfaces.
- **Quick assembly and disassembly**- suitable for temporary and long-term solar installations.



Ballast solar additional construction for a flat roof

Regardless of the location, the key factors affecting the efficiency of the system are the correct orientation and slope of the structure. The orientation is determined according to the geographical position and the availability of solar radiation, while the slope is adjusted to seasonal changes in order to achieve the maximum production of electricity.

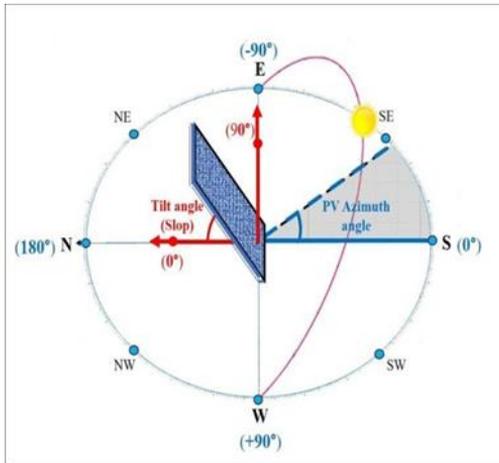
Tools such as a compass, inclinometer, laser level and GPS device are used to check the correctness of orientation and inclination. Precise adjustments ensure that the solar panels operate at maximum efficiency and minimize energy losses due to improper mounting.

Correct orientation and tilt of solar panels are key factors for optimizing their performance and maximizing the use of solar energy. The panels are usually placed to face south (in the northern hemisphere) or north (in the southern hemisphere) to receive the greatest amount of solar radiation during the day. The tilt of the panels depends on the latitude of the location and is optimally adjusted to achieve maximum electricity production throughout the year.

Orientation and Tilt Check Procedure:

- **Determining the direction of the panels** - A compass or GPS device is used to precisely determine the direction in which the panels are facing.
- **Slope measurement** - The slope of the panel is adjusted using a protractor, inclinometer or tilt level, with the use of a laser level for precise leveling of the structure.
- **Slope Adjustment** – If the system allows for angle change, the slope can be seasonally adjusted to optimize energy production at different times of the year.

- Alignment Verification – After the panels have been installed, a final check of their alignment and stability is carried out to ensure that there will be no unwanted movement due to wind or vibration.



The ideal angle for installing the solar panel

The angle of a solar panel is the angle between the surface of the panel and the horizontal plane. This angle affects the amount of sunlight that the panel can absorb and convert into electricity.

Precise settings and checks ensure maximum system efficiency and minimize potential energy losses due to improper orientation or tilt.

In order for the solar panels to work with maximum efficiency, it is necessary to precisely set their orientation and tilt. Different tools are used for checking:

- Compass – determines the direction in which the panels are facing.
- Angle meter and inclinometer - measure the exact tilt of the panel.



Angle meter and inclinometer

- Spirit level and tilting spirit level - allow precise leveling of panels.
- GPS device - used for precise location determination.
- Laser leveler - ensures accurate alignment of supports and panels.

After installing the supports, the panels are placed on the structure and fastened according to the technical documentation. It is necessary to ensure that all panels are properly aligned to avoid unnecessary shading and energy loss. These procedures ensure proper assembly and stable operation of solar photovoltaic systems, which enables a long service life and high efficiency.

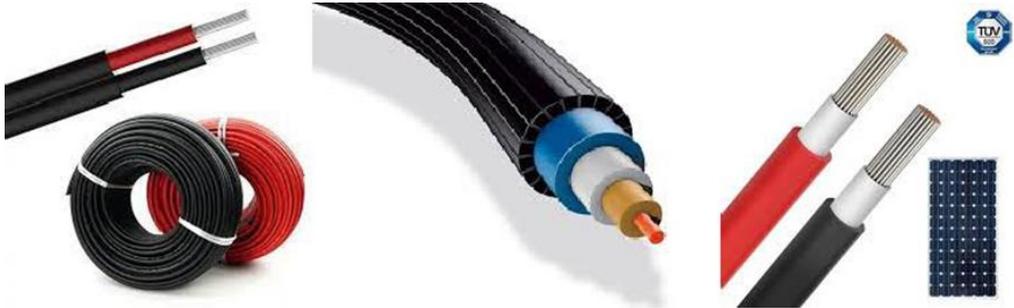
Proper laying and routing of DC cables when connecting photovoltaic panels

Correct laying and routing of DC (direct current) cables is crucial for the safety, efficiency and longevity of solar PV systems. This process ensures a stable transfer of electricity from the solar panels to other system components, minimizes losses and prevents potential breakdowns or fire hazards.

Basic rules for laying and connecting DC cables

- Choosing the right type of cables

DC cables connecting photovoltaic panels must be resistant to UV radiation, moisture, temperature changes and mechanical loads. Most often, solar certified cables (FN cables) are used, which have a special insulation resistant to external influences.



Examples of photovoltaic cables

- Proper cable sizing

Cables must have an appropriate cross-section to reduce power losses and ensure adequate current carrying capacity. The larger section reduces the resistance and heating of the cables, which is especially important for longer cable runs.

- Cable laying method
 - Inside the solar structure - the cables are passed through special supports, cable ducts or protective tubes to avoid mechanical damage.
 - On the roof or on the ground - the cables are secured with special UV-resistant ties or run through flexible protective tubes to prevent wear.
 - Underground - cables are laid in protected pipes that ensure protection against moisture and mechanical damage.
- Proper connection of cables and connectors
 - Using the appropriate MC4 connectors ensures a secure and waterproof connection between the panel and other components.



Examples of connectors for photovoltaic cables

- When connecting, pay attention to the polarity - the positive (+) and negative (-) poles must be connected correctly to avoid short circuits or reducing the efficiency of the system.
- The connectors must be firmly connected and insulated to prevent oxidation of the contacts.
- Minimization of loops and crossing of cables
 - DC cables should be laid so that they do not form unnecessary loops that can cause electromagnetic interference or induced voltages.
 - Cables must not be crossed with AC cables to prevent interference and potential safety hazards.
- Cable and connector protection
 - The cables must not be exposed to direct contact with sharp edges or metal parts of the structure, as this may damage the insulation.
 - Cables should be secured properly using UV-resistant ties or brackets, ensuring they are not over-tightened to prevent cracking of the insulation.
- Marking and testing of cables
 - All cables should be clearly marked according to technical documentation to facilitate system maintenance and diagnostics.
 - After laying and connecting, it is necessary to measure the continuity and insulation with a multimeter to ensure that there are no breaks in the lines and that the connections are correct.

Proper laying and routing of DC cables ensures long-term, safe and efficient operation of solar photovoltaic systems, while reducing the risk of breakdowns and energy losses.



VIDEO

Procedure for roof assembly of supporting structure and solar panels:

<https://www.youtube.com/watch?v=X51ZnslbWNY>.



PRACTICAL EXERCISE

Task 1: Mounting the photovoltaic panels on the supporting structure, while checking their alignment and stability

Mount the photovoltaic panels on the prepared supporting structure and check their alignment and stability. Fix the panels correctly and use the appropriate tools to check the correct position and tightness of the joints.

Material and tools:

- Photovoltaic panels;
- Supporting structure (guides, supports, clamps, screws);
- End and intermediate clamps;
- Connecting material (screws, nuts, washers);
- Level, inclinometer;
- Screw wrench;
- Protective equipment (gloves, safety glasses).

Procedure:

1. Prepare the workplace
 - Review the technical documentation and assembly plan.
 - Ensure that the supporting structure is stably placed and fixed.
 - Prepare all the necessary tools and materials.
2. Install photovoltaic panels
 - Place the panels on the guides of the supporting structure.
 - It uses end and intermediate clamps to fix the panels.
 - Fasten the clamps with screws and check that all connections are tight.
3. Check the orientation and tilt of the panel
 - Use a spirit level and tilt meter to check the exact position of the panel.
 - If necessary, adjust the tilt of the panel so that it is in the optimal position.
4. Ensure panel stability
 - Inspect all connections and fasteners.
 - Tighten all fastening elements so that the panels are resistant to wind and other external influences.

Final check:

- Visually inspect the position and attachment of the panel.
- Check all connections and fasteners to ensure they are secure and stable.
- Ensure that the panels are properly installed and ready for further work.



PRACTICAL EXERCISE

Task 2: Connecting the photovoltaic panels, according to the technical documentation, with the correct laying and routing of the DC cables

Connect the photovoltaic panels in accordance with the technical documentation. Properly lay and route the DC cables, ensure safe electrical connections and check the correctness of the system.

Material and tools:

- Photovoltaic panels;
- DC cables of suitable dimensions;
- MC4 connectors;
- Cable supports and UV-resistant ties;
- Protective pipes for cables;
- Multimeter for measuring electrical parameters;
- Connector crimping tool;
- Protective equipment (gloves, safety glasses)

Procedure:

1. Plan to connect the panels
 - View the technical documentation and connection diagram.
 - Determine the type of connection - serial, parallel or mixed.
 - Select the appropriate cables and connectors.
2. Properly lay and route the cables
 - Inside the solar structure: pass the cables through the supports and protective pipes.
 - On the roof or on the ground: secure the cables with UV-resistant ties.
 - Underground: lay the cables in protective tubes to protect against moisture and mechanical damage.
3. Connect panels
 - Connect the panels in series or parallel according to the technical documentation.
 - Uses MC4 connectors for secure connection.
 - Check that all connections are properly secured and insulated.
4. Test the electrical characteristics of the system
 - Measure the voltage and current with a multimeter to confirm the correct connection.
 - Check the continuity of the connections and remove any irregularities.

Final check:

- Inspect all connections and cables to ensure their safety and correctness.

5.3. Installation and connection of solar equipment photovoltaic systems

Mounting and connecting solar PV system equipment are key steps in the system installation process. This segment includes the installation of the supporting structure for the equipment, the organization of cable installations, and the correct installation and connection of the inverter and charge controller. Correct installation of all components ensures long-term, safe and efficient operation of the system.

1. Assembly of the supporting structure for the equipment

The supporting structures are used for proper placement and fixing of electrical equipment, enabling its stability, protection and ease of maintenance. Constructions are chosen depending on the type of equipment, available space and installation conditions. There are different types of mounts used in solar PV systems:

Wall brackets

Wall mounts are used for mounting inverters, charge controllers and distribution cabinets inside buildings or on external walls. They are made of steel or aluminum and designed to allow for firm and secure attachment of equipment.

The installation procedure of wall supports includes:

- Determining the position - The mounting location is determined according to the technical documentation and the available space.
- Marking the points for drilling - Mark the points on the wall where the supports will be attached.
- Drilling holes and installing anchor screws or dowels - The stability of the support is ensured.
- Bracket fixing and stability check – After the brackets are installed, their strength is checked before mounting the equipment.

Floor supports (free-standing structures)

Floor supports are used when it is not possible to mount the equipment on the wall. They enable flexible placement of devices and better organization of the system.

Installation of floor supports includes:

- Site selection and terrain preparation – The surface must be flat and stable.
- Installation of metal supports - They are fixed using anchor screws or concrete foundations.
- Stability check – After fastening, stability and vibration resistance are checked.

Rail mounting

Rail mounting implies the use of aluminum or steel rails that enable the modular installation of several devices on the same structure.

Assembly steps include:

- Fixing the rails to the wall or floor construction using special fasteners.
- Device placement using clamps - Allows for easy movement and adjustment of the layout.
- Ensuring proper spacing and checking stability – Rail mounting facilitates space organization and future system maintenance.

Equipment cabinets

Cabinets for electrical equipment protect devices from dust, moisture and mechanical damage. They are placed on wall or floor supports, where it is important to ensure good ventilation.

The procedure includes:

- Preparing the installation site and fixing the cabinets.
- Passing the cables through the provided openings for orderly installation.
- Installation of doors and protective covers to protect the equipment.

Cable construction

Cable construction ensures proper laying and protection of cables in the system. Different types of cable carriers are used:

- **Cable trays and racks**- They organize the cables inside the technical rooms, allowing a clear view and easy access.
- **Cable ducts and channels**- They protect cables in closed spaces, reducing the risk of mechanical damage.
- **Cable pipes**- They provide additional mechanical protection of cables, especially for underground installations.
- **Cable trays**- They enable the secure attachment of cables to the structure, preventing them from falling out or being damaged.
- **Cable trenches**- They are used to protect underground cables, especially in industrial plants or larger solar power plants.



Display of the rack distribution system



The method of guiding installation cables on a flat roof with obstacles in the direction of the route

Installation and connection of the inverter and charging regulator

Inverter installation

Inverters enable the conversion of direct current (DC) to alternating current (AC), which is essential for powering devices connected to the electrical distribution network or home installation. Correct installation ensures their efficiency, long service life and system safety. Inverters must be placed in a well-ventilated place, protected from direct exposure to the Sun and moisture, in order to prevent overheating. After fixing it on the wall bracket or floor structure, it is connected to the DC cables from the solar panels and the AC cables leading to the distribution cabinet. It is important to ensure proper polarization and adequate grounding to prevent power losses and electrical failures. Finally, the inverter is tested to ensure proper energy conversion and distribution in the system.

Installation of charge controller

The charge controller controls the charging process of the batteries and prevents overcharging or discharging. Correct installation is essential for efficient and safe operation of the system.

The assembly process includes:

- **Select location**– The charge controller should be placed close to the battery system in order to reduce energy losses.
- **Fixing on a support or inside a cabinet**– The regulator is attached using mounting screws or rail systems, depending on the model and technical requirements.
- **Connecting to solar panels**- DC cables from solar panels are properly connected according to polarity to ensure proper energy flow.
- **Connecting to batteries**- The connection to the battery system is made according to the manufacturer's specifications in order to optimize the charging and discharging process.
- **Checking connections and ensuring cable protection**- The safe functioning of the system is ensured by the use of insulating materials and protective channels
- **Testing and checking the operation of the regulator**– After the installation is complete, the controller is tested to ensure proper functioning of the charging and protection of the batteries.

Connecting the mounted equipment of solar photovoltaic systems

Connecting the installed equipment of solar photovoltaic systems requires the use of specialized materials and tools to ensure the safe and efficient operation of the system. Proper connection of all elements reduces energy losses, ensures system stability and contributes to its long-term operation.

Material and equipment for connecting the system:

- **DC and AC cables** –They are used to connect solar panels, charge controllers, battery systems and inverters.
- **MC4 connectors**– Special connectors for safe connection of solar panels and regulators.
- **Fuses and circuit breakers**– They protect the system from overload and short circuits.
- **Ground rods and copper conductors**- They provide protection against overvoltage and electric shocks.
- **Cable supports and protective tubes**- They serve for the organization and protection of cables.
- **Thermal imaging camera (optional)**– Used to check for overheating of joints.
- **Insulating gloves and protective equipment**– Necessary for safe work with electrical installations.

Tools needed:

- **Multimeter**– For measuring voltage and checking the correctness of connections.
- **MC4 connector pliers**- They enable precise connection of solar cables.
- **Insulation stripping pliers**– Facilitates the preparation of cables for connection.
- **Insulation screwdrivers and set of socket wrenches**– Necessary for attaching connectors and fuses.
- **Ground resistance meter**– It is used to check the correctness of the earthing system.

After all the components of the solar photovoltaic systems are properly mounted, the connection process is approached. Each connection must be made precisely and in accordance with the technical documentation in order to ensure the efficiency, safety and reliability of the system. Connecting equipment requires careful handling of electrical connections, use of adequate tools and adherence to prescribed safety measures.

Connecting the solar panels to the inverter

The first step in connecting the mounted equipment is establishing the connection between the solar panels and the inverter. Solar panels generate direct current (DC) that must be transferred to an inverter for conversion to alternating current (AC).

The connection process includes:

- **Checking the polarity of the cables**– The DC cables must be connected correctly, with the red cable (positive pole) and the black cable (negative pole) properly routed to the corresponding terminals on the inverter.
- **Using solar MC4 connectors**- The cables are connected using specialized MC4 connectors that enable a safe and reliable connection without energy losses.
- **Cable protection and wiring organization**– DC cables are routed through protective tubes to prevent mechanical damage and then secured with ties along the structure.
- **Voltage measurement before connection**- Using a multimeter, check the voltage of the DC connections to ensure correctness before connecting to the inverter.

Integration of the battery system with the charge controller

The battery system enables the storage of excess produced energy, which ensures power supply in periods when there is no solar radiation. The charge controller manages the process of charging and discharging the batteries, preventing them from being overcharged or deeply discharged.

The connection process includes:

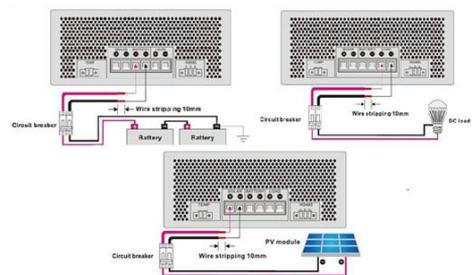
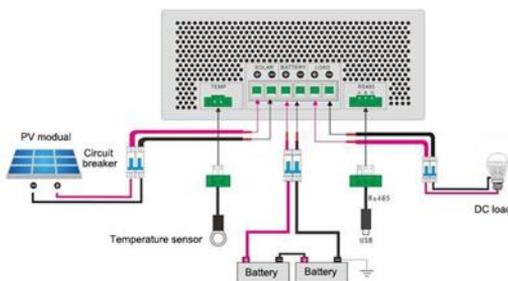
- **Connecting the battery pack to the charge controller** - DC cables are properly connected according to the marked connections on the regulator, paying attention to the polarity.
- **Placing a fuse between the regulator and the battery**– The installation of a protective fuse protects the battery system from overload and short circuit.
- **Establishing a connection between the charge controller and the solar panels**- This connection enables the delivery of energy from the solar panels to the batteries with automatic voltage regulation.
- **Measurement of battery current and voltage**- Using a multimeter, it is checked whether the system functions within the intended limits.

Connecting the inverter to the distribution cabinet

The inverter converts direct current (DC) to alternating current (AC), which is then distributed throughout the system using a switch cabinet. This connection is crucial for the integration of the photovoltaic system with consumers or the electrical distribution network.

The connection process includes:

- **Connecting the AC cables from the inverter to the distribution cabinet**- Voltage lines (L, N and PE) are connected according to the marked connections in accordance with electrical installation standards.
- **Installation of protective switches and fuses**- Automatic fuses are installed in the distribution cabinet to protect the system from overload and short circuits.
- **Checkconnections to consumers** - The correctness of the connection is tested to ensure a stable voltage for the connected devices.



Connecting the inverter to the appropriate components



VIDEO

Connecting the elements of a hybrid solar system (step by step):

<https://www.youtube.com/watch?v=cCH4IEs1Vzc>.

Procedure for mounting and connecting solar photovoltaic panels:

<https://www.youtube.com/watch?v=oeFePOJU28w>.

Connection of earthing and protective systems

The grounding system ensures the safety of the solar photovoltaic system by reducing the risk of electric shock and atmospheric discharges. All system components must be connected to a ground point to allow safe operation.

The connection process includes:

- **Connecting the grounding of the solar panels, the inverter and the distribution cabinet-** With the help of copper cables and grounding rods, it is ensured that excess current is diverted to the ground.
- **Installation of lightning protection-** On buildings where there is a greater risk of lightning strikes, a lightning protection system with drainage lines is installed.
- **Measuring ground resistance-** A measuring instrument is used to check the correctness of the grounding system.

System correctness testing

After all the elements of the system are connected, it is necessary to carry out testing to ensure that the solar photovoltaic power plant works correctly and safely.

The testing procedure includes:

- **Measurement of voltage and current in key points of the system–** System parameters are checked with a multimeter and an ammeter.
- **Checking the operation of the inverter and battery system–** By simulating different loads, the correct operation of the inverter and batteries is checked.
- **Functional testing of protective switches and fuses-** Their response to overload and short circuits is tested, as well as testing of relay protection settings (undervoltage, overvoltage, underfrequency, overfrequency).

Connecting the mounted equipment of solar photovoltaic systems requires precision, safety measures and technical knowledge of the system. Every step, from connecting the solar panels to testing the correctness of the system, must be performed in accordance with technical regulations to ensure reliable and efficient operation of the power plant.



QUIZ

Quiz 7: Montazand connecting equipment of solar photovoltaic systems:

<https://forms.office.com/e/g1CTChgFNp>.



PRACTICAL EXERCISE

Task 1: Mounting the inverter on the supporting structure and connecting it to the solar panels

Carry out the correct placement of the inverter on the supporting structure and connect it to the solar panels according to the technical documentation.

Material and tools:

- Inverter;
- Brackets for wall or floor mounting;
- DC cables with MC4 connectors;
- Pliers for MC4 connectors;
- Set of insulated screwdrivers and keys;
- Multimeter;
- Protective equipment.

Procedure:

1. Choose a suitable location for mounting the inverter, taking care of ventilation and moisture protection.
2. Mark and drill holes for attaching the bracket to the wall or floor surface.
3. Attach the inverter to the brackets using screws and ensure its stability.
4. Connect the DC cables to the solar panels, taking care of the correct polarity.
5. Check the voltage values with a multimeter before finally connecting the inverter.
6. Ensure proper grounding of the inverter and check whether the installation is carried out according to safety regulations.

Final check:

- Visually inspect all connections.
- Test the functionality of the inverter.
- Document the measured voltage values and record any irregularities.



PRACTICAL EXERCISE

Task 2: Mounting the charge regulator and connecting it to the battery system

Install the charging regulator and connect it to the solar panels and battery system, while checking the correct operation.

Material and tools:

- Charging controller;
- Wall bracket;
- DC cables;
- Set of screwdrivers and pliers;
- Multimeter;
- Fuses;
- Protective equipment.

Procedure:

1. Determine the location for mounting the charge regulator, taking into account protection from moisture and ambient temperature.
2. Place the regulator on the wall bracket and fasten it with the appropriate screws.
3. Connect the solar panels to the charge controller using the appropriate connectors.
4. Connect the battery system to the charge controller, paying attention to the correct polarity.
5. Install fuses between the regulator and the battery to protect against overload.
6. Measure the voltage and current of the system to verify proper operation.

Final check:

- Check all connections and fuses.
- Check that the batteries are charging properly.
- Document the voltage and current readings.

5.4. Selection of protective means and equipment for work on mounting and dismantling elements of the solar power plant

In the previous chapters of the manual, the tools, equipment and devices used in the construction and maintenance of solar power plants, as well as the basic protective equipment for work in power plants, were covered. In this chapter, the focus is on the specific protective equipment and measures that are applied when mounting elements of solar photovoltaic power plants.

Works on mounting and dismantling elements of the solar power plant are high-risk tasks that require the use of adequate protective means and equipment. These jobs often involve working at heights, handling heavy components, exposure to electrical installations and adverse weather conditions, so it is essential that all workers use appropriate personal and collective protection.

Personal protective equipment (PPE)

Personal protective equipment protects workers from potential dangers and is mandatory for everyone who participates in the assembly and disassembly of elements of solar photovoltaic power plants. Equipment includes:

- **Protective helmet**- Protects the head from blows, falling objects and electric shocks. The helmet must have a safety strap to keep it stable while working at height.
- **Safety belt and lanyards (system for working at height)**- All workers working on the roof must use safety belts with energy absorbers, as well as lanyards attached to fixed points.
- **Protective gloves**- They must be resistant to wear and mechanical damage, and dielectric gloves that prevent electric shock are used to work with electric power components.
- **Protective clothing and footwear**- Workers must wear antistatic and fireproof weatherproof clothing. Footwear should have protective toe caps and non-slip soles.
- **Hearing and vision protection**- Depending on the working environment, antiphons (noise protection) and protective glasses are used to prevent dust, metal particles and wind from entering the eyes.
- **Respiratory protection**– When working with chemicals, such as anti-corrosion agents or paints for metal parts, masks with anti-evaporation filters are used.

MANDATORY PROTECTIVE EQUIPMENT							
Helmet	Work clothes	Protective footwear	Protective gloves	Safety glasses	Protective earmuffs	Respirator	Float vest
							

Collective protective equipment

In addition to personal protection, collective protective equipment is installed at the construction site of the solar power plant, which reduces the risks for all workers.

- **Safety barriers and protectivenets** – Placed around critical areas to prevent tools and materials from falling from a height.
- **Lightning protection systems**- The installation of solar panels involves working with metal components in an open space, so special attention is paid to protection against lightning strikes through grounded structures and surge arresters.
- **Signage and marking of work zones**- Marking dangerous areas with reflective strips and safety signs reduces the risk of accidents and collisions with heavy equipment.
- **Auxiliary systems for lifting and manipulating loads**– They include cranes, winches, cranes and specialized systems for transporting heavy components, in order to reduce the physical effort of workers and the risk of injury.

Electrical protective equipment

Since solar power plants involve working with power components, special attention is paid to protection against electric shock and correct handling of high voltages.

- **Dielectric gloves and footwear-** They ensure protection when working with cables, distribution cabinets and electrical installations.
- **Voltage rectifiers and insulating pads-** They are used when testing and connecting electrical devices to prevent direct contact with dangerous voltages.
- **Tools with insulated handles-** Every tool used for connection and maintenance of electrical installations must be insulated and comply with the standards of protection against electric shock.
- **Voltage testers and circuit breakers-** Enables safe checking of voltage before working on electrical components.

Procedure for checking and using protective equipment

Before the start of any work on mounting or dismantling elements of the solar power plant, an inspection of protective equipment and mandatory training of workers is carried out. Key procedures include:

- **Checking personal protective equipment-** All workers must check the correctness of their helmets, safety belts, gloves and other equipment before entering the work zone.
- **Checking electrical protection-** Measurement of cable insulation, grounding test and verification of the surge protection system is performed before working on power installations.
- **Testing safety systems for work at height-** Ropes and safety systems are regularly tested for load capacity and resistance to ensure that they can withstand dynamic loads during operation.
- **Introduction of Standard Operating Procedures (SOP)-** Workers must follow defined procedures for safe handling of equipment, including lockout and tagout rules (LOTO - Lockout/Tagout) to prevent unintended system starts.

Emergency measures and evacuation plan

In addition to standard protective equipment, any team working on the installation and dismantling of a solar power plant must be familiar with emergency procedures.

- **Gondola and tower evacuation plan-** In case of fire, electrical failure or other incidents, workers must have access to escape routes and rapid descent systems.
- **First aid kit and AED device-** First aid must be available on site, including an automated external defibrillator (AED) for cardiac arrest emergencies.

The use of adequate protective equipment and the implementation of safety procedures are crucial for the prevention of accidents and the protection of the lives of workers who work on the construction, maintenance and dismantling of solar power plants. The implementation of these measures contributes to the efficient and safe performance of all works within the plant.



QUIZ

QUIZ 8: Checking knowledge about protective equipment and equipment:

<https://forms.office.com/e/Esgnr67zKf>.



EXERCISE

Personal or collective protective equipment in solar power plants

Task: Write a seminar paper/PPT presentation on personal or collective protective equipment used at solar power plant construction sites.

6. PERFORMANCE OF ELECTRICAL INSTALLATIONS OF SOLAR PHOTOVOLTAGE SYSTEMS

Electrical installations represent a key segment of solar photovoltaic power plants, enabling the transmission, distribution and security of electricity produced by solar panels. Proper design and execution of installations ensures efficient operation of the system, minimal energy losses and protection against electrical failures.

6.1. Elements and method of performing solar electrical installations photovoltaic systems

Electrical installations of solar photovoltaic systems represent a key component of the system, responsible for the transmission, conversion and distribution of electrical energy. Their correct performance ensures long-term and efficient operation of the system, as well as the safety of users and equipment. This unit provides basic information on types of electrical installations, cables, wiring equipment, grounding and surge protection systems.

Types of electrical installations of solar photovoltaic systems

Electrical installations in solar photovoltaic systems can be divided according to function and type of energy transfer:

- **DC (direct current) installations-** include cables, connectors, distribution cabinets and protective devices that enable the transmission of electricity from the solar panels to the inverter.
- **AC (alternating current) installations-** include equipment that is used after converting direct current into alternating current and enables its distribution to consumers or the electrical distribution network.
- **Grounding and lightning protection installations-** ensure the safety of the system, reducing the risk of electric shocks and damage caused by overvoltages.
- **Installations for monitoring and management-** enable monitoring of power plant operation, data recording and performance optimization.

Supporting cable structures

Cable structures play a key role in the organization and protection of cables, enabling efficient laying and preventing mechanical damage:

- **Cable trays-** enable organized routing of cables in technical rooms.
- **Cable racks-** are used for placing cables at longer distances, allowing ventilation and easy access.
- **Cable ducts and channels-** provide additional mechanical protection of cables in internal spaces.
- **Cable pipes-** are used to protect cables in underground installations.
- **Cable trays-** fasten the cables to the structure, reducing the risk of wear.
- **Cable trenches-** they ensure the protection of cables laid in the ground, especially in the case of larger solar power plants.

DC and AC cables in electrical installations

Cables in solar photovoltaic power plants must be resistant to high temperatures, UV radiation and mechanical loads. They differ according to the type of electricity they transmit:

- **DC cables-** are used to transfer direct current from the solar panels to the inverter or batteries. They must have double insulation and UV protection.

- **AC cables**- are used to distribute alternating current from the inverter to consumers or the electrical distribution network. Their characteristics depend on the voltage level of the system.

Electrical installation equipment in electrical installations

Electrical installation equipment is used for protection, management and monitoring of system operation:

- **Circuit breakers, 4p main switch with motor drive, disconnectors and contactors**- enable power lines to be disconnected in case of emergency.
- **Fuses and surge protectors**- protect the system from short circuits and lightning strikes.
- **Measuring devices**- include voltmeters, ammeters, wattmeters and meters, which enable monitoring of system operation.
- **Busbars, insulators and connecting terminals**- ensure reliable connection of all system components.



Four-pole switch with motor drive

Appearance of different types of cam clutches b)

Fusible fuse inserts: a) fuse type D, fuse type B, c) fuse type NV



The picture shows: a) Layout of automatic installation switches (fuses),

b) Differential current protection device

Layout of the surge arrester: a) for an alternating current circuit, b) for a direct current circuit

Elements of DC electrical installations

DC electrical installations in solar photovoltaic power plants include:

- **DC cables and connectors**- ensure quality transmission of direct current from the panel.
- **DC distribution harness** – contains protective switches, fuses and overvoltage protection, ensuring the safety of the system.

Elements of AC electrical installations

AC electrical installations include:

- **AC power cables**- connect the inverter with the distribution cabinet and the electrical distribution network.
- **AC distribution cabinet** - includes protective switches, measuring equipment and automatic switches.

Grounding of solar photovoltaic power plants

The grounding system ensures the protection of the user and the equipment, allowing the safe discharge of excess current into the ground. The main elements of the grounding system are:

- **Grounding device** - metal electrodes that enable current to be carried into the ground.
- **Busbars and connecting lines** - ensure the connection of all metal parts of the system to the ground.

Lightning protection of solar photovoltaic power plants

Lightning protection prevents system damage:

- **Lightning rods** - they are placed at the highest points of the power plant and redirect the electricity into the ground.
- **Downpipes** - connect the clamps to the ground, allowing controlled discharge of electricity.
- **Measuring joints and connecting element** - are used to check and maintain the protection system.



QUIZ

Quiz 9: Elements and onhand indeed electricity billshinstallations of solar photovoltaic systems:

<https://forms.office.com/e/5CE9DnvnUd>.

6.2. Execution of DC electrical installation of solar photovoltaic systems

Performing the DC (direct current) electrical installation of solar photovoltaic systems is one of the key steps in the implementation of these systems. DC installation enables the efficient transmission of produced electricity from photovoltaic panels to inverters and other consumers. In this part, we will describe the specifics of the DC system, the installation rules, the choice of cables, the connection of components and the safety measures that must be observed.

Characteristics of DC installation in solar photovoltaic systems

DC installation in photovoltaic systems has specific requirements due to high voltage and continuous current flow. Key features include:

- **High voltage**(up to 1000V DC in large systems) – which requires special care in the insulation and protection of cables.
- **Direct current**– which can cause increased heating and degradation of cables if they are not properly dimensioned.
- **Series and parallel connection**– in order to achieve an optimal balance between voltage and current.
- **Protection against reverse polarity and reverse current**- necessary to preserve the longevity of components and prevent breakdowns.
- **Standards and regulations**- the execution of the installations must be in accordance with the IEC 62548 standard that regulates the installation of solar photovoltaic systems.

Laying and protection of DC cables

Proper laying and protection of DC cables are crucial for long-term and safe operation of the system. The process includes:

- **Cable routing planning**– from solar panels to switchboards and inverters, while avoiding mechanical damage.
- **Cable laying methods:**
 - **Inside the structure**- the cables are passed through special cable supports or protective tubes.
 - **On the roof or on the ground**– they are attached with UV-resistant laces and protected with flexible pipes.
 - **Underground**- cables are laid in protected pipes to prevent moisture and mechanical damage.



Solar PV cable made of stainless steel with braid against mice and ants



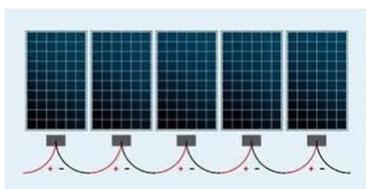
DC parallel FN cable

- Use of solar MC4 connectors - to ensure a safe and efficient electrical connection.
- Protection against UV radiation and mechanical damage - cables must be resistant to atmospheric influences.

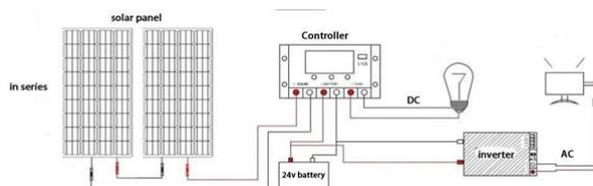
Connecting solar panels and forming photovoltaic arrays

Connecting solar panels is a key step in the construction of solar photovoltaic systems, as it determines the voltage and current of the system. There are two basic ways of connecting panels: series and parallel connection, while in large systems a combination of these methods is often used.

In a series connection, the solar panels are connected so that the positive terminal of one panel is connected to the negative terminal of the sitting panel. In this way, the total voltage of the system increases, while the current remains the same as with the individual panel. This method is most often used to achieve the desired operating voltage of the system, especially in systems powered by a grid inverter.

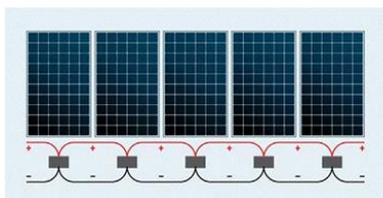


Serial connection of panels

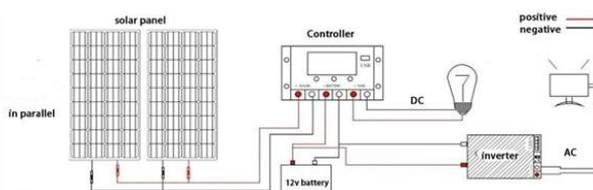


Schematic representation of serial connection of panels

In parallel connection, all the positive terminals of the solar panels are connected together, while the negative terminals are also connected to each other. This method of connection increases the total current of the system, while the voltage remains the same as with an individual panel. A parallel connection is used when it is necessary to increase the power of the system while maintaining a stable voltage.



Parallel panel bonding



Schematic representation of parallel connection of panels

To connect the panels, it is necessary:

- Check the polarity of the cables to avoid short circuits and system errors.
- Use appropriate cables and MC4 connectors to ensure a quality electrical connection.
- Ensure that all joints are properly tightened and protected from atmospheric influences.
- Perform voltage and current measurements before connecting to the distribution cabinet to ensure correctness of the system.

The procedure for connecting solar panels includes:

- **Preparation and organization of cables**- Before connecting the panels, it is necessary to ensure that the cables are properly arranged and protected from damage. Cables must not be over-tightened or left hanging, to prevent mechanical damage.
- **Using MC4 connectors**- Solar panels are connected using specialized MC4 connectors that enable safe, waterproof and permanent connections. These connectors allow easy joining and separating of panels without additional tools.
- **Ensuring water resistance and resistance to UV radiation**- All cables and connectors must be UV resistant and placed so that they are protected from direct exposure to the Sun and rain. The use of flexible protective pipes additionally increases the safety of the system.

- **Testing the connection-** After the panels are connected in series, it is necessary to make voltage and current measurements using a multimeter. This ensures that the system is connected correctly and that all panels are functioning according to technical specifications.

MPPT (Maximum Power Point Tracking) for optimizing energy production

Maximum Power Point Tracking(MPPT) is a technology built into solar inverters that enables automatic monitoring and maintenance of the maximum power point of the solar photovoltaic system. Given that the intensity of solar radiation and temperature are constantly varying, the MPPT system continuously adjusts the voltage and current to ensure the maximum possible efficiency of electricity production.

How does MPPT work?

The MPPT controller monitors the IV characteristic of photovoltaic panels, i.e. the relationship between current (I) and voltage (V), in order to find the optimal operating point at which the solar panels deliver the maximum possible power. This process includes:

- Continuous adjustment of the working voltage of the panel in real time,
- Monitoring changes in weather conditions and automatic optimization of output power,
- Preventing losses due to voltage mismatch between panel and load.

Advantages of MPPT technology

- **Greater system efficiency** –MPPT enables an increase in energy production by 15-30% compared to systems without this technology.
- **Adaptation to weather conditions-** Automatic optimization in conditions of reduced sunlight, temperature changes or shading.
- **Less energy loss**– Prevents inefficiencies in energy conversion between panels and inverters.
- **Ability to combine with power optimizers**– Additional optimization in case of different levels of insolation of individual panels.

MPPT in inverter connection and voltage regulation

Inverter size and type

When choosing an inverter, key factors include:

- **Inverter power-** must be matched with the total power of the solar panels,
- **Inverter type**– string inverters, microinverters or hybrid systems, depending on the size of the system and the method of connection,
- **Number of MPPT inputs**– inverters with multiple MPPT inputs allow greater flexibility in connecting strings of different orientations.

Comparative analysis of inverter types

INVERTER TYPE	ADVANTAGES	DISADVANTAGES
String Inverter	Lower cost, efficient for large systems	Less resistance to shading, problems with uneven sun exposure
Micro Inverter	Optimization at the level of each panel, resistance to shading	More expensive system, requires more devices
Hybrid Inverter	Possibility of energy storage, higher flexibility	More expensive system, requires batteries for optimal function

MPPT inverter range

The MPPT range defines the minimum and maximum operating voltage of the inverter at which it achieves maximum efficiency. When sizing:

- The total string voltage must be within the MPPT range of the inverter,
- Be aware of temperature variations that can increase or decrease the voltage,
- Exceeding the MPPT range can result in production losses or even damage to the inverter.

Inverter ventilation and cooling

The efficiency of the inverter also depends on the cooling system that prevents overheating:

- Natural ventilation – passive cooling through case design,
- Forced air flow - built-in fans that reduce the operating temperature,
- Installation in ventilated areas - it is recommended to install the inverter in locations with good air flow to avoid excessive heat and reduce the risk of reduced efficiency. In solar systems, the MPPT is a key component of string inverters, microinverters and solar charge controllers. The connection to the inverter is made in a way that allows:
 - Optimum DC voltage at the inverter input for maximum conversion to AC current,
 - Prevention of overloading and damage to photovoltaic modules due to changes in operating conditions,
 - Increasing the stability of system operation, reducing voltage fluctuations and increasing energy efficiency.

By using this method, solar photovoltaic systems can significantly improve their efficiency, reduce energy losses and enable maximum utilization of available solar energy. The integration of MPPT controllers with inverters ensures stable and reliable operation of the system in all weather conditions.

Dimensioning of strings and MPPT in solar photovoltaic systems

Analysis of the technical specification (data sheet) of panels and inverters

When designing solar photovoltaic systems, it is necessary to understand the technical specifications (data sheet) of photovoltaic panels and inverters. Each panel and inverter has its own operating characteristics that define:

- Rated voltage (V_{mp}) and current (I_{mp}) at maximum power,
- Open circuit voltage (V_{oc}) and short circuit current (I_{sc}),
- Temperature coefficients that define voltage changes depending on the ambient temperature,
- The number of MPPT inputs and the maximum allowed voltage and current at the DC input of the inverter.

Voltage on the DC side of the system and string sizing

Solar photovoltaic systems usually operate with a voltage on the DC side between 600-800V, and string sizing is based on:

- **Operating characteristics of the inverter**– each inverter has a minimum and maximum operating voltage (eg 200V - 1000V) and an optimal MPPT range.
- **Temperature effects**- the drop in temperature increases the panel voltage, which can lead to exceeding the maximum voltage of the inverter.
- **Cable lengths and voltage drops**- properly dimensioned cables reduce losses and maintain stable system operation.
- **Critical values at -10°C** –At low temperatures, the panel voltage can reach critical values, which can lead to damage to the inverter if the number of panels in the string is not determined correctly.

MPPT and the importance of correctly determining the number of panels in a string

Maximum Power Point Tracking (MPPT) enables optimization of solar panel performance. The key is to size the number of panels in the string so that their total voltage in all weather conditions is within the MPPT range of the inverter.

- If the voltage is low, the system will not work efficiently.
- If the voltage is too high, the inverter may be damaged.

String sizing rule:

- Calculate the open circuit voltage (Voc) at the lowest temperatures (eg -10°C) using the temperature coefficients from the data sheet panel.
- Ensure that the total voltage of the string does not exceed the maximum permissible voltage of the inverter.
- Take care of the MPPT range to ensure optimal energy production.

Installation and connection of the DC distribution cabinet

The DC distribution cabinet is a key element in the system of solar photovoltaic power plants, as it serves as the central point for connecting the solar panels to the inverter, enabling system protection and efficient management of the flow of electricity. Its correct assembly and connection are essential for the safe and reliable operation of the installation.

Inside the DC distribution cabinet are the following components:

- **Fuses**- protect the system from overload and short circuits, thus preventing damage to electrical components.
- **DC switches**- enable safe shutdown of the system for servicing and maintenance
- **Surge protection**- protects the system from lightning strikes and other overvoltage phenomena, thus extending the life of the equipment.

Assembly procedure of the DC distribution cabinet:

Selection and preparation of the installation site

- Choose a suitable location that is protected from moisture and direct sunlight.
- Provide sufficient ventilation around the cabinet to prevent internal components from overheating.
- Clean and prepare the surface on which the cabinet will be mounted.

Fixing the distribution cabinet

- Using a drill, drill holes for dowels or anchor bolts, depending on the type of substrate.
- Place the DC distribution cabinet in the intended place and fasten it with screws.
- Check stability and leveling to ensure proper placement.

Connecting incoming cables from solar panels

- Identify the positive and negative connections on the panels and arrange the cables correctly.
- Use suitable cables resistant to UV radiation and temperature variations.
- Pass the cables through the provided entrances in the cabinet and secure them using cable clamps.
- Connect the cables to the appropriate fuse and switch connections, taking care of the correct polarity.

Installation of protective elements

- Install DC fuses and switches according to the technical documentation.
- Install surge protection to reduce the risk of lightning strikes and surges.
- Ensure proper connection of all protective components according to the installation scheme.

Connecting the output cables to the inverter

- Correctly identify and connect the output cables according to the polarity of the inverter.
- Use high-quality connection terminals to reduce energy losses.
- Check all connections and cable fixings to avoid loose contacts.

Final check and testing

- Check the correctness of the connections and the continuity of the circuit with a multimeter.
- Ensure that all cables are properly insulated and protected from external influences.
- Perform a test commissioning of the system and monitor any irregularities.

Proper installation and connection of the DC distribution cabinet ensures long-term and safe operation of solar photovoltaic systems, reducing the risk of failures and improving the efficiency of the system.

Connecting the DC installation to the inverter

Connecting the DC installation to the inverter is a key step in the integration of solar PV systems, as this is where the direct current (DC) produced by the solar panels is converted into alternating current (AC) suitable for grid or household use. This process requires precision and careful adherence to technical specifications to ensure the correctness and longevity of the system.

Before starting the connection, it is necessary to check the technical documentation and ensure that all connections are correctly dimensioned and the system voltage corresponds to the inverter specifications. It is also necessary to use appropriate tools and protective equipment to prevent electric shocks or short circuits.



Inverter cables 5AWG 16mm² - complete with cable terminals. Copper solar wire with eyelets.

Checking technical documentation and tools

Before any connection, it is necessary to review the instructions of the inverter manufacturer and the technical documentation of the installation. It is also necessary to prepare the appropriate tools, including:

- Multimeter for checking voltage,
- Pliers for cutting and removing cable insulation,
- Wrenches and screwdrivers for fixing connections,
- Insulating gloves and safety glasses.

Checking the voltage and polarity of the cable

Before connecting the cables, a multimeter is used to measure the voltage of the incoming DC cables from the distribution cabinet. Polarity must be clearly marked to prevent incorrect connection, which may damage the inverter.

Connecting the positive (+) and negative (-) cables

- The red (positive) cable connects to the corresponding + terminal on the inverter.
- The black (negative) cable is connected to the - terminal of the inverter.
- The connectors must be firmly attached to prevent energy losses and heating of the joints.



Photovoltaic wire solar cable 4mm² for PV connections

Securing cables and protecting connections

- DC cables are routed through appropriate protective conduits or secured with UV-resistant cable ties to prevent mechanical damage or wear.
- The connections are additionally fixed with clamps to prevent the cables from moving due to vibrations or external influences.

System verification and testing

- Before commissioning, the voltage at the inverter terminals is measured once again to ensure that the values correspond to the designed parameters.
- It is checked whether all connections are properly tightened and protected.
- After that, the inverter is switched on and its operation is tested, according to the manufacturer's procedure.

Documentation and final inspection

- After successful connection, all connections are documented and recorded in the technical documentation of the system.
- A final inspection of the entire DC circuit is performed to ensure that there are no irregularities that could compromise the operation or safety of the system.

The connection of the DC installation with the inverter must be performed precisely and in accordance with the standards in order to ensure the reliability of the system and prevent possible failures. Quality installation and proper testing guarantee long-term and efficient operation of solar photovoltaic systems.

Safety aspects when performing DC installations

When performing DC electrical installation, it is necessary to observe safety measures:

- **Operation with the voltage switched off**– DC cables should always be de-energized before connection.
- **Use of protective equipment**– rubber gloves, safety glasses and insulated tools.
- **Preventing cable overheating**- by proper dimensioning and ensuring good ventilation.
- **Use of appropriate fuses and switches to avoid overvoltage and current anomalies.**

Testing and verifying the correctness of the DC installation

Testing the installation involves:

- Measuring voltage and current using a multimeter.
- Checking the correctness of protective elements such as fuses and switches.
- Continuity testing of joints to ensure quality contact.

- Documenting all measurements and recording any irregularities.



PRACTICAL EXERCISE

Task 1: Connecting photovoltaic panels in arrays

Connect PV panels in series and parallel arrays, checking polarity and measuring voltage to ensure proper system configuration.

Material and tools:

- Photovoltaic panels;
- DC cables with MC4 connectors;
- Multimeter;
- UV resistant laces;
- Insulating gloves.

Procedure:

1. Organize the panels according to the project documentation.
2. Connect the panels in series by connecting the positive end of one panel to the negative end of the other.
3. Make a parallel connection by connecting all the positive ends together and then all the negative ends.
4. Secure the cables with UV-resistant cable ties and protective tubes.
5. Check the polarity and measure the string voltage using a multimeter.

Final check:

- Check the strength of the connector and the protection of the joints.
- Compare the measured values with the technical documentation.



PRACTICAL EXERCISE

Task 2: Assembling and connecting the DC distribution cabinet

Mount and connect the DC distribution cabinet, with the correct placement of protective fuses and switches according to the technical documentation.

Material and tools:

- DC distribution cabinet;
- DC cables;
- Fuses and switches;
- Multimeter;
- Set of insulated wrenches;
- Screws and fasteners.

Procedure:

1. Prepare the place for installing the distribution cabinet and check its stability.
2. Fasten the cabinet to the wall bracket or floor structure using the appropriate fastening elements.
3. Install and secure fuses, DC switches and surge protectors.
4. Connect the incoming cables from the solar panels according to the technical documentation.
5. Connect the output cables to the inverter, taking care of the correct polarity.

Final check:

- Check the correctness of all connections and ensure that the connectors are securely fastened.
- Test the voltage values with a multimeter.



PRACTICAL EXERCISE

Task 3: Connecting the inverter to the DC installation

Task: Make the correct connection of the inverter to the DC distribution cabinet, with a connection check and voltage measurement before commissioning.

Material and tools:

- Inverter;
- DC cables;
- Multimeter;
- Pliers for MC4 connectors;
- Screws and fasteners.

Procedure:

1. Prepare the inverter and choose a suitable place for its installation.
2. Attach the inverter to the bracket according to the technical specifications.
3. Connect the positive and negative cables from the DC distribution cabinet to the corresponding inverter terminals.
4. Secure the cables by fastening them to the structure and protect them from mechanical damage.
5. Measure the voltage at the input terminals of the inverter before commissioning.

Final check:

- Check that all connections are made correctly and securely fastened.
- Confirm the correct voltage at the inverter connections before putting the system into operation.

6.3. Execution of AC electrical installation of solar photovoltaic systems

The execution of AC (alternating current) electrical installation is a key segment in the installation of solar photovoltaic systems, as it enables the conversion of the produced direct current (DC) into alternating current (AC) that can be used to power consumers or be distributed to the electrical distribution network. This process requires precise planning, proper cabling, installation of protective systems and testing of system functionality.

Purpose of AC installation in solar photovoltaic power plants

The alternating current (AC), generated by the inverter, must be efficiently transmitted and distributed through the system to the final consumer or the power distribution network. AC installation enables:

- **Energy distribution**– Transmission of electricity from the inverter to the grid connection point (PCC) or local consumers within the facility.
- **System protection**- Implementation of safety devices such as fuses, switches and surge arresters.
- **Monitoring and control**– Measurement of key electrical parameters such as voltage, current and power.
- **Network integration**- On-grid systems require proper synchronization with the electrical distribution network in order to enable a stable supply of electricity.

AC installations must be performed in accordance with alternating current distribution standards, with integrated protection devices for overload, short circuit and other abnormalities.

Elements of AC installations

AC installation consists of several key elements that enable safe and efficient operation of the system:

AC cables and connectors

Cables and connectors are used to transmit electricity from the inverter to the AC distribution cabinet (AC RO) and further to the grid or consumer. They must be properly dimensioned to ensure minimal energy losses and a long system life.

When choosing AC cables, it is important to consider:

- Conductor cross-section in relation to system power,
- Resistance to external influences (UV radiation, moisture, mechanical damage),
- Using insulated connectors to prevent electrical losses and increase safety.

AC distribution cabinet (AC RO)

The AC distribution cabinet serves as a central point for connecting the inverter to the grid or consumers. It contains:

- **Buses**- They distribute current between different parts of the system.
- **Fuses**– They protect the system from overload and short circuits.
- **Switches**- They enable the control and protection of current flows within the system.
- **Surge arresters**– They protect the system from damage due to overvoltage.
- **Measure devices** – Ammeters, voltmeters and wattmeters for measuring current, voltage and power within an AC system.

Network Connection Point (PCC)

In the case of an on-grid system, the solar power plant is connected to the electricity distribution network via a grid connection point (PCC). This segment includes:

- Synchronization of inverter operation with the grid,
- Installation of protective devices that prevent reverse current,

- Measurement of network parameters before connection to ensure system compatibility.

AC installation process Laying and connecting AC cables

Correct laying of AC cables minimizes energy losses and increases the longevity of the system. The procedure includes:

- Planning the cable route to reduce losses and avoid overlapping with other installations,
- Using proper insulation and protective piping to prevent damage,
- Fixing the cables with cable supports to ensure the stability of the installation.

Connecting the inverter to the AC distribution cabinet

Connecting the inverter to the AC switchboard is a key step in the integration of the solar power plant. The procedure includes:

- Connection of phase, neutral and protective line according to technical specifications,
- Installation of protective switches and fuses to prevent damage to the system,
- Checking the correctness of connections before commissioning.

Installation and connection of the AC distribution cabinet

Placing an AC distribution cabinet requires precise installation to ensure efficient power distribution. The process includes:

- Installation of cabinets in the intended place,
- Connecting all incoming and outgoing lines,
- Testing the correctness of electrical connections using measuring instruments.

Testing and commissioning of AC installations

After completing the installation, it is necessary to carry out detailed tests:

- Measurement of voltage and current at key points of the system,
- Simulation of system operation under different loads,
- Checking of protective devices and their functionality.

Safety aspects when performing AC installations

When performing AC electrical installation, it is necessary to observe safety measures:

- Use of protective equipment - gloves, safety glasses and insulated tools,
- Operation on a disconnected system - the AC installation is connected while the system is de-energized,
- Checking the correctness of protective devices - all fuses, switches and surge arresters must be tested before putting the system into operation.



PRACTICAL EXERCISE

Task 1: Assembly and connection of the AC distribution cabinet

Carry out the installation and connection of the AC distribution cabinet, including the installation of busbars, protective switches and measuring devices, in accordance with the technical documentation.

Material and tools:

- AC distribution cabinet;
- Buses;
- Protective switches (fuses, automatic switches, differential switches);
- Measuring devices (voltmeter, ammeter, wattmeter);
- Electric cables;
- Pliers for cables and steel supports;
- Insulation tool;
- Protective equipment (gloves, glasses).

Procedure:

1. Prepare the workplace
 - Review the technical documentation and assembly plan.
 - Ensure that the work surface is clean and safe to work on.
2. Install and fix the AC distribution cabinet
 - Determine the exact position of the cabinet assembly according to the technical plan.
 - Fasten the cabinet with dowels and screws to a suitable surface.
3. Install the busbars
 - Place the busbars inside the cabinet according to the specifications.
 - Check the correctness of the connections and ensure secure fastening.
4. Install and connect circuit breakers
 - Install fuses and circuit breakers in the designated locations.
 - Connect them to the busbars according to the technical documentation.
5. Install measuring devices
 - Place the voltmeters, ammeters and wattmeters in the designated positions.
 - Connect them with the appropriate cables and busbars.
6. Perform a visual and functional check
 - Check all connections and make sure they are firmly connected.
 - Check that the system is installed correctly before testing.

Final check:

- Check the physical stability of the cabinet and components.
- Inspect all connections and make sure they are well insulated.



PRACTICAL EXERCISE

Task 2: Connecting the inverter to the AC system

Connect the inverter to the AC system, including connecting the AC cables according to the technical documentation and checking the voltage before commissioning.

Material and tools:

- Inverter;
- AC cables;
- Cable pliers;
- Multimeter for measuring voltage;
- Insulation tool;
- Electrical clamps;
- Protective equipment (gloves, glasses).

Procedure:

1. Prepare the workplace
 - View technical documentation and connection plan.
 - Ensure that all necessary materials and tools are available.
2. Check the correctness of the inverter and AC system
 - Ensure that the inverter is disconnected from the power supply.
 - Check the voltage of the AC installation using a multimeter.
3. Connect the AC cables from the inverter
 - Find the appropriate connections for phase (L), neutral (N) and earth (PE).
 - Connect the AC cables according to the technical documentation and secure them with clamps.
4. Perform cable protection and organization
 - Place the cables in protective pipes or ducts to prevent damage.
 - Ensure that all connections are well insulated.
5. Check the connection and test the system
 - Measure the voltage at the output of the inverter with a multimeter before switching it on.
 - Simulate the operation of the system and check whether the inverter has correctly connected to the grid or local consumers.

Final check:

- Inspect all connections and confirm that they are securely connected.
- Check the voltage and current at the connection points of the inverter.



PRACTICAL EXERCISE

Task 3: Testing the electrical installation of solar photovoltaic systems according to IEC 60364-6

Testing of the electrical installation of the solar photovoltaic system in accordance with the requirements of the IEC 60364-6 standard. Testing will include conductor continuity, polarity, insulation resistance, functional tests and other key parameters to ensure proper operation of the solar PV system.

Material and tools

- Multifunctional tester for testing electrical installations (eg Fluke 1664 FC, Megger MFT);
- Digital multimeter;
- Current clamps;
- Insulation tester (megger);
- Scheme of solar photovoltaic system with test points;
- Protective equipment (gloves, safety glasses, voltage tester).

Procedure

1. Continuity testing of grounding and potential equalization conductors
 - Check the continuity of the ground conductor using a continuity tester.
 - Connect one probe of the tester to the main ground and the other to the protective conductor.
 - Read the result and compare with standard values according to IEC 60364-6.
2. Polarity test
 - Using a digital multimeter, check whether the phase conductor is properly connected.
 - Place one probe on the phase conductor and the other on the protective conductor and check the voltage readings.
 - If the voltage does not match the expected, check and correct the connection.
3. Combo box test (combiner box string)
 - Check the fuses, protective switches and connections in the combiner box.
 - Perform a voltage test on the input and output terminals.
 - Check the operation of protective devices by testing the earthing switch.



PRACTICAL EXERCISE

4. Open Circuit Voltage (Voc) or HSA test
 - Disconnect the photovoltaic string from the inverter.
 - Using a multimeter, measure the open circuit voltage between the positive and negative terminals of the photovoltaic string.
 - Compare the measured values with the expected ones, according to the technical documentation of the panel.
 5. Short circuit (Isc) or operating current test
 - Connect the ammeter to the circuit of the photovoltaic string.
 - Short-circuit the positive and negative terminals and read the short-circuit current.
 - Compare the measured values with the manufacturer's data.
 6. Functional tests
 - Connect the photovoltaic system to the inverter and the grid.
 - Check the operation of the inverter at different levels of insolation.
 - Test the operation of protective devices by turning off the photovoltaic string.
 - Check that the inverter is tracking the MPPT point correctly.
 7. DC circuit insulation resistance test
 - Turn off the inverter and photovoltaic strings.
 - Connect the insulation tester (megger) to the DC cables and carry out the test at a voltage of 500V or 1000V.
 - Check whether the measured values meet the minimum requirements of the standard.
- Final check
- Compare all measured values with the manufacturer's specifications and the IEC 60364-6 standard.
 - Identify possible installation errors.
 - Document the test results in a control sheet.

6.4. Execution of grounding installation and solar lightning protection installation photovoltaic systems

The installation of grounding and lightning protection is a key component of the safety system of solar photovoltaic systems. These installations ensure the protection of people and equipment from electric shocks and atmospheric discharges, minimizing the risks of breakdowns and fires.

Grounding installation

Grounding in solar photovoltaic systems plays a key role in the safety of the system. It ensures the protection of the metal parts of the equipment, prevents the occurrence of dangerous voltage differences and enables the safe discharge of electricity to the ground, in case of failure.

Grounding installation elements

Grounding consists of several basic components:

- **Grounding devices**– metal rods, strips or plates buried in the ground that ensure good contact with the ground.
- **Grounded conductors**- cables that connect the equipment to the grounding devices.
- **Grounding busbars**- devices that connect multiple grounded conductors to ensure a single grounding of the system.

Preparatory work for earthing installation

Before performing the earthing installation, it is necessary to perform a series of preparatory activities:

- **Analysis of technical documentation**- review of project documentation in order to determine grounding requirements.
- **Delivery of equipment and tools**- ensuring the necessary materials and tools.
- **Cleaning and leveling the terrain**– removal of obstacles and soil preparation.
- **Marking the position for earthing devices**- determination of the exact locations for the placement of the grounding device.
- **Digging trenches**– adapted to the specifics of the terrain and the depth required for grounding devices.
- **Soil quality check**- soil conductivity testing to ensure earthing efficiency.

Installation and connection of the grounding system

Proper installation and connection of the grounding system are key steps in ensuring the safety of solar PV plants. The grounding system enables the safe discharge of excess electricity into the ground, protecting equipment and personnel from possible electric shocks and surges.

The grounding installation procedure includes the following steps:

Placement of grounding devices - Metal rods or strips are placed in the ground in accordance with technical requirements and standards. Before installation, a soil analysis is performed in order to determine the most favorable location for the grounding devices. Grounding devices can be placed vertically (by driving them into the ground) or horizontally (by placing them in dug trenches). After installation, their stable contact with the ground is checked.

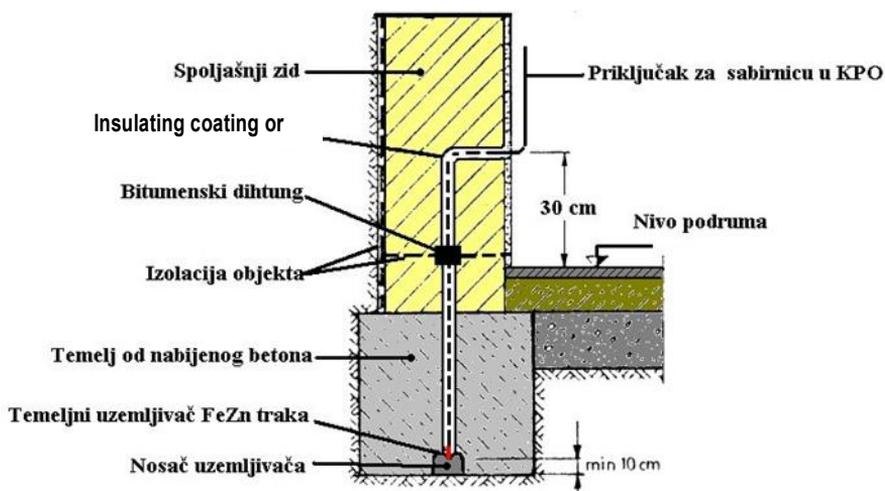
Connection of busbars and lines - Grounded conductors are connected to busbars using clamps, connectors and copper strips. The connections must be mechanically strong and electrically conductive to ensure uninterrupted current flow in the event of an atmospheric discharge or system failure. The use of welded joints or specially designed clamps improves durability and corrosion resistance.

Establishing connections with the electrical power system - After installing the grounding device and connecting the busbars, the grounding system is connected to the metal parts of the electrical power installations of the solar photovoltaic system. This step involves connecting the ground to the inverter's metal enclosures, switch cabinets, and

panel construction. The connection is made using special lines with low resistance, which ensures efficient conduction of electricity into the ground.

Continuity Check of Connections - After mounting and connecting all elements of the grounding system, it is necessary to perform testing to ensure proper functioning. Earthing resistance is measured using specialized measuring instruments (eg earthing resistance meter). The goal is for the measured resistance to be within the permitted limits according to the standards, in order to ensure safe current dissipation in the event of a lightning strike or system failure.

The grounding system of solar photovoltaic systems must be performed according to current regulations and technical standards in order to ensure the long-term functionality and safety of the entire system.



Execution of the grounding device

Installation of lightning protection

Lightning protection protects solar photovoltaic systems from atmospheric discharges by redirecting the energy of the lightning strike to the ground. This reduces the possibility of damage to electrical and mechanical equipment, as well as potential fires.

Elements of lightning protection installation

- **Lightning rods (clamps)**- placed on the highest points of the building attract lightning and direct the energy towards the ground.
- **Lightning conductors**- metal conductors connect the lightning rods to the grounding conductor.
- **Grounding devices**- metal rods buried in the ground redirect the lightning energy in a safe way.

Preparatory works for lightning rod installation

- **Analysis of project documentation**- review of technical requirements.
- **Delivery of materials and tools**- providing the necessary components for installation.
- **Cleaning and preparation of the work area**- removal of obstacles for safe work.
- **Installing protective equipment**- ensuring worker protection.
- **Marking the location for mounting the lightning rod**- determining the positions of system elements.

Installation and connection of the lightning protection system

Installation and connection of the lightning protection system are key steps in ensuring the protection of solar photovoltaic systems from atmospheric discharges. This process includes the installation of all necessary components, their connection and testing to ensure their functionality and long-term reliability.

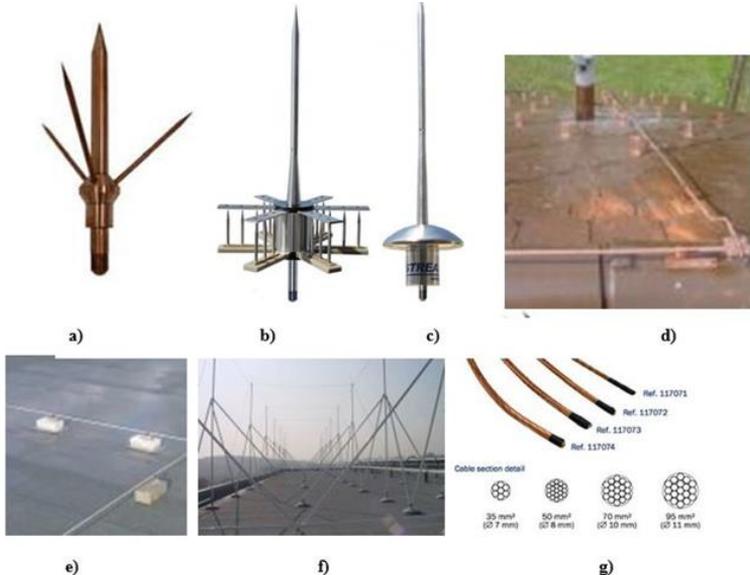
The first step in the process is the installation of lightning rods, which are placed at strategic points of the building or solar panels. Their role is to attract atmospheric discharge and direct it to a safe drain. During the installation, it is necessary to ensure a firm attachment of the bars by means of appropriate supports and anchoring elements, thus ensuring resistance to weather conditions and mechanical forces. The position of the grippers must be coordinated with the technical documentation, in order to ensure optimal coverage of the protected area.

After placing the rods, it is possible to connect the conductors for the lightning discharge, which redirect the electricity from the atmospheric discharge towards the ground. These conductors are made of highly conductive materials, such as copper and aluminum, and must be properly connected to the lightning rods. When connecting, it is important to use appropriate connecting elements, such as clamps, screws and special joints, which ensure reliable and long-lasting contact.

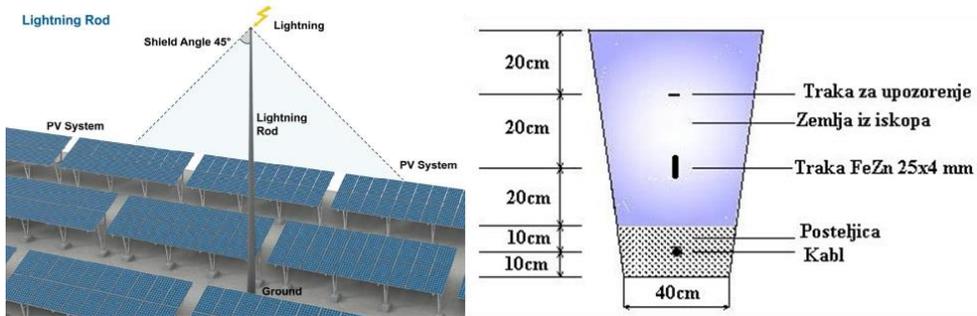
Next comes the installation and connection of the grounding devices, which represent the final element in the separation of excess electricity into the ground. These grounding devices can be made in the form of metal rods driven into the ground or metal strips buried in the ground, and their position and number depend on the specific requirements of the system. Connecting the grounding conductors to the lightning conductors is done using high-quality joints, which ensure minimal energy losses and long-term corrosion resistance.

The last step in the process is to measure the resistance of the lightning protection, in order to ensure its functionality. This check is performed using special measuring instruments that allow precise determination of system efficiency. If the measured resistance values do not meet the technical standards, additional measures should be taken, such as increasing the number of grounding devices or improving the connections between components.

Properly performed lightning protection is crucial for the safety of solar photovoltaic power plants, as it minimizes the risk of fire and damage to electrical components due to lightning strikes. Therefore, it is important to comply with technical regulations and standards when performing all work on this system.



Acceptance systems: a) lightning rod spread spike; b) lightning spike; c) lightning spike with enhanced electronic effect (ESE Early Streamer Emission); d) galvanized strips on a flat roof (Faraday cage); e) isolated gripper system; f) system with stretched wires; g) sections of copper wires for lightning protection installation



A lightning rod placed above the solar panels to provide a protective cone

Protection against atmospheric discharges of the underground cable using FeZn 25x4mm tape

Testing and verification of grounding and lightning protection installations

After installation, it is necessary to test the functionality of the system:

- Measurement of grounding resistance - to ensure the efficiency of current draining into the ground.
- Conductor continuity testing - checking the quality of all connections.
- Inspection of mechanical stability - checking all components for resistance to weather conditions.
- Checking connections and electrical contacts - to ensure long-term uninterrupted operation.



Testing lightning protection installation



QUIZ

Quiz 10: Grounding and lightning rods for solar photovoltaic power plants:

<https://forms.office.com/e/d8mq2i23jd>.



PRACTICAL EXERCISE

Task 1: Installation and connection of the grounding system

Perform the installation and connection of the solar PV system grounding system, including the installation of grounding rods, connection of conductors and measurement of grounding resistance.

Material and tools:

- Ground rods or plates;
- Copper or galvanized conductors;
- Clamps, lugs and connecting elements;
- Excavation equipment (axe, pickaxe);
- Ground resistance meter;
- Pliers and screwdrivers;
- Protective equipment (gloves, safety glasses).

Procedure:

1. Prepare the field by marking the locations for the grounders and clearing the area of obstacles.
2. Install grounding rods by driving metal rods into the ground or placing strips in dug trenches.
3. Connect the earthing bars to the busbars using suitable conductors and fasten them with clamps or welded joints.
4. Connect the grounding system to the metal parts of the solar installation using copper or galvanized cables.
5. Measure the ground resistance using a measuring instrument and check that it meets the prescribed standards.

Final check:

- Inspect all connections and attached conductors.
- Verify ground resistance and compare to reference values.
- Document the procedure and record any irregularities.



PRACTICAL EXERCISE

Task 2: Assembly and connection of lightning protection installation

Install and connect the lightning protection elements of the solar PV system, including lightning rods, conductors and grounding devices.

Material and tools:

- Lightning rods (clamps);
- Copper or aluminum conductors;
- Earthing rods;
- Connecting elements (clamps, screws, connecting tapes);
- Drill, pliers, screwdrivers;
- Insulating protective equipment.

Procedure:

1. Determine the installation points of the lightning rod according to the technical documentation and mark the installation locations.
2. Place the lightning rods in the designated places and fix them with the brackets.
3. Connect the arresters to the lightning conductors using suitable connectors and ensure tight connections.
4. Install the grounding devices for the lightning protection system and connect them to the conductors according to the technical documentation.
5. Check the electrical conductivity of the system using a measuring device.

Final check:

- Visually inspect all connection points and mounting elements.
- Verify electrical conductivity and ensure that all connections meet protection standards.
- Document the procedure and any corrections.



PRACTICAL EXERCISE

Task 3: Testing of grounding and lightning protection

Perform grounding and lightning protection system testing using appropriate measurements and checking connections.

Material and tools:

- Ground resistance meter;
- Test instrument for lightning protection;
- Pliers and screwdrivers;
- Protective equipment (gloves, glasses).

Procedure:

1. Measure the earth resistance with a measuring instrument and record the values.
2. Check the integrity of all connections within the grounding and lightning protection installation.
3. Test the conductivity of the conductors of the lightning protection system to ensure the functionality of the lightning strike protection.
4. Analyze measurement results and compare them with standards.
5. Remove possible irregularities and repeat the test after corrections.

Final check:

- Ensure that all measured parameters meet the prescribed standards.
- Document all measurements and possible corrections.
- Prepare a report on the verification of the correctness of the system.

6.5. The most common mistakes when installing solar photovoltaic system

The installation of a solar photovoltaic system requires precise planning and execution to ensure optimal efficiency and longevity of the system. The most common mistakes that occur in practice include:

Incorrect dimensioning of the system

- **Incorrectly calculated system power**– If the system is too small, it will not be able to cover consumption needs; if it is too large, the investment will not be profitable.
- **Inverter and panel mismatch**– If the inverter is not properly dimensioned, the energy conversion efficiency may decrease.
- **Local energy consumption not sufficiently taken into account**- System planning without analyzing the facility's energy needs can lead to inefficiency.

Poorly positioned panel orientation and tilt

- The panels are not oriented to the optimal side (south in the northern hemisphere, north in the southern hemisphere).
- **Improperly Adjusted Panel Pitch** – Fixed panels should be angled to match latitude to maximize year-round production.
- **Misalignment with seasonal variations** - In some systems it is better to use adaptive mounts that change the slope seasonally.

Improper installation of supports and structures

- **Inadequate fastening to the roof**– May lead to roof damage or system instability in high winds.
- **Using inappropriate materials**– Susceptibility to corrosion and degradation can significantly reduce the durability of the structure.
- **Bad application of ballast systems on flat roofs**– If the correct ballast weight is not calculated, the wind can move or damage the panels.

Errors in electrical installations

- **Poorly dimensioned cables**– Excessive energy losses due to insufficiently thick cables.
- **Improper connection of the DC side of the system**– If the panels are not properly connected in strings, uneven load distribution and power losses may occur.
- **Faulty surge protection and poor grounding**- Lack of adequate protection can lead to damage to the inverter and panels during a lightning strike.
- **Bad connection between the inverter and the grid**– May cause voltage oscillations and network stability issues.

Shading and misplaced panels

- Objects that cast shadows are not taken into account - Trees, chimneys, poles and surrounding buildings can significantly reduce production.
- **Improper use of optimizers and MPPT inputs** - If the optimizers are not set correctly, uneven output can occur within the same string of panels.
- **Poor positioning of panels on different roof surfaces** – If the strings are placed at different angles without optimization, the system will not work efficiently.

Ignoring thermal effects

- **Poor panel ventilation**– If there is no space between the panel and the roof, overheating and reduced efficiency can occur.
- **Insufficient resistance of components to high temperatures**– Incorrectly selected cables and connectors can overheat and cause malfunctions.

Lack of protection and security measures

- **Lack of fire protection**- solar photovoltaic systems can cause fire if they are not properly secured with thermal and electrical protection.
- **Poor grounding and inadequate fuses** –It can lead to an increased risk of electric shock and short circuit.
- **Non-compliance with local regulations and standards**– Improper installation can lead to legal and technical problems.

Lack of monitoring and maintenance systems

- **Uninstalled monitoring system (data loggers, optimizers, analyzers)**– Without monitoring the operation of the system, it is difficult to detect failures or energy losses.
- **Neglecting maintenance (cleaning panels, checking cables and connectors)**- Over time, the efficiency of the system can be reduced due to dust accumulation and faulty connections.

How to avoid these mistakes?

- Careful planning and sizing of the system before installation.
- Using software for the simulation of a solar photovoltaic production system (PVGIS, PVSyst, SAM) to estimate the optimal configuration.
- Adherence to technical standards and regulations during installation.
- Regular maintenance and monitoring to prevent breakdowns and system degradation.

7. OPERATION AND MAINTENANCE OF SOLAR PHOTOVOLTAGE SYSTEMS

7.1. Preparatory works and initial testing of solar photovoltaic systems

Before putting solar photovoltaic systems into operation, it is necessary to carry out a series of preparatory activities and tests to ensure the correctness and safety of the system. This phase includes the review of technical documentation, preparation of tools and equipment, intervention planning and functional testing of all key components.

Overview of technical documentation and key system parameters

Each solar system has specific technical characteristics that should be analyzed before starting. Review of technical documentation includes:

- **Electrical system diagrams**- They show the way of connecting photovoltaic panels, inverters, distribution cabinets, protection devices and consumers.
- **System information**- Voltage, current, power and efficiency of the system.
- **Specifications of key components**- Data on panels, inverters, batteries (if any), protective circuits and grounding.
- **Security guidelines**- Regulations for protection against electric shock, rules for working at height and recommended procedures for system testing.
- **Warranties and manufacturer's instructions**- Proper use and maintenance of equipment in accordance with the instructions.

Preparation of tools, equipment and protective equipment

To properly test the system, it is necessary to use the appropriate tools and protective equipment:

- Measuring instruments:
 - Multimeter - for measuring voltage and current in the DC and AC part of the system.
 - Clamp ammeter (ampere clamp) – for checking the load current.
 - Thermal imaging camera – to detect overheating of components.
 - Earthing tester - for checking earthing continuity.
- Other equipment:
 - Insulated screwdrivers and wrenches - for safe work with electrical components.
 - Cable ties – for securing cables and connectors.
 - Laptop with system monitoring software - for checking remote communication and operating parameters.
- Protective equipment:
 - Insulating gloves and safety glasses.
 - Safety belts for working at height.
 - Antistatic footwear to prevent electrical discharge.

Planning of activities and schedule of interventions

In order to avoid mistakes and ensure an efficient process, it is necessary to plan all activities in advance:

- **Creating a testing schedule**- Defining the sequence of system checks (visual inspection, electrical measurements, load test).
- **Assignment of tasks**- Technicians and electricians are assigned according to their competences (inverter testing, wiring checks, grounding checks, etc.).

- **Weather forecast-** Planning works in optimal weather conditions to avoid problems such as condensation on the panels.
- **Coordination with the network operator-** If the system is connected to the electrical distribution network, it is necessary to agree on an appointment for the official connection.

Pre-launch system check and component testing

Before the system is officially put into operation, a series of checks are carried out to ensure that all parts are working properly:

- **Visual inspection:**
 - Inspection of joints and connectors - Checking that all joints are properly connected and securely fastened.
 - Checking the cable installation - Ensuring that the cables are properly organized, without mechanical damage.
 - Inspection of protective devices - Inspection of DC and AC fuses, circuit breakers and surge arresters.
- **Voltage and current measurement:**
 - Testing the DC voltage between the solar panels and the inverter.
 - Checking the AC output voltage from the inverter.
 - Measurement of load current during system operation under different conditions.
- **Grounding testing:**
 - Earthing resistance measurement using an earthing tester.
 - Checking the continuity of the ground from the panel to the main busbar.
 - Examination of protective grounding assemblies and verification of the correctness of lightning protection.

Activation of inverters and solar panels with controlwork

After all the checks have been completed, the system activation can be started:

- **Turning on the inverter-** Step-by-step switching on of the inverter and checking the operation of the protective circuits.
- **Setting initial parameters-** Input of the maximum power, voltage and frequency values of the system.
- **Monitoring of initial data-** Observation of the first measurements of output power and operating parameters in order to detect possible irregularities.
- **Load simulation-** Testing of system operation under lower and higher load in order to check the stability of operation.

Verification of communication systems and protective devices

Modern solar systems often include monitoring systems and protective devices that must be properly configured:

- **Checking communication with tracking software-** Connecting the inverter to the monitoring system and checking data transmission.
- **Testing of protective devices-** Simulation of faults (overload, short circuit) to check the reaction of protective devices.
- **Verification of auto-shutdown settings-** Ensuring that the system automatically shuts down in the event of an emergency.
- **Final documentation-** Recording of all measurements and test results in technical documentation.

Correct performance of preparatory work and initial system testing is of key importance for the safe and efficient operation of solar photovoltaic systems. This phase enables the identification of possible problems before the system is officially put into operation. After successful testing, the solar power plant is ready for continuous operation and monitoring.



PRACTICAL EXERCISE

Task: Initial testing of the solar photovoltaic system

Perform visual inspection, electrical measurements and activation of the solar photovoltaic system, following technical documentation and safety guidelines.

Material and tools:

- Multimeter (for measuring voltage and current);
- Clamp ammeter;
- Thermal imaging camera;
- Grounding tester;
- Laptop with System monitoring software;
- Insulated screwdrivers and wrenches;
- Protective equipment (gloves, glasses, antistatic shoes).

Procedure:

1. Review of technical documentation
 - Analyze system wiring diagrams and check key component specifications.
 - Identify the locations of photovoltaic panels, inverters, switch cabinets and protection devices.
2. Preparation of tools and protective equipment
 - Ensure that all necessary tools and measuring instruments are ready for use.
 - Uses protective equipment properly to ensure safe work.
3. Visual inspection of the system
 - Inspect the joints and connectors, make sure there are no loose connections.
 - Check the organization and integrity of the cable installation.
 - Check grounding and protective devices by inspection.
4. Voltage and current measurement
 - Using a multimeter, measure the DC voltage between the solar panels and the inverter.
 - Check the AC output voltage of the inverter and measure the load current under different operating conditions.
5. Grounding testing
 - Uses a ground tester to check continuity of connections and measure ground resistance.



PRACTICAL EXERCISE

6. System activation and initial testing
 - Turn on the inverter and monitor the initial operating parameters (voltage, current, power).
 - Check communication with the monitoring software system.
 - Simulate different operating conditions and test protective devices.

7. Verification of results and documentation
 - Record all measurements and results in technical documentation.
 - Identify and report possible irregularities.

Final check:

- Confirm the correctness of all connections and protection systems.
- Document the procedure and record the measurement results.
- Ensure that the system functions according to the set parameters before official commissioning.

7.2. Monitoring of system operating parameters

Continuous monitoring of the operating parameters of solar photovoltaic power plants is of essential importance for the optimization of operation, the detection of irregularities and the extension of the working life of the system. Parameters such as voltage, current, power, temperature and intensity of solar radiation enable system performance analysis and quick response to potential failures.

Continuous monitoring of voltage, current and power

Before the initial testing and start-up of solar photovoltaic systems, it is necessary to define the key operating parameters of the system that enable efficient and safe operation. Continuous monitoring of these parameters enables timely detection of deviations, prevention of failures and optimization of power plant operation.

The key operating parameters monitored in solar photovoltaic power plants are:

- **Voltage (V)**- It is crucial to monitor the voltage of the solar panels, the voltage on the DC buses and the output voltage of the inverter. A drop in voltage may indicate problems with the panels, poor connector connections, or cable degradation.
- **Current (A)**- The current is measured to check the evenness of the load in the solar system. Sudden deviations in values may signal wiring problems or faulty PV modules.
- **Power (W, kW, MW)**- The analysis of the current power and the total energy produced enables the prediction of system performance and comparison with the designed one.
- **Energy (Wh, kWh, MWh)**- total energy produced in a certain period of time.
- **Panel temperature (°C)**- the temperature of the surface of the photovoltaic modules, because high temperatures can reduce their efficiency.
- **Intensity of solar radiation (W/m²)**- the amount of solar energy that falls on the surface of the panel, which directly affects the production of electricity.
- **Network frequency (Hz)**- frequency stability must be maintained in network systems.
- **System efficiency (%)**- assessment of how effectively the system converts solar energy into electrical energy.

Measurement of solar irradiation in real time - Irradiationmeters

Irradiationmeters are specialized sensors that measure solar irradiance (W/m²) in real time, enabling accurate monitoring of available solar energy at the system location. They are positioned to follow the slope of the panel, thus enabling:

- Monitoring of expected energy production,
- Reading of key electrical parameters (voltage, current, power),
- Verification of the operation of the photovoltaic system and recognition of anomalies.

The advantages of using irradiation meters are the precise monitoring of solar radiation, which enables optimization of production, diagnosis of problems, i.e. recognition of losses due to faulty components, adjustment of operation according to real conditions and long-term analysis of the performance of the solar photovoltaic system.

Their use enables accurate analysis of system operation, problem detection and optimization of energy production. Their integration with remote control systems significantly improves the efficiency and long-term stability of the solar system.

The importance of monitoring working parameters

Monitoring of operating parameters is key to ensuring reliable and efficient operation of solar photovoltaic power plants. Accurate data allows detection of potential problems at an early stage - for example, a sudden drop in voltage or power may indicate a faulty panel or connection problem, then analysis of system performance, ie comparison of expected and actual energy production. By monitoring temperature and radiation intensity, efficiency can be improved,

for example by cleaning panels or adjusting tilt, while controlling overvoltages, overloads and temperatures reduces the risk of malfunctions and fires.

Operating parameters are monitored through a variety of methods, including manual multimeter measurements, power analyzers, thermal cameras for temperature monitoring, as well as advanced remote monitoring software systems that allow automatic analysis and report generation.

Monitoring methods:

- Using multimeters and analyzers of electrical parameters for local measurements.
- Implementation of digital sensors and measuring stations for constant monitoring.
- Using inverters with integrated monitoring of electrical parameters.

Monitoring of panel temperature and intensity of solar radiation

The efficiency of solar panels significantly depends on their temperature and the amount of received solar radiation. High temperatures can reduce the efficiency of the panels, while uneven lighting can cause shading problems and reduced energy production.

- Panel temperature measurement:
 - Thermal sensors and infrared cameras are used to detect overheating.
 - Normal operating temperatures of solar panels range from 25°C to 60°C, but can reach higher values during the summer months.
 - Uneven heating may indicate problems with individual cells in the panels (the so-called "hot-spot" effect).
- Measuring the intensity of solar radiation:
 - Pyranometers and solar sensors are used to measure the amount of solar energy (W/m^2) reaching the panels.
 - The expected intensity of solar radiation varies depending on the geographical location, time of day and season.
 - The relationship between panel temperature and radiation intensity can help estimate losses and optimize performance.

Systems for monitoring and optimizing the operation of photovoltaic power plants

Monitoring systems for solar photovoltaic power plants enable continuous monitoring of performance, fault diagnosis and optimization of energy production. These systems provide users with real-time data and enable better control over the operation of solar panels and inverters.

Monitoring system components

Solar photovoltaic systems use a variety of devices to collect and analyze data:

- **Sensors**- measure solar radiation, temperature, humidity and electrical parameters of photovoltaic systems.
- **Inverters with monitoring functions**– convert direct current (DC) to alternating current (AC) and record energy production data.
- **Data loggers (data loggers)**- record and archive key data on the operation of photovoltaic systems.
- **User interfaces**- enable data visualization through mobile applications, web portals or central control panels.

Technologies for optimization and security

Advanced technologies allow not only monitoring, but also automation and increasing the efficiency of photovoltaic power plants. Key devices include:

- **Controllers for monitoring photovoltaic systems**
 - They are connected to inverters and sensors to monitor voltage, current and temperature.
 - They optimize the operation of the system depending on the weather conditions.
 - They detect malfunctions and send alarm signals to operators.

- **Network analyzers**
 - They monitor the quality of the supplied energy and the stability of the mains supply.
 - They detect harmonic distortions, voltage oscillations and overvoltages.
 - They help in optimizing the integration of the solar photovoltaic system into the distribution network.
- **Data loggers and long-term data analysis**
 - They record historical data on the operation of photovoltaic systems.
 - They help identify trends in panel degradation.
 - They enable advanced performance analysis through software tools.
 - Optimizers for panel monitoring and fire prevention
 - Optical optimizers – analyze the insolation, reflection and shading of the panels.
 - Electronic optimizers – measure voltage, current and panel temperature, identifying potential problems.
 - They prevent fires by detecting overheating and bad electrical connections.
 - They automatically shut down problematic modules to protect the system.



Supervision and optimization of solar photovoltaic system operation

Data collection and analysis process

- **Data collection**– sensors and inverters measure electrical and environmental parameters.
- **Data transfer**– data is sent via Wi-Fi, Zigbee, Bluetooth or wired connections.
- **Data storage**– data loggers store information for later analysis.
- **Data analysis**– software processes data, detects anomalies and provides recommendations.
- **Visualization of results**– users monitor the state of the system and receive alerts through applications.

Types of systems for monitoring photovoltaic power plants

- **Real-time monitoring systems**- enable immediate insight into the state of the solar photovoltaic system.
- **Offline systems**– store data locally for later analysis.
- **Intelligent systems with automation**– use machine learning and advanced analytics for predictive maintenance.

Practical examples of application

System Monitoring Controllers – On a large 1MW solar farm, the controller monitors the operation of the inverter and detects a power drop in one string due to shading, sending an alarm to the operators.

Network analyzers– In an industrial solar photovoltaic system, the analyzer detects voltage oscillations, allowing the inverter to be adjusted to stabilize the delivered energy.

Dataloggers– On a 10kW residential solar power plant, long-term analysis shows a gradual decline in efficiency of 5% per year, indicating the need for panel cleaning.

Optimizers for system protection– On the roof of a commercial building, the optimizer detects the overheating of a single panel and automatically shuts down the module, preventing failure or fire.

Cost-effectiveness and economic benefits

Investment in monitoring and optimization systems for photovoltaic power plants brings long-term financial benefits:

- **Increased energy efficiency**- work optimization reduces energy losses.
- **Savings on electricity bills**- better planning of consumption enables maximum utilization of produced solar energy.
- **Long-term sustainability of the system**- preventive maintenance reduces repair costs and extends the life of the equipment.

The integration of advanced systems for monitoring and optimizing photovoltaic power plants enables:

- Increased efficiency and stability of work.
- Reduction of failures through early detection of problems.
- Remote management and automatic optimization of the system.

The combination of controllers, network analyzers, data loggers and optimizers is crucial for the long-term reliability and safety of photovoltaic systems.

Use of remote monitoring software systems

Modern solar systems use advanced software platforms for remote monitoring and analysis of plant performance. These systems enable constant monitoring, timely alarms in case of deviations and generation of reports on system operation.

- Basic functions of software systems:
 - Automatic data collection from sensors and inverters.
 - Deviation detection and alert generation.
 - Historical data tracking and performance analysis.
 - Integration with meteorological data to forecast energy production.
- Examples of software solutions:
 - SCADA systems for industrial monitoring of large solar power plants.
 - Web and mobile applications of inverter manufacturers (SMA, Huawei, Fronius, SolarEdge).
 - Open-source platforms like PVsyst for data modeling and analysis.

Advantages of remote monitoring:

- It reduces the need for physical inspections and optimizes maintenance costs.
- It enables early detection of problems and prevents production losses.
- It provides detailed insight into system performance and helps in making decisions about improvements.

Application of modern software systems further facilitates monitoring and reduces maintenance costs, making solar photovoltaic systems a sustainable and reliable source of energy.



PRACTICAL EXERCISE

Task 1: Using online software to predict the production of 10 kW photovoltaic systems

Task

Students will use online power generation prediction software to analyze the expected annual and monthly output of a 10 kW solar PV system at a specific location. It will also simulate the influence of various factors (slope, orientation, location) on energy production and optimize the system.

Material and tools

- Computers or tablets with internet access.
- Online prediction software (eg PVGIS, PVSyst, SAM, HOMER Energy).
- Specifications of the 10 kW solar PV system:
 - 25 panels, 400 W each,
 - Inverter power 10 kW,
 - Standard fixed construction.
- Map of solar radiation for selected regions.

Procedure

1. Location Input – Students enter geographic coordinates (city/state) into the software.
2. Defining the parameters of the solar photovoltaic system:
 - Total power: 10 kW.
 - Panel tilt: 30° (standard optimization for mid-latitudes).
 - Orientation: South (180°).
 - Loss coefficient: 15% (cables, dirt, temperature).
3. Running the simulation – The software calculates the expected monthly and annual energy production.
4. Analysis of results:
 - Compare production in different months.
 - Assess how the season affects production.
 - Compare results for different locations (eg coastal region versus mountain region).



PRACTICAL EXERCISE

5. System optimization:

- Simulate a change in panel tilt (15° , 45°) and analyze the impact.
- Change the orientation (southeast, southwest) and compare the results.
- Analyze how shading or dirt reduces production.

Evaluation and discussion:

- Which configuration gives the best production?
- How does geographic location and climate affect the efficiency of a solar photovoltaic system?
- How does the software help in realistic planning of solar power plants?

Final check

- Students compare the obtained results with theoretical expectations.
- They discuss how various factors can affect the performance of a solar PV system.
- They draw conclusions about the optimal parameters for a specific location.

7.3. Preventive maintenance and diagnostics

Preventive maintenance of solar photovoltaic systems is key to preserving their efficiency, extending the life of the system and preventing unplanned breakdowns. Regular inspection and diagnostics enable early detection of problems and optimization of the operation of all components. This process includes a visual inspection of the system, cleaning of solar panels and other components, and testing of key electrical connections and protective devices.

A visual overview of the elements of a solar photovoltaic system

Visual inspection is the first and basic step in preventive maintenance. It checks the condition of all key components of the system, and special attention is paid to the following elements:

- **Supporting structure**- Check the stability and integrity of the structure, the presence of corrosion, damage or loose joints. If loose screws or deformations are noticed, additional tightening and adjustment is performed.
- **Photovoltaic panels**- The physical condition of the panel is examined, including the appearance of cracks, scratches, delamination or clouding of the protective layer. It also checks for the presence of dirt, leaves, birds and insects that can reduce efficiency.
- **Cables and connectors**- The insulation of the cables, the condition of the MC4 connectors and protective tubes are inspected. Damaged cables or loose connections can lead to energy losses and are a safety risk.
- **Charge controller and battery system**- It is checked that the batteries are properly connected and that there are no signs of electrolyte leakage, corrosion or overheating. The indicator lights and the functionality of the protective circuits are also checked.
- **Inverter**- The physical condition of the inverter, the presence of unusual sounds, overheating, and the correctness of the ventilation openings are inspected.
- **Electrical installations**- All connections, fuses and switches are inspected to ensure there are no signs of overheating, oxidation or loose connections.
- **Grounding installation**- It is checked whether the grounding devices and grounding lines are in good condition, and that there is no damage to the connections.
- **Lightning rod installation**- The correctness of lightning rods, connecting lines and clamps is inspected to ensure that the system provides adequate protection against lightning strikes.

Washing and cleaning of solar panels and other components

Dirt and dust deposits can significantly reduce the electricity production of photovoltaic panels. Regular cleaning of the panel and other parts of the system ensures optimal performance.

Cleaning solar panels:

- Use clean water or special panel cleaning agents that do not contain abrasive ingredients.
- Soft brushes and sponges are used to remove stubborn dirt, while high-pressure devices are avoided to prevent surface damage.
- Cleaning is done in the morning or in the evening when the panels are cold, in order to avoid thermal shock and cracking of the glass surfaces.



VIDEO

Photovoltaic panel cleaning

procedure: <https://www.instagram.com/smarthome.co.me/reel/C4fiybxlrch/>

Photovoltaic panel cleaning procedure: https://www.youtube.com/watch?v=Q6_bFdkuhOk

Cleaning other components:

- **Supporting structure**- Removes dust, leaves and insect remains that can impair stability or cause corrosion.
- **Connectors and joints**- Cleanliness of connectors and joints is checked to prevent oxidation and ensure good contact.
- **Cables**- It is checked whether the cables are covered with dust, mud or insects that can endanger the insulation.
- **Inverter ventilation openings**- They are cleaned to prevent overheating and ensure smooth operation.
- **Battery system housing**- Dust and impurities are removed to prevent overheating and extend battery life.
- **Earthing contacts and lightning conductors**- It is checked that the joints are clean and in good contact to ensure functionality.

Other preventive works on components of solar photovoltaic systems

In addition to visual inspection and cleaning, preventive maintenance includes a series of interventions that help preserve the stability and efficiency of the system.

- **Setting the positions of the solar panels**- If the system uses mechanical supports with a variable tilt angle, periodic adjustment optimizes energy production throughout the year.
- **Replacement of scrapped or worn parts**- If worn clamps, corroded screws or worn connectors are found, it is necessary to replace them.
- **Calibration of sensors and measuring devices**- Sensors that measure the intensity of solar radiation, panel temperature or electrical parameters must be precisely adjusted to provide accurate data.
- **Control of stability and tightening of joints of the supporting structure**- Over time, due to weather conditions and vibrations, the joints of the structure can loosen, so it is necessary to periodically check and strengthen the joints.
- **Replacement of damaged connectors and cables**- Any mechanical damage to the cables or connectors can lead to system interruption or electrical problems.
- **Measuring ground resistance**- Using measuring instruments, the effectiveness of the grounding is checked and corrections are made if necessary.
- **Testing the functionality of protective switches and fuses**- The correctness of the protective devices is crucial for the prevention of failures and the safety of the system.
- **Testing of grounding and protective devices**- Grounding testing involves measuring grounding resistance using specialized measuring equipment. This ensures effective protection against electric shocks and surges.
- **Checking electrical installations and connection points**- In addition to inspecting the visible elements of the system, it is necessary to regularly check the correctness of electrical installations. This check includes checking the connection points to the solar panels, switch cabinets and inverters.

One of the key steps in preventive maintenance is testing the system under load. This includes simulating different levels of electricity consumption to check voltage stability and system response to increased demands. These tests help identify potential weak points in the system.

Analyzing system performance data makes it possible to predict potential failures and problems before they actually occur. Software tools enable monitoring of system performance, comparison with historical data and detection of unusual oscillations in energy production. These data are crucial for the long-term optimization of the operation of solar photovoltaic power plants.

Regular visual inspections, cleaning and replacement of damaged elements reduce the possibility of breakdowns and optimize the operation of the solar photovoltaic system. By using modern tools for system diagnostics and control, it is possible to prevent potential problems and extend the life of key components.



PRACTICAL EXERCISE

Task 1: Visual inspection and cleaning of solar panels and system components

Perform visual inspection and cleaning of solar panels, cables, connectors and other components of the solar photovoltaic system. Through this task, you will learn how to recognize potential problems, assess the condition of the system, and properly clean panels and other elements to ensure their longevity and optimal efficiency.

Material and tools:

- Protective gloves and goggles;
- Soft brush or sponge;
- Distilled water and mild detergent;
- Microfiber cloths;
- Water sprinkler or flushing system;
- Inspection mirror;
- Infrared camera (optional);
- Hand multimeter for basic connection checking

Procedure:

1. Perform a visual inspection of the solar panels
 - Inspect the surface of the panel for cracks, scratches and signs of damage.
 - Check for deposits of dirt, leaves, bird droppings or other impurities.
2. Inspect mechanical and electrical connections
 - Check the fastening elements of the panel supports and the fuses at the joints.
 - Inspect cables and connectors for signs of overheating, oxidation or loose connections.
3. Clean solar panels and mounts
 - Use a soft brush and mild detergent with distilled water to remove impurities.
 - The panels are washed in circular motions, without too much pressure, in order to prevent damage to the surface.
 - After cleaning, rinse them with water and let them dry naturally.
4. Clean connectors, cables and electrical components
 - Wipe the dust off the cables and connectors with a dry cloth.
 - Check the connectors for signs of corrosion and, if necessary, clean them with a special agent for contact joints.



PRACTICAL EXERCISE

5. Test the system after cleaning

- Perform a visual inspection again to verify that all connections are in place.
- Use a multimeter to measure the voltage and current of the system before and after cleaning and compare the results.

Final check:

- Check that all panels are clean and that there are no residual impurities.
- Document any irregularities and damages so that appropriate measures can be taken.
- Compare operating parameters before and after cleaning and record any changes in system efficiency.



PRACTICAL EXERCISE

Task 2: Testing of grounding and protective devices

Check the grounding system and test the protective devices of the solar photovoltaic system. Through this assignment, you will learn how to use appropriate instruments to measure grounding resistance, check protective fuses and switches, and ensure proper operation of the system's protective mechanisms.

Material and tools:

- Ground resistance meter;
- Multimeter;
- Insulated pliers and screwdriver;
- Clamps and connecting elements;
- Protective equipment (gloves, glasses).

Procedure:

1. Inspect the grounding system
 - Visually check the grounding and connected cables.
 - Check the clamps and connections to make sure they are tight.
2. Measure ground resistance.
 - Connect the ground resistance meter to the system points.
 - Compare the measured values with the standard limits (usually below 10 Ω).
 - If the resistance is too high, identify the cause and take corrective measures (eg additional earthing devices or replacement of damaged connections).
3. Test circuit breakers and fuses
 - Check that the circuit breakers are working properly by simulating a short circuit.
 - Check the automatic fuses and their reactions to overload.
 - Record all malfunctions and suggest solutions.
4. Reconnection and final testing
 - After all the checks, make sure all connections are tight.
 - Perform final system testing and compare results with previous measurements.

Final check:

- Ensure that all parts of the grounding system are in good condition.
- Check that the circuit breakers and fuses functioned properly during the test.
- Document results and compare them to benchmarks to ensure system security.

7.4. Interventions and troubleshooting

Corrective maintenance of solar photovoltaic systems involves the detection, diagnosis and repair of faults in order to ensure the continuous and safe operation of the system. Timely intervention and replacement of damaged components are key factors for minimizing downtime and preserving system efficiency. In this segment, we will cover the process of fault identification, necessary remedial actions, safety measures, and post-repair procedures.

Determining the place and type of failure of solar photovoltaic systems

The first step in corrective maintenance is to correctly identify the problem. Malfunctions can be manifested through a drop in system performance, interruptions in operation, faulty signals from protective devices or anomalies in electrical parameters.

The most common failures include:

- **Problems with photovoltaic panels**– glass breakage, delamination, hot-spot effects.
- **Damage to cables and connectors**– burnt or melted connectors, breaks in lines.
- **Inverter malfunction**– overheating, errors in current conversion.
- **Problems with protective devices**– failure of fuses, automatic switches or grounding.
- **Lack of communication with the monitoring system**– errors in the software monitoring of parameters.

Determining the location and type of failure involves:

- **Monitoring of alarm signals and operating parameters**- many modern solar systems have built-in software alarms that signal operational malfunctions (voltage drop, unstable operation of the inverter, failure of protective circuits, etc.).
- **Visual inspection**- the physical condition of panels, cables, connectors and other components is checked, looking for signs of damage, corrosion, overheating or faulty connections.
- **Thermographic testing**- using thermal cameras to detect hot spots on solar panels and connectors, which can indicate bad connections or damaged cells.
- **Measurement of electrical parameters**– using a multimeter and a clamp ammeter.
- **Voltage, current and resistance are checked at various points in the system to detect possible problems with connection points or faulty components.**
- **Checking of protective and safety circuits**– fuses and circuit breakers are tested to determine whether they have responded correctly in the event of a short circuit or overload.

Delivery of necessary parts, equipment, materials and tools for performing corrective maintenance works

After diagnosis, it is necessary to prepare the appropriate components and tools in order to eliminate the malfunction as quickly as possible. Preparation includes:

- **Identification of required replacement parts**- for example new solar panels, cables, inverters, fuses.
- **Choosing the right tool**– insulated tools for electrical work, pliers, screwdrivers, voltage tester.
- **Providing protective equipment**– electrician's gloves, safety glasses, safety belts (for working at height).
- **Delivery of materials to the site**- organization of transport in order to carry out the works in the shortest possible time.

Application of safety measures and protective means and equipment for performing corrective maintenance works

Before any intervention, it is necessary to ensure a safe working environment. Application of appropriate safety measures minimizes the risk of electric shock, mechanical injury and fire.

Basic security measures include:

- **Shutting down the system before intervention**- complete disconnection of AC and DC voltage from the system.
- **Checking the voltage before starting work**- voltage measurement at key points using a multimeter.
- **Using an isolated tool**- all tools must have high voltage protection.
- **Protection against electric shock**- use of protective gloves, dry shoes and standing on insulating surfaces.
- **Ensuring the stability of the working platform**- when working on the roof, the use of safety belts is mandatory.
- **Fire protection**- ensuring the availability of fire fighting equipment (CO2 fire extinguisher).

Specific safety measures when repairing various malfunctions:

- **When repairing an inverter**- ensure that it is disconnected from the mains and check the capacitors.
- **When replacing the panel**- use the correct methods for handling glass surfaces.
- **When replacing cables**- ensure correct connection according to technical standards.

The process of disassembling defective elements and assembling a new element

After implementing safety measures, physical removal of the defective component and installation of a new one is undertaken. The process varies depending on the type of failure and the component being replaced.

Procedure for replacing damaged solar panels:

- Disconnect the PV array from the system and ensure that no current is flowing.
- Remove the fastening elements and carefully dismantle the defective panel.
- Place the new panel and fasten it with the appropriate screws.
- Connect the panel using the MC4 connector and check the polarity.
- Test panel voltage before returning to system.

Procedure for repairing cable lines and connectors:

- Identify a broken or damaged cable using a continuity tester.
- Turn off the power supply and isolate the part of the cable that is being repaired.
- Remove the damaged cable segment and prepare new ends using pliers.
- Connect the new cable using the appropriate connectors and isolate the connections.
- Test voltage and continuity before restarting.

Inverter replacement procedure:

- Switch off the inverter and check that there is no residual voltage.
- Release the AC and DC connectors, then carefully remove the device from the bracket.
- Install the new inverter and fasten it to the supporting structure.
- Connect AC and DC cables according to technical specifications.
- Run the test run and check the output parameters.

Commissioning of a replaced or repaired element after corrective maintenance

After repairing the fault and installing new components, the system gradually returns to operation with a series of control tests.

Commissioning steps include:

- **Checking the correctness of all connections**– physical inspection of connection points.
- **Voltage and current measurement**- ensuring that the electrical parameters are within the permissible limits.
- **Inverter testing** –error-free DC to AC conversion check.
- **Checking protective devices**- ensuring that all fuses and switches are functional.
- **System monitoring in the first few hours of operation**- data reading using software tools.

Drafting of protocols on completed corrective works

Every intervention on the solar photovoltaic power plant must be recorded. Corrective maintenance documentation serves as a basis for future analysis and system improvement. Documentation of interventions includes:

- **Recording of performed repairs-** entering data on replaced parts, identified problems and applied repair methods.
- **Analysis of the cause of failure** –looking at the factors that led to the problem in order to take preventive measures in the future (eg poor quality components, unfavorable weather conditions, system overload, etc.).
- **Proposing preventive measures-** if it is found that the failure is due to poor maintenance or incorrect installation, it is necessary to propose changes and corrective measures to prevent the same problem from occurring again.

Electronic records of interventions can be used to monitor long-term system performance and optimize maintenance.



PRACTICAL EXERCISE

Task 1: Diagnostics and repair of faults in solar photovoltaic systems

Identify and repair faults in the solar PV system using available diagnostic tools. Through this exercise, you will acquire the skills of visual inspection, measurement of key parameters and replacement of damaged components.

Material and tools:

- Multimeter and clamp ammeter;
- Thermographic camera;
- Continuity tester;
- Set of insulated tools (screwdrivers, pliers, wrench for MC4 connectors);
- Replacement and (fuses, cables, connectors);
- Protective equipment (gloves, goggles, safety belt).

Procedure:

1. Visual inspection of the system
 - Inspect the photovoltaic panels and notice any physical damage (cracks, delamination).
 - Check the condition of cables and connectors - look for signs of overheating, melted joints or corrosion.
 - Inspect the inverter, battery system and protective devices for faults or malfunctioning indicators.
2. Measurement of electrical parameters
 - Use a multimeter to measure the voltage at the output of the solar panels.
 - Use a clamp-on ammeter to measure the current in the system and verify that it is within expected limits.
 - Identify possible "hot spot" points on the panels or bad contacts by thermographic inspection.
3. Repair of the fault
 - If a faulty cable or connector is detected, turn off the power and replace the damaged part.
 - In the event of a faulty fuse, replace it with a suitable one according to the system specification.
 - Check all connection points and tighten loose connections.
4. Testing after repair
 - Re-measure and verify that the system is operating within normal parameters.
 - It monitors the operation of the system for a few minutes to make sure that there are no new irregularities.

Final check:

- Compare the measured values before and after the rehabilitation.
- Check whether the fault has been completely eliminated and record the intervention.



PRACTICAL EXERCISE

Task 2: Replacing a defective photovoltaic panel

Dismantle and replace the faulty solar panel in the system, with proper connection and functionality testing.

Material and tools:

- A new solar panel of suitable specifications,
- Key for MC4 connectors,
- Set of insulated tools (screwdrivers, pliers),
- Multimeter for checking voltage,
- Protective equipment (gloves, goggles, safety belt).

Procedure:

1. Preparing for replacement
 - Turn off the system and ensure that there is no voltage in the circuit you are going to service.
 - Check the technical documentation to determine the specifications of the replacement panel.
2. Dismantling the faulty panel
 - Disconnect the panel from the serial/parallel connection using the MC4 connector.
 - Carefully remove the bracket fasteners and release the panel.
 - Inspect the contacts and verify that they are correct for reuse.
3. Installation of a new panel
 - Place the new panel on the bracket and secure it with the appropriate screws.
 - Connect it to the other panels using MC4 connectors, paying attention to the polarity.
 - Check all connections to ensure safe and stable contact.
4. System testing
 - Measure the output voltage with a multimeter and compare it with the expected values.
 - Turn on the system and monitor the operation for a few minutes to ensure stability.

Final check:

- Check the physical stability of the mounted panel and ensure that it is properly attached.
- Test whether the system functions according to the intended parameters.
- Document the performed intervention with data on the replaced component and the test result.

7.5. Seasonal and long-term system preparations

Seasonal and long-term preparations of solar photovoltaic power plants are crucial for maintaining the efficiency and reliability of the system. Regular checks and optimization of components enable stable operation, reduce breakdowns and extend the life of the system.

- Preparing for seasonal changes

Solar power plants are exposed to different weather conditions, which requires adaptation of the system:

- **Winter conditions**- Checking the stability of the structure, ensuring the adequate slope of the snow removal panel and checking the battery capacity.
- **Summer conditions**- Ensuring ventilation of the inverter and regular cleaning of the panel from dust and pollen.
- **Stormy periods**- Checking the correctness of lightning protection and securing fasteners on the structure.

Revision and optimization of the system

- **Panel and bracket overview**– Identification of damage and phenomena such as hot-spot effects.
- **Electrical installation check**– Inspection of cables, connectors, grounding and protective devices.
- **Calibration of sensors and measuring devices**- Ensuring the accuracy of data for timely diagnostics.
- **Testing of protective systems**– Load simulation to check the correctness of fuses and switches.

Long-term maintenance and modernization

- **Replacement of critical components**– Timely replacement of batteries, inverters and fuses to avoid breakdowns.
- **System modernization**- Gradual replacement of older components with more efficient technologies.
- **Optimization of software solutions**- Updating the system for remote monitoring and automatic fault diagnosis.

Proper maintenance of technical documentation enables monitoring of performance and planning of future interventions. Through regular inspections, testing, optimization and modernization, stable operation of the system is ensured in all weather conditions. Proper planning and monitoring of performance enables timely remediation of problems, thereby reducing maintenance costs and increasing the overall efficiency of the solar power plant. Based on the recorded data, maintenance experts propose improvements in system operation, optimization of consumption and the possibility of improving the system through new technologies and improved maintenance methods.



QUIZ

Quiz 11: Drive and maintain installation of solar photovoltaic power plants:

<https://forms.office.com/e/Y4DvWyr6Gg>.

7.6. The financial aspect of solar photovoltaic system

Investing in a photovoltaic system brings long-term financial benefits, but requires a careful analysis of costs and return on investment. Consideration of operating costs, investment payback period and potential income is key to making the right investment decision.

Operating costs

Operating costs of solar PV systems include:

- **Maintenance and repair costs**– Regular cleaning of panels, replacement of inverters after 10-15 years, control of cables and connectors.
- **System monitoring and management costs**– Software tools for system monitoring, remote performance monitoring, periodic inspection.
- **Insurance and licensing costs**– Insurance against damages and natural disasters, permits for connection to the network.

Return on investment (ROI) and payback period

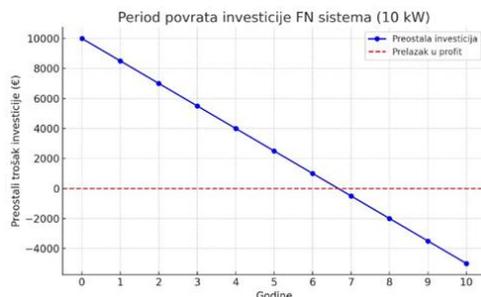
Example of a detailed calculation of the costs of a home solar photovoltaic system installation 10 kW (prices may vary depending on the company performing the work)

Initial investment:

- Solar panels (25 panels x 400 W) – €4,500;
- Inverter (10 kW, hybrid) – €2,000;
- Assembly and construction – €1,500;
- Electrical installation (cables, connectors, fuses, grounding) – €1,000;
- Project documentation and permits – €500;
- Total investment cost: €10,000.

Annual savings and income:

- Annual energy production: ~11,000 kWh,
- Annual savings on electricity bills: €1,500 - €2,000,
- Selling excess energy to the grid (if enabled): €200 - €500/year.



The payback period of the solar photovoltaic system investment



Graph of seasonal energy production from the photovoltaic system

*Half-Cut*cells provide better efficiency and greater resistance to shading, making them more cost-effective for installations in urban areas or locations with possible partial shading. However, their initial price is somewhat higher, so the economic choice depends on the budget of the investor and the location of the system.

After the payback period, the solar PV system continues to generate savings and income, while operating costs remain low (on average €100 - €200 per year for maintenance and insurance).

- Return on investment (ROI) is calculated as the ratio of realized income and savings in relation to the initial investment costs.
- Calculation of the investment return period includes an analysis of installation costs, expected annual savings and additional income.
- A typical payback period ranges between 5 and 10 years, depending on subsidies, the price of electricity and the location of the power plant.

Financial benefits

- **Savings on electricity bills**- solar photovoltaic systems significantly reduce electricity costs, especially for consumers with high daily consumption.
- **Profit from selling excess energy to the grid**- Depending on the accounting system (net metering, feed-in tariff), the surplus of produced energy can be sold to the distributor.

Cash flow and life cycle analysis of a solar PV system

- Life cycle cash flow analysis involves forecasting income and expenses over 25-30 years of system operation.
- The annual forecast of income and expenditure includes operating expenses, depreciation and expected income.

The financial viability of a solar PV system depends on operating costs, return on investment and potential savings. A long-term cash flow analysis shows that solar PV systems provide stable income and significant savings over their lifetime.

8. CONCLUSION AND RECOMMENDATIONS

Installation and maintenance of solar photovoltaic systems represent a key segment in the development of sustainable energy systems and the transition to renewable energy sources. This manual provides the necessary theoretical and practical knowledge that is essential for the safe and efficient performance of work in solar photovoltaic systems.

Through detailed thematic units, users are introduced to the basic principles of operation of solar photovoltaic systems, system components, the execution of electrical installations, protective measures, as well as commissioning, monitoring and maintenance processes. Special emphasis is placed on practical exercises that enable participants to apply the acquired theoretical knowledge in real working conditions.

Reliability and longevity of solar photovoltaic systems directly depend on the quality of the installation, proper maintenance and timely response to possible failures. That is why the manual covers the key methods of preventive and corrective maintenance, along with guidelines for detecting and repairing faults. Also, the importance of safety at work, correct handling of equipment and application of safety standards in daily work was particularly emphasized.

The global growth trend of solar energy and the increasing need for a skilled workforce in this sector provide excellent opportunities for professional development and employment. An increasing number of countries are investing in solar power plants, both for decentralized energy production and for large grid systems, which opens up opportunities to work in the dynamic and promising sector of renewable energy sources.

Quality education and continuous professional training are necessary for the improvement of the solar industry and the improvement of the energy efficiency of the system. Therefore, it is recommended to further upgrade knowledge through specialized courses, follow innovations in the field of photovoltaic technologies and adopt new technological solutions that can optimize the operation of solar photovoltaic systems.

This manual not only provides a basis for understanding and practical application of solar photovoltaic systems, but also encourages users to further research, develop professional skills, and actively participate in the development of sustainable energy systems. Its application will contribute to a safer, more efficient and more environmentally friendly use of solar energy, thus ensuring energy stability and environmental protection.

We hope that this material will serve as a foundation for the successful application of acquired knowledge and skills and contribute to the further development of renewable energy sources in the future.

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