



Manual for installing and maintaining electrical equipment in wind farms

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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/attendees to acquire the necessary knowledge and skills for installing and maintaining power equipment in wind farms. Through clearly explained theoretical foundations, users will understand the key operating principles of wind turbines, their components and how 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, 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."

Given that the transition to renewable energy sources is a global priority, qualifications in this field are becoming extremely sought after and valued, opening up new opportunities for professional development and employment. The wind energy industry is experiencing constant growth, and the demand for experts in this field is increasing year by year. According to data from 2025, the global wind energy industry employs more than 1.4 million people, with projections that this number will grow significantly in the coming decades. According to future estimates, the wind energy sector could employ over 2.3 million people by 2030 and over 4 million by 2050.

The key goal of the manual is to train users to install and maintain power equipment in wind farms. Through clearly structured theoretical foundations and detailed practical guidelines, students/participants will be able to:

- They install and connect the electrical components of wind turbines in compliance with technical and safety standards, thus ensuring reliable and safe operation of the system.
- They maintain the power infrastructure of wind farms, thereby extending the life of the system and increasing efficiency.
- They recognize and solve possible problems during the operation of electrical installations.

This approach of connecting theoretical knowledge and practical skills enables students/participants not only to acquire technical competence, but also to be confident and ready to recognize opportunities, propose solutions and improve the application of wind energy in different contexts. Thus, they are additionally empowered for active participation in the development of the industry of renewable energy sources.

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

In addition to acquiring theoretical foundations and practical knowledge, students/participants are provided with an insight into the latest achievements and examples from practice, including realizations that demonstrate a high level of success in the application of wind energy. Through these examples, users will develop a deeper understanding of the potential of wind farms.

The goal of the manual is to inspire students/participants to contribute to the development and spread of wind energy solutions and their application in the most diverse sectors of society.

Finally, the handbook represents the basis for acquiring qualifications that are highly valued in the labor market. Considering the constant growth of the sector of renewable energy sources, the skills of installation and maintenance of power equipment in wind farms enable students/participants to develop professionally in this dynamic field, providing them with the opportunity to adapt to the challenges and needs of the modern market and train them to work in one of the most promising industries of our time.

1.2. Significance and application of wind energy

Wind energy represents one of the most important renewable energy sources, with a key role in the transition towards sustainable energy solutions. Its availability, environmental benefits and growing economic profitability, including falling technology costs and increasing efficiency, make wind energy one of the most promising solutions in the global clean energy transition.

According to data from the International Renewable Energy Agency (IRENA), the global capacity of wind power plants in 2025 exceeded 1,000 GW, with a constant increase in installed capacity. By 2030, wind energy is expected to account for a significant portion of global electricity production, thanks to technological innovation, optimization of wind turbine performance and increased support for renewable energy sources.

The key advantages of wind energy are:

- **Long-term inexhaustible potential:** Wind energy is a natural and renewable source of energy, available all over the world, especially in coastal and mountainous areas, where the winds are the most intense and constant.
- **Environmental sustainability:** Wind power plants produce energy without the emission of harmful gases and other pollutants, which directly contribute to the reduction of the carbon footprint and the fight against

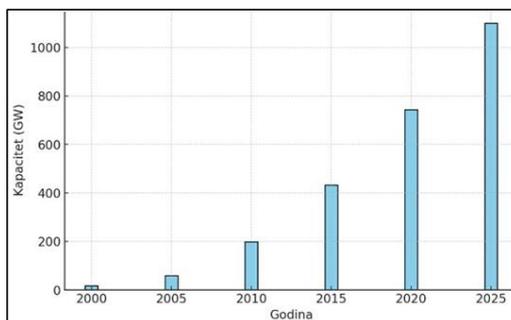


Chart: Growth of wind farm capacity

climate change. Their operation does not require the burning of fossil fuels, which makes them a key factor in environmental protection and sustainable development.

- **Energy security:** The use of wind farms reduces dependence on fossil fuels and centralized power systems. Thanks to decentralized electricity production, a more stable and resilient energy supply is enabled, reducing vulnerability to economic and geopolitical risks.
- **Economic viability:** Falling construction costs and increasing the efficiency of wind turbines, along with the availability of subsidies and incentive policies, make wind energy an increasingly competitive solution in the power sector. Long-term savings on electricity costs, as well as the

possibility of earning through the purchase of produced energy, additionally contribute to its wide application.

Wind energy is widely used in the production of electricity. It is most often used through wind turbines that convert the kinetic energy of the wind into electrical energy using a generator. Wind farms can be divided into land (onshore) and coastal (offshore) systems. Onshore wind farms have been in use all over the world for a long time, while offshore wind farms, thanks to the more stable and stronger winds at sea, represent an increasingly important source of electricity, especially in developed power grids.



Wind farm view

In addition to the production of electricity in power systems, wind energy is also used in independent power supply systems for remote facilities, such as farms, rural households, telecommunication towers and other infrastructures in locations without access to the power grid.

Wind energy also plays a significant role in modern technological solutions, such as integration into smart grids, connection to energy storage in the form of battery systems and hydrogen technologies, and the development of hybrid systems that combine wind power plants with solar panels and other renewable sources.

With its environmental benefits, economic sustainability and constant technological development, wind energy is a key element of the global transition to sustainable energy. Its increasingly widespread application contributes to reducing dependence on fossil fuels, increasing energy efficiency and mitigating the negative consequences of climate change. In the future, wind farms will play an even more important role in the global energy mix, providing a sustainable and reliable source of electricity for generations to come.

1.3. Manual structure

The manual for installation and maintenance of power equipment in wind farms is designed as a comprehensive guide that covers all key aspects of installation, i.e. mounting and dismantling of equipment, as well as 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 seven Chapters dedicated to the elaboration of the issues that are the subject of the Manual. At the end, Conclusion and recommendations, Labels and abbreviations and References and used sources are given.

In the Introduction the basic purpose and goals of the manual are presented, emphasizing the importance of wind energy and its application.

Chapter 2, Renewable energy sources, provides basic information about different forms of renewable energy sources, with special emphasis on wind energy.

Chapter 3, Safety at work and environmental protection elaborates the key safety guidelines that should be observed during the installation and maintenance of electric power equipment in wind farms in order to preserve health and safety at work, as well as measures to protect the environment.

Chapter 4, Wind energy, from a theoretical point of view, explains the types of wind turbines and wind power plants, their working principle and elements.

Chapter 5, Installation and dismantling of power equipment in wind farms, is a key chapter in the Manual with a detailed elaboration of procedures and procedures for practical implementation.

Chapter 6, The execution of electrical installations in wind power plants is dedicated to the elaboration of the assembly and installation procedures of electrical installations, including a brief description of the installation of grounding and lightning protection.

Chapter 7, Equipment maintenance and monitoring in wind farms, describes preventive and corrective maintenance procedures, procedures for their implementation and monitoring in wind farms.

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

At the end of the Manual, there is an overview of Literature and useful sources with a list of used sources and additional materials that can be useful for a deeper understanding of thematic areas of wind power plants.

2. RENEWABLE ENERGY SOURCES

Energy is all around us. It moves all living things. 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 arise 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, or 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 renewability

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 means 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**- occurs 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 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**– It includes energy from tides, 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.

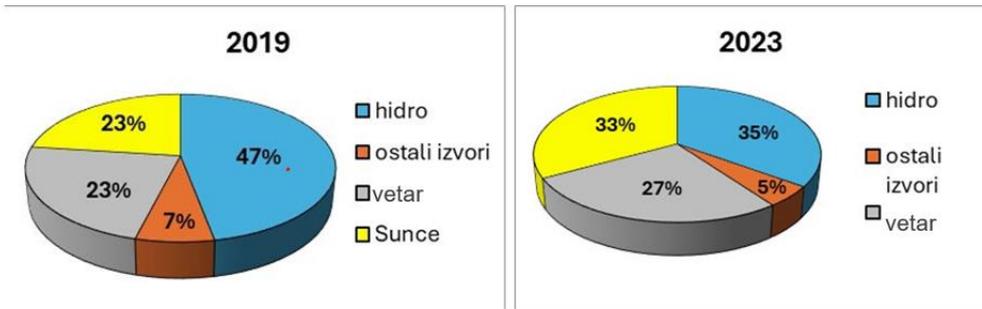
One of the main reasons for the accelerated development of renewable energy sources is their significantly lower negative impact on the environment compared to conventional sources.



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.

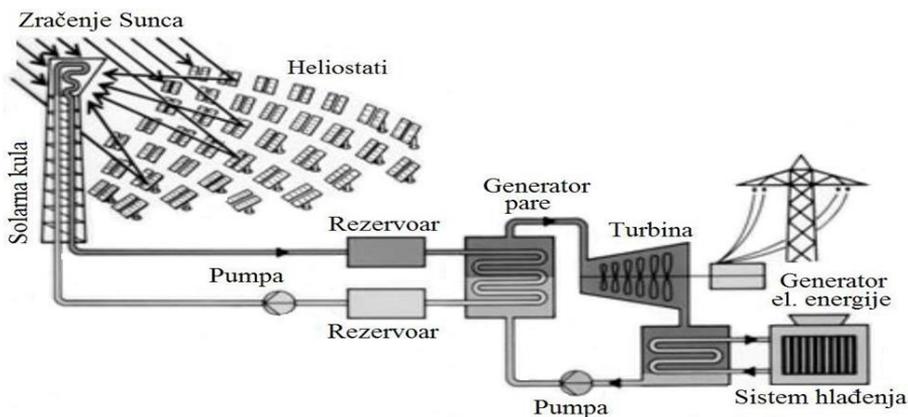


Solar power plant PS10 in Spain

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.

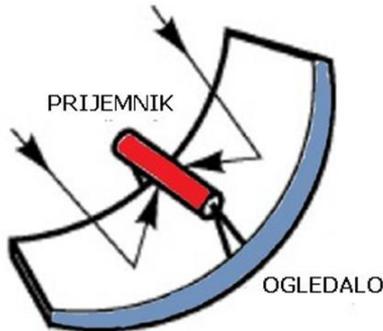
Solar thermal power plants with a solar tower use a heliostat field.

A heliostat is a device that has an ordinary mirror that rotates so that throughout the day, it reflects sunlight towards a specific target tower (helios-from the Greek word for the sun, and stat 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. The tube contains a liquid, 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.



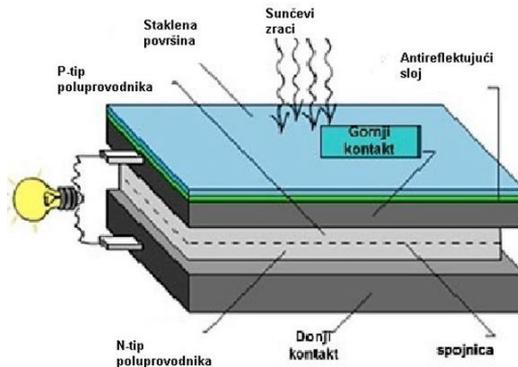
Parabolic collectors

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)

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 belong to facilities that use water as a renewable energy source. 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:

- amounts of water
- meteorological conditions in the wider basin area,
- height of water fall,
- the 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 i
- 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 mainly 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 set before it, specific equipment and devices are needed for its construction, primarily in terms of simplicity, the amount of investment and the 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 in these tasks. 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

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.

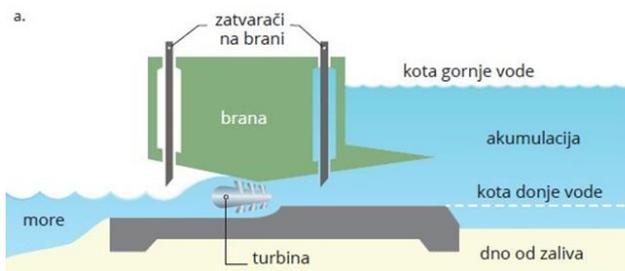
Power plants that use tidal energy (renewable energy source) to drive turbines are a special type of storage hydropower plants. Tides and ebbs (sea tides) occur under the influence of the Sun and the Moon on the water in the seas and oceans. Sea tides are the periodic rising (tide) and lowering (low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

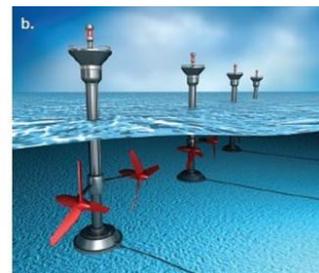
The technology used for the conversion is very similar to the technology used in conventional hydroelectric power plants. However, tidal power plants cannot operate continuously, but only during periods when the tides occur.

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 basin/reservoir, as well as 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 of water flow.

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 in 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 the difference between 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.

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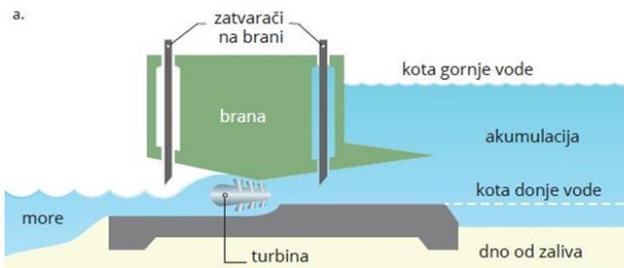
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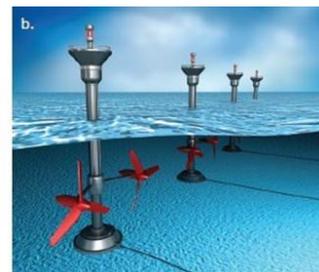
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- using tidal currents (picture b).



a) Tidal dam



b) Tidal currents

With tidal dams, the dam serves to prevent water from entering the basin/reservoir, as well as 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 of water flow.

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 in 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 the difference between 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 southwest 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, a "drive room" that contains the control system, a connection to the electricity transmission grid, a hydraulic system for raising and lowering the plant, and a rotor that is attached to the tower and forms the heart of the plant.



Strangford Lough Power Station

2.5 Wave energy

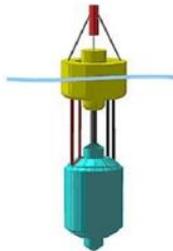
Sea wave power plants are those that use wave energy (renewable energy source) to produce electricity. The main cause of the generation of wave energy is the action of the wind (a consequence of the action of the Sun) on the surface of the sea and ocean. Since wave power differs from daily tides and 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/m^2 , 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/m^2 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 waves on the surface of the ocean, thus transferring energy to them.

Plutajući plovak



Prenosnik snage

Povezne šipke

Potopljeni cilindar



Floating systems

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.



OWS system Islay LIMPET (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

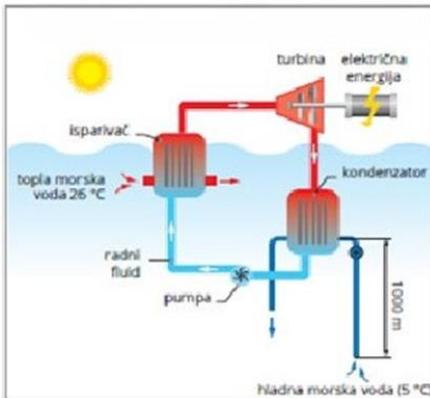
Underwater devices - range from balloon-like objects attached to the ocean floor to long tubes that extend for great lengths. When the waves cause them to oscillate they drive a turbine and generate electricity.



Underwater devices

2.6 Ocean thermal energy (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.

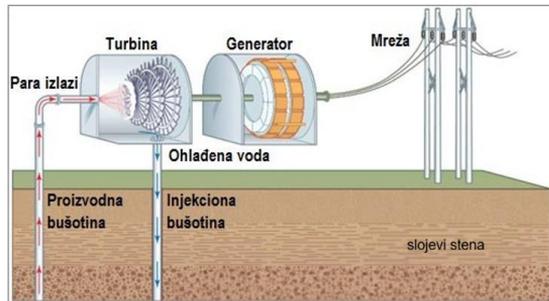
Geothermal energy has a wide range of applications, from direct heating of space and industrial plants to the production of electricity in geothermal power plants.

Geothermal power plants

Geothermal power plants use thermal energy from the interior of the Earth 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:

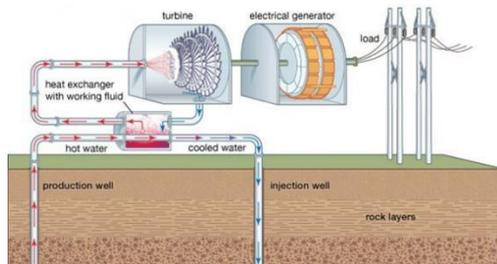
Dry steam power plants- they use the oldest way of converting geothermal energy into electricity. Steam from the Earth's interior is fed directly to a turbine, which drives a generator. This type of power plant was first used in 1904 in Tuscany, Italy. Today, they are rarely used due to the specific 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 interior of the earth 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 electricity generation, geothermal energy is directly used for heating and other practical applications, enabling efficient and environmentally friendly use of thermal energy.

- **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 hot water tank is properly managed, i.e. 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.

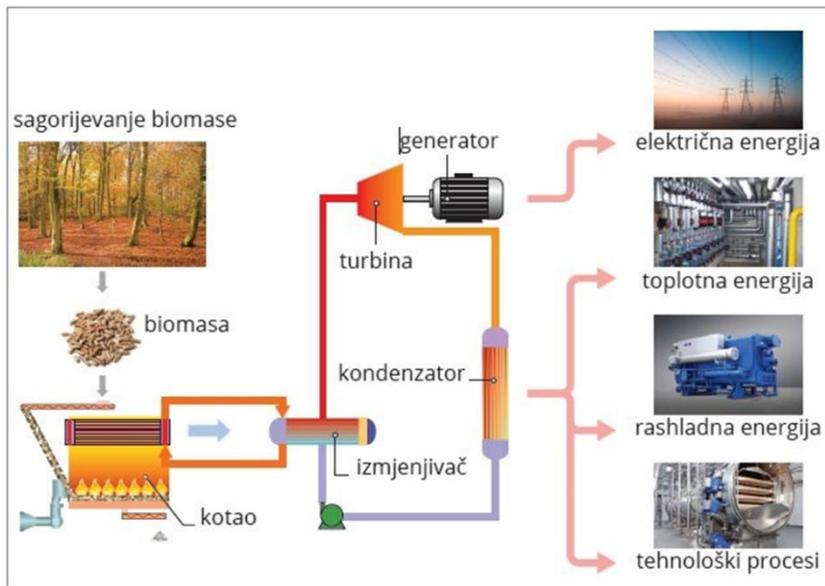
When burned, biomass energy is released in the form of heat. If you have a fireplace, you are already participating in the use of biomass, because the wood that burns is actually biomass.

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 - thanks to photosynthesis, biomass resources grow again in a relatively short period of time compared to fossil fuel sources 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.

- The principle of operation of biomass power plants is basically based on the thermodynamic Rankine cycle, which uses the heat generated by burning biomass to produce steam or heat 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 electricity and heat 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.
- The Organic Rankine Cycle (ORC) is an increasingly common 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 installed 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.
- Sea (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 - are placed on elevated terrain, where the wind accelerates due to orographic effects, which enables more efficient use of energy.
- Wind farms in deserts - use stable, dry climatic conditions with constant winds, although the problem is sand erosion and specific protection equipment.



Examples of different types of wind farms

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.



EXERCIS

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>



VIDEO

Types of renewable electricity sources:

<https://www.energyencyclopedia.com/en/free-downloads/videos/types-of-res-and-the-use-of-renewable-56>.

Comparing renewable electricity sources:

<https://www.energyencyclopedia.com/en/free-downloads/videos/comparison-of-renewable-energy-source-55>.

3. SAFETY AT WORK AND PROTECTION OF THE ENVIRONMENT

3.1. Possible hazards to the health and safety of workers when working on wind farms

Working in the environment of wind farms involves exposure to various factors of the work 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. The relative humidity of the air additionally affects the feeling of temperature and can make the body's thermoregulation more difficult. Strong winds, which are characteristic of areas where wind farms are located, not only make it difficult to carry out work, but can also cause loss of balance, especially when working at height.



Weather conditions



Lifting heavy loads



Danger of high voltage

Noise and vibrations from the operation of generators and other power components can damage hearing in the long term, cause headaches and negatively affect the nervous system. Continuous exposure to vibration, especially in workers who operate tools or heavy machinery, can cause circulatory disorders and problems with the musculoskeletal system. Bad ground on the construction site, uneven and slippery terrain, as well as the presence of obstacles represent an increased risk of falls, sprains and fractures.

Working at height is one of the most dangerous activities in the construction and maintenance of wind farms. Workers often have to perform tasks on wind turbine towers and nacelles, where they are exposed to the risk of falling from great heights. Safety harnesses and proper use of collective and personal protective equipment are key to minimizing risk. Carrying heavy loads during ascent and descent further increases the load on the musculoskeletal system and can lead to injuries to the spine and joints.

Long-term incorrect body position during work can cause pain in the back, neck and shoulders, which over time can result in chronic 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.



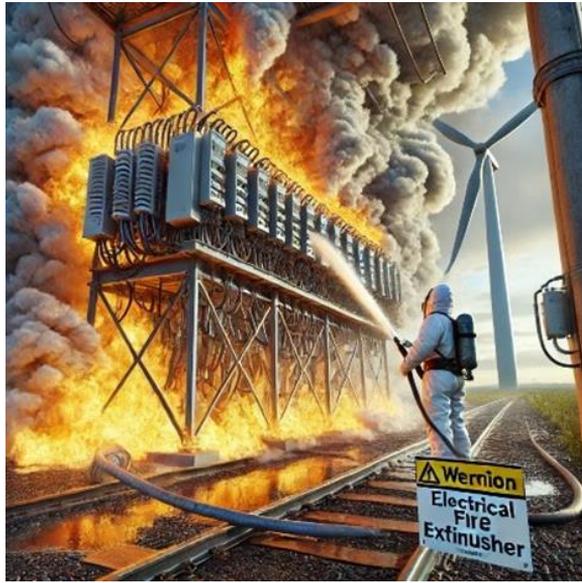
Effect of electric current on the human body

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. Different chemical preparations are used in certain segments of work, which, if not properly stored and handled, can cause serious consequences for the health of workers. The presence of pollution in the air, especially in the form of dust and fine particles, can cause long-term lung damage and increase the risk of occupational respiratory diseases.

Another important aspect is the risk of fire.

Sources of fire danger: short circuits and overloads in electrical installations, defective electrical components, accumulation of flammable material, increased temperature, etc.

Fires represent an additional threat to the safety of workers, because in power plants they often occur due to short circuits and overloads in electrical installations. Faulty electrical components, damaged cables and inadequate equipment maintenance can increase the risk of fire. Accumulation of flammable materials, such as oils and lubricants used in mechanical parts of turbines, further increases the possibility of flame spread. The increased temperature of the components can cause self-ignition, especially if the cooling systems are not functioning properly.



Fire hazard

In the event of an accident, quick and proper first aid can be crucial to saving a life. 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 trained 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.



Freeing the casualty due to electric shock

After release, 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 wind farms 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.

3.2. Application of safety and protection measures at work during the performance of works on wind power plants

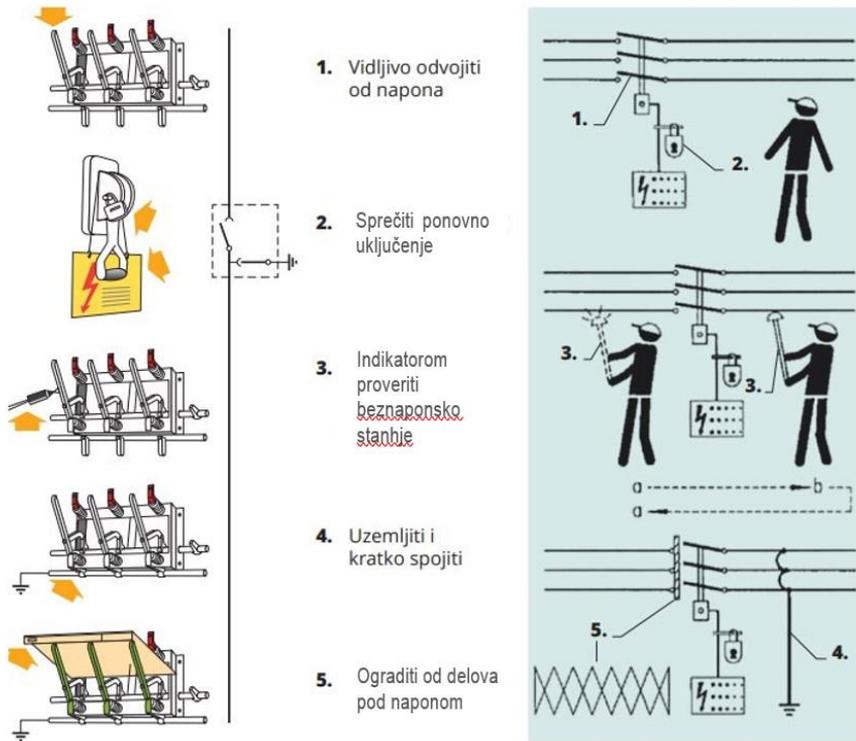
When carrying out work on wind farms, it is crucial to implement safety and occupational health and safety measures in order to reduce the risks of injuries and accidents. The methods of work in relation to the presence of voltage are divided into works in a de-energized state, works near voltage and works under voltage. Works in a de-energized state imply complete disconnection of the power supply with the implementation of prescribed protection measures to prevent unintentional reactivation. Working near voltage requires additional precautions, including the use of protective barriers and safety distances. Works under voltage are carried out with special technical and organizational measures, as well as the use of specialized equipment and isolation tools.

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. Correct selection and use of protective equipment are key to minimizing risks at work.

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, coverings,
- 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: safety helmets, safety glasses, visors, welding shields, ear protectors, dust masks, protective gloves, anti-vibration gloves, protective clothing, safety shoes, safety belts and equipment for working at height.



3.3. Implementation of safety measures and personal protection measures when working at height in wind power plants

When performing work at height in wind farms, workplaces include different locations, such as wind turbine towers, access platforms, gondolas and specially arranged access systems. These locations require special attention due to specific hazards, as workers operate at great heights, often in adverse weather conditions, and on surfaces that may sometimes be inadequately prepared or improperly maintained.

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



Equipment required for work at height

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.

When performing work at height, it is necessary to thoroughly record the factors of the working environment. For example, when inspecting a wind turbine, workers should pay attention to weather conditions - wind speed and direction, temperature and the possibility of precipitation - as well as to the condition of the working surface, including the stability 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 the installation of protective fences and barriers at workplaces, the use of fall protection systems, securing workplaces using safety belts, anchor points and specialized equipment for working at heights, as well as regular inspections and maintenance of access systems. Also, it is extremely important to ensure constant communication between workers and to implement detailed evacuation procedures, so that in the event of an emergency, one can react quickly and efficiently.



QUIZ

Quiz 2: Application of safety and protection measures at work during the performance of works on wind farms:

<https://forms.office.com/e/gbHp9CACVp?origin=IprLink>.



VIDEO

Emergency evacuation simulation: <https://www.youtube.com/watch?v=UWSckm8zTc8>.

Use of protective equipment:

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



PRACTICAL EXERCISE

Task 1: Evacuation simulation

Material and tools:

- Seat 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),
- Seat belts,
- Communication equipment,
- First aid.

Procedure:

1. Preparing 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.
 - Correctly fasten the safety belts of the rescued worker and secure him until the team lowers him to a safe place.
4. Rescue procedure analysis
 - 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 wind power plants on the environment

Environmental protection is one of the key aspects in the construction and exploitation of wind power plants. 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.

Wind farms can have multiple negative impacts on the environment. First of all, the construction of wind farms can lead to habitat degradation and changes in the landscape, which can affect flora and fauna. Also, the rotating blades of wind turbines pose a risk to birds and bats, especially in migration corridors. The noise produced by the turbines can negatively affect animal species and local communities. In addition, electromagnetic interference resulting from the operation of power plants can affect communication systems and radar devices. The Danish company Vestas has developed blades with jagged edges inspired by owl feathers, which reduce noise by 10 dB compared to standard blades.

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

In order to reduce the negative impact of wind farms on the environment, it is necessary to implement a series of measures. Proper planning of the locations of wind farms enables the reduction of negative effects on the ecosystem, while respecting biological corridors and protected areas. The use of noise reduction technologies, such as blade design optimization and active turbine control systems, can significantly reduce negative impacts on fauna. Also, the implementation of a system for monitoring the movement of birds and automatically turning off the turbines during critical periods of migration is an effective preventive measure.

In Spain, wind farms near bird migration routes are equipped with radars that automatically stop the turbines when a flock of birds approaches, reducing the number of collisions.



Stopping the wind turbine during bird migration

The recycling of wind turbines and other equipment of wind farms after the end of their useful life is essential for reducing waste and protecting 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, 43 million tonnes of wind turbine blades will have reached the end of their life, making them a key waste management issue. The blades are made of a durable polymer composite, but it is precisely this strength that makes them difficult to recycle.

Currently, many blades are disposed of in landfills, which is not sustainable. Some European countries have already banned this practice. The expected lifetime of wind turbines is 20–30 years, and the global capacity of wind farms is growing rapidly. In order to achieve energy neutrality by 2050, it is necessary to significantly increase the installation of new capacities, which implies the use of millions of blades.



Recycling of wind turbine blades

More than 90% of wind turbine components can be recycled, including steel, copper and aluminum from towers and nacelles. However, blades are a challenge due to their size and material. Their transportation is complex, because newer blades reach a length of over 100 meters, and wind farms are often in remote areas.

Innovation is key to solving problems. The researchers recommend switching to thermoplastic resins that can be remelted and reused.

One cost-effective method is the mechanical grinding of fiberglass for use in cement production, while cement co-processing involves burning the blades in kilns. GE Renewable Energy has already implemented this practice. The German firm Enercon uses circular recycling systems in which the metal components of the turbines can be reused in new wind turbines, thus reducing the need for raw materials. GE Renewable Energy uses recycled blades in the cement industry, thereby reducing CO₂ emissions in cement production.

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



PRACTICAL EXERCISE

Task 1: Waste management at wind farms

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 premises of the wind 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:

- Review the correct application of protective equipment during the performance of all steps.
- Ensure that waste materials are properly packaged, labeled and prepared for transport.
- Discuss potential risks and ways to improve environmental protection measures in the wind farm.

4. WIND ENERGY

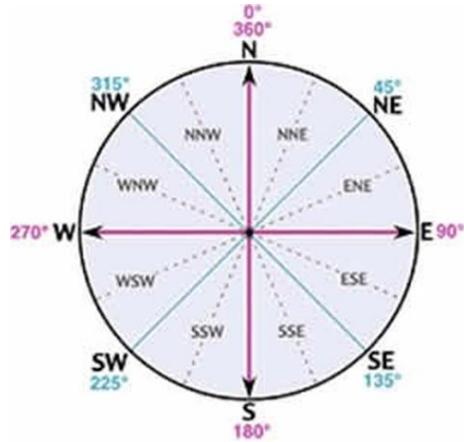
Wind can be described in the simplest way as a flow of air masses that occurs due to the difference in temperature or pressure on the Earth's surface. And the wind, like a significant number of other available energy sources, is a consequence of the Sun's action on the Earth, and belongs to renewable energy sources.

Air flow causes friction, i.e. loss of kinetic energy in contact with a solid surface, which results in differences in flow speed in space and time.

Wind is most often described by two simple components: direction and strength. A weather vane is used to determine the direction, and we mark it with the side of the world it comes from.

Winds located at heights of 1000 m above the Earth's surface are not affected by the Earth's soil. On the other hand, surface winds up to 100 m height depend on the ground.

It is precisely the surface winds that are important for the analysis of wind energy efficiency as required for wind farms.



Wind directions

Local winds are driven by differences in the temperature of land and sea as well as valleys and plateaus. Although global winds are important in determining the prevailing winds in a particular area, local climate conditions can override the influence of prevailing wind directions. Local winds are always added to larger scale wind systems, ie. wind direction is influenced by the sum of global and local effects. When the upper-scale wind is weak, the local wind may dominate the pattern.

$$P = \frac{1}{2} \rho v^3 A$$

- P - wind power in W
- ρ - air density in kg/m³
- v - speed of wind flow m/s
- A - turbine area in m²

It can be seen from the equation that the power P increases proportionally with the third potential of the wind speed and the area of the turbine A.

Wind power cannot be calculated without measuring the wind speed in a certain area over a period of a year and several days. Wind speed changes within fractions of an hour.

Wind strength is traditionally expressed by the Beaufort scale.

Table: Beaufort scale

Beaufort designation, Bf	Description of the wind	Operation	Speed at 10m above ground		
			m/s	km/h	knot
0	Silence	Smoke rises straight up, flags and leaves do not move	0.0 - 0.4	0.0 - 1.4	0.0 - 0.9
1	Lahore	One does not feel it, but the smoke no longer rises uniformly, the weather vane does not move	0.4 - 1.8	0.4 - 6.5	0.9 - 3.5
2	Breeze	You can feel it on your face, the leaves start to flutter and the weathervane starts	1.8 - 3.6	6.5 - 13	3.5 - 7
3	Light wind	The leaves are constantly swaying and rustling, the light flag is swaying	3.6 - 5.8	13 - 20.9	7 - 11
4	Moderate wind	Dust, dry leaves and pieces of paper rise from the ground, the flag unfurls, smaller branches sway	5.8 - 8.5	20.9 - 30.6	11 - 17
5	Moderately strong wind	Large leafy branches and small trees are swaying, people are uncomfortable, small waves are created	8.5 - 11	30.6 - 39.6	17 - 22
6	Strong wind	It buzzes on objects, wires whistle, big branches sway, it's hard to carry an umbrella	11 - 14	39.6 - 50.4	22 - 28
7	Strong wind	The trees are constantly swaying, the waves are foaming, it is difficult to walk	14 - 17	50.4 - 61.2	28 - 34
8	Storm wind	Thick trees are swaying, large branches are breaking, walking is impossible	17 - 21	61.2 - 75.6	34 - 41
9	Strong storm wind	Small objects are moved, roof tiles are moved, damage to houses occurs	21 - 25	75.6 - 90	41 - 48
10	Hurricane wind	Trees are felled and uprooted, causing major damage to buildings	25 - 29	90 - 104.4	48 - 56
11	Strong hurricane wind	Great damage over a larger area, devastating action	29 - 34	104.4 - 122.4	56-65
12	Hurricane	Heavy devastation of the entire area	43	154.8	65

1 m/s = 3.6 km/h = 1.944 knots

4.1. Basic applications of wind energy

For some more serious assessments, how this resource could be used for the purpose of obtaining electricity, detailed analyzes must be made.

Today, in the presence of modern technology, the use of wind energy for the purpose of electricity production is much easier and wind generators are used for this. There is no single, generally accepted international consensus related to the definition of a wind farm, but there is a widespread belief that wind farms are one of the most ecological ways of producing electricity today.

Humans have been using wind energy for at least 5,500 years. Some examples are that the boat with sails has been used for at least 5000 years, and architects have used controlled wind for natural ventilation since ancient times. With ups and downs, mainly related to the rise and fall of oil prices, the development is particularly accelerated after 2000 with the continuous rise of oil prices.

It is precisely wind power plants that play an important role in the distributed production of electricity. They are built and placed in areas with high wind utilization. Such areas are often located within relatively low-voltage parts of the network that are located in rural areas, which makes their efficient connection to the distribution network much more difficult. The use of wind farms could provide relatively cheap electricity, but it is necessary to meet a number of conditions such as specific equipment and devices, the ideal location for the construction of a wind farm, conditions for its construction and operation.

The main advantage of wind farms compared to conventional sources of electricity is the absence of fuel costs. Namely, the main indicator that wind power plants have a bright future are a relatively small impact on the environment, a shorter construction period compared to other sources, a long lifespan, and the most important thing for investors - a quick return on invested capital. The use of wind energy is the fastest growing segment of energy production from renewable sources.

In the last few years, wind turbines have been greatly improved. However, it is clear that wind power plants will never reach the load factor as, for example, thermal power plant, because it is by its nature a different source and depends on natural conditions, but at the same time, wind power plants have free and unlimited renewable fuel.

Wind farms also save the fuel needed to generate electricity from fossil fuel power plants. If a KWh is produced from a wind farm, the fuel needed to produce that KWh in a conventional fossil fuel plant is saved. In unfavorable conditions such as a strong storm or a storm that will affect the operation of wind power plants, it is possible to stop wind power plants, however, the stoppage of wind power plants under these conditions can be extended for several hours, which shows that stopping wind power plants is not as dramatic a case as the outage of a larger power plant (e.g. thermal power plant 300 MW) from the EES, in a much shorter time.

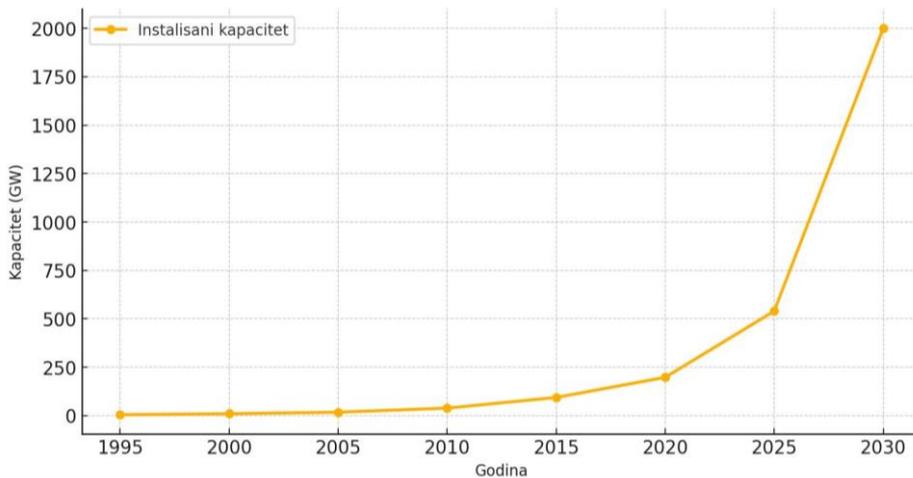
One of the oldest windmills is the De 1100 Roe (pictured) built in 1674 and its first role was to keep the land below the sea dry. It was moved in 1965 because it was no longer so important and needed. Today it is sometimes used to pump water to the neighboring sports park.



Windmill De 1100 Roe

Installed capacities of wind farms in the world and market growth forecast

The total installed capacity of wind power plants in the world is constantly growing, led by technological progress, reduction of production costs and increasing investments in renewable energy sources. The global wind power market is characterized by rapid capacity growth, led by regions such as Europe, North America and Asia, and especially China, which today has the largest share of total installed capacity.



Graph: Growth of installed capacities of wind power plants

Trends show that onshore capacity is developing at a steady pace, while the offshore wind sector is experiencing significant growth thanks to improved turbine efficiency, higher utilization factors and support for decarbonisation policies.

It is predicted that in the coming decades, wind farms will become the dominant source of electricity in many countries. The global energy transition and set climate goals are encouraging increased investment, and predictions suggest that by the middle of the 21st century, installed wind power capacity will exceed fossil fuel generation in many parts of the world.

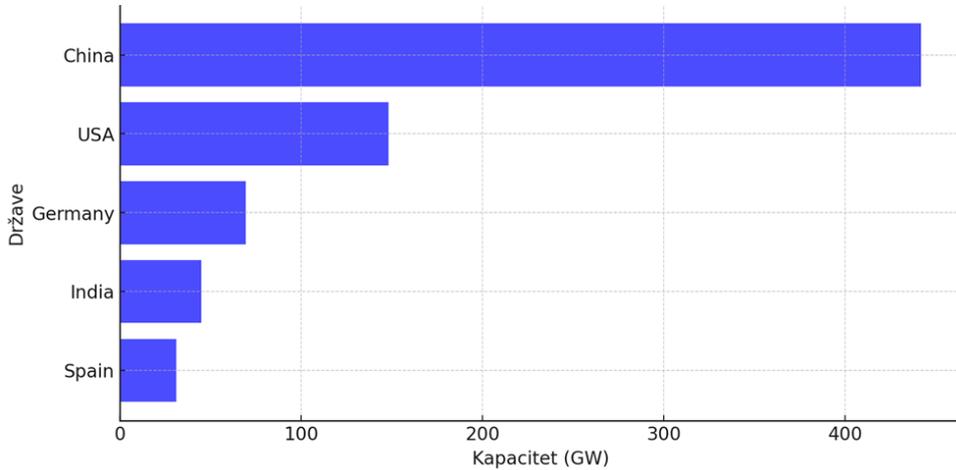


Chart: Installed capacities of wind farms in 2023

Advances in energy storage, development of smart grids and digitization of the power system will further increase the efficiency and reliability of wind farms, reducing dependence on fossil fuels and ensuring a stable supply of electricity.



EXERCISE

Research the installed capacities in your region and compare them with the world market in the field of wind power plants.

4.2. Characteristics of wind farms

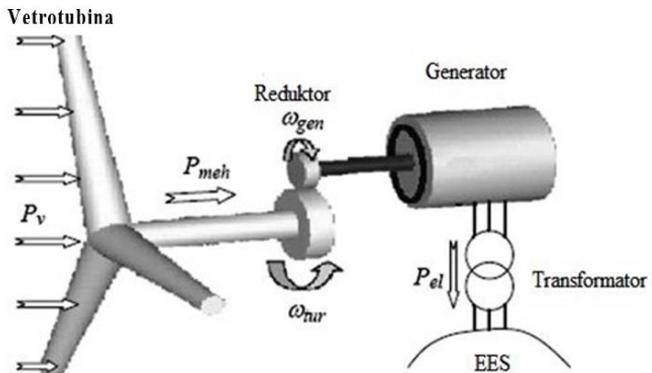
4.2.1. Definitions of wind turbines and wind farms

Today's systems for harnessing wind energy are wind turbines. Wind turbine is also known as wind aggregate and wind generator. A wind power plant is a device that converts the kinetic energy of the wind into electrical energy. It consists of one or more wind turbines that, by means of rotating blades, drive a generator that produces electricity.

A wind turbine is a rotating machine that converts the kinetic energy of the wind first into mechanical energy, and then through electrical generators into electrical energy. The rotor of the wind turbine and the rotor of the electric generator are located on the same shaft.

Wind turbines are cold machines, which means that they convert the energy of a natural fluid that has an ambient temperature. The main characteristic of wind as a driving fluid is its renewable nature. After the air leaves the system to which it gave energy, it returns to the environment with unchanged physical and chemical properties. The remaining energy of the fluid at the exit from the turbine is sufficient for it to leave the system.

The principle scheme of wind energy conversion into electrical energy is given in the figure.



Principle scheme of wind energy conversion into electrical energy.



VIDEO

The principle of operation of a wind turbine:

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

4.2.2. Types of wind turbines and their characteristics

According to the type, wind turbines can be divided into several categories

- according to the position of the shaft,
- according to the type of wind turbine,
- according to rotation speed (with constant rotation speed, with variable rotation speed).

4.2.2.1. Wind turbines according to shaft position

According to the position of the axis, wind turbines can be divided into those with a horizontal axis and those with a vertical axis.

Wind turbines with a horizontal axis of rotation or VSHO

Turbines with a horizontal axis of rotation are those whose axis is parallel to the direction of the wind current and the ground. Most commercial turbines are of this type. The most common are wind turbines with 3 blades, and sometimes you can see models with 2 blades. They have a rotor, a shaft and an electric generator located in a cabin on top of a tall pole, so they must face directly into the wind, for which they use a sensor paired with a servo motor. VSHO turbines can be divided into those facing downwind and those facing away from the wind. The vast majority face the wind, because in this way the impact of the turbulence that occurs behind the turbine is avoided. The main advantage of wind-facing VSHO turbines is that they do not have to be equipped with turbine turning mechanisms, but they are not as reliable and durable as "regular" VSHO turbines.

As already mentioned, most modern wind turbines have 3 blades and an electronic system that directs them towards the wind. They have a high peripheral speed (several times higher than the wind speed), a high degree of utilization, and good reliability. The blades are usually painted gray to blend in with the surrounding clouds. Shovels can be from 20 to 50 or more meters long. Steel towers vary in height from about 60 to 100 or more meters in height. Tower design is an important factor in horizontal axis wind turbines because at higher altitudes the wind flows faster. To illustrate, with a doubling of altitude, the wind speed increases by 10% during the day and between 20% and 60% during the night. For VSHO, the height of the tower is usually taken to be 2 to 3 times greater than the length of the blades. The blades rotate at a speed of 10 to 22 revolutions per minute. That speed is increased by means of a transmission system (reducer) and transmitted to the electric generator.

Advantages of horizontal axis wind turbines:

- The main advantage is greater efficiency in the production of electricity.
- Placing on tall towers allows access to higher wind speeds.
- The blades are located on the side, when viewed from the center of mass of the wind turbine, which improves stability.
- The ability to turn the blades, which gives greater control, allows the optimal arc to be set, so that the wind turbine uses the maximum of the wind's energy.
- The ability to fix the blades in a storm, which minimizes potential damage.

Disadvantages of horizontal axis wind turbines

- Most of these wind turbines require a system to turn the turbine, which makes it even more expensive.
- Problematic operation in low altitude winds that are often turbulent.
- Tall towers and long turbine rotor blades are problematic for transport both at sea and on land. Transport costs can take up to 20% of the total equipment costs.
- VSHO turbines are problematic to install, as they require very tall and expensive cranes.

- Structures facing downwind have reduced durability and reliability due to the turbulence they are exposed to.



Wind turbines with a horizontal axis

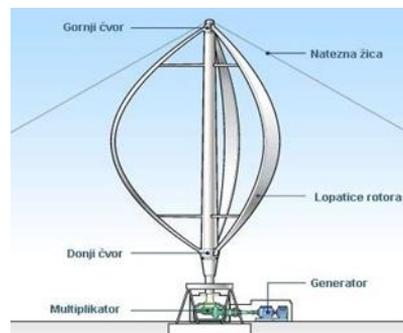
Wind turbines with a vertical axis of rotation or VSVO

Their main characteristic is that the axis of rotation is placed vertically. The main advantage of this configuration is that the turbine does not need to be pointed directly into the wind to be efficient. This is an advantage in locations where the wind direction is quite variable. Therefore, the VSVO turbine can use energy from different wind directions. Vertical axis wind turbines can be placed closer to the ground and do not need tall towers, making them more affordable to maintain. The downside is that wind speeds at lower altitudes are much lower, which entails the fact that less energy is available for transformation. In addition, the air flow near the ground and other objects is often turbulent, which means more frequent vibrations, and faster bearing wear and a shorter life as a result. However, if a wind turbine is placed on the roof of a building, it redirects the flow of wind which significantly increases (sometimes doubles) the speed of the flow.

VSVO turbines can be roughly divided into Darius and Savonius turbines.

Darius turbine

The Darius turbine has long thin C-shaped blades that are joined at the top and bottom of the vertical axis. It is most often made with 2 or 3 blades. They have good efficiency, but also produce significant cyclic stresses that lead to lower reliability. Also, they require an external power source, which helps them in starting due to the weak starting torque. Due to less stability, they have to be supported by metal cables, which is not always practical. With newer constructions, this is not always the case because they have an external substructure attached to the top bearing.



Darius turbine

Spiral Gorlov turbine

The Gorlov turbine was created as a design improvement of the Darius turbine. She uses spiral paddles. It solves some problems of the Darius turbine, first of all, it can start by itself, that is, it does not need an external electrical source, so vibrations and noise are reduced. Its efficiency (up to 35%) is comparable to the best VSHO turbines.



Spiral turbine

Gyromil turbine

This is another subtype of the Darius turbine that uses straight blades rather than curved blades. Allegedly, Russian scientists managed to improve the efficiency of this turbine to as much as 38%.



Gyromil turbines

H type turbine

One of the well-known constructions is the H-type, where the blades are placed parallel to the axis of rotation. Compared to the usual Darius turbine, this is a simpler construction, but the problem is that the mass of the blades is displaced relative to the bisector of the tower. For this reason, the blades must be stronger.

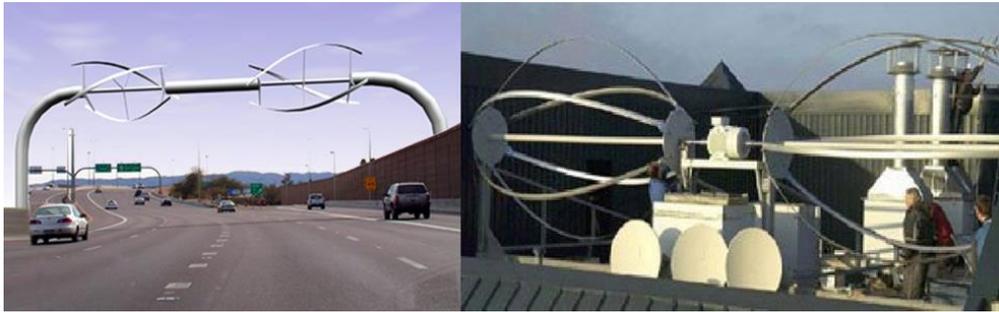


H type turbine

Cycloturbines

This wind turbine construction is similar to the H-type, the difference being that the blades have the ability to rotate around their axis. This allows the blades to be positioned so that they always capture some angle of attack of the wind. The main characteristic of this type of turbine with three or four blades is that the torque is approximately constant. Due to the rotation system, almost the maximum possible torque is obtained, which contributes to increasing the usefulness of such a wind turbine, which means that we get more energy. A positive feature is the possibility of self-starting by turning the blades in the optimal position to generate a sufficiently large buoyancy force for starting. On the other hand, the turning mechanism is complex and requires some kind of sensor to determine the direction of the wind.

In addition to vertical constructions, there are also horizontal constructions of the Darius wind turbine, which greatly facilitates and expands their range of application. The advantage is that the bearings are better placed on the structure and are therefore less axially loaded. With this construction, the turbine is placed at a certain height where it captures an evenly distributed wind speed, thus avoiding the problem of low speeds on the part of the turbine that is near the ground. The negative aspect of this construction is the impossibility of capturing the wind from all directions (as with VSHO), so the spectrum of their application is reduced.



Horizontal designs of Darius wind turbines

Savonius wind turbine

This wind turbine is the brainchild of Finnish engineer Sigurd J. Savonius. This is the first construction of a vertical wind turbine, and it was created in 1922. Sometimes it can have three blades. This type of wind turbine works on the principle of thrust force. Viewed in cross-section, the turbine has the shape of the letter S. Because of the roundness, the blade generates less thrust when moving against the wind with the convex side than when moving in the direction of the wind with the concave side. In this way, the thrust is always stronger in one direction and rotation occurs. Due to this principle of operation, these wind turbines provide much less energy than lift turbines of the same size.



Spiral Savonius wind turbine

Such wind turbines have a very simple construction, so they are used in cases where price and reliability are more important than efficiency, e.g. at anemometers. Another use of this principle appears on the very famous Fletner fan. It is used on the roofs of houses or buses and serves to ventilate the space, and it is driven by the power of the wind. You can also sometimes see advertising signs in the shape of this wind turbine, their goal is to rotate the advertising sign to attract attention.

There is also a construction of this type of turbine where the blades are spirally rotated along their length, thus obtaining a uniform torque on the shaft.

Advantages of turbines with a vertical axis of rotation

- Easier to maintain, because basically all rotating parts are located closer to the ground.
- They do not need a turning mechanism.
- Good for use in places where the wind speed is high near the ground (eg various passes and canyons).
- They do not need a high tower, which significantly lowers the construction costs.
- They don't have to turn in the direction of the wind, which makes them very good in turbulent wind conditions.

- Theoretically, they can be much larger than VSHO turbines, e.g. floating turbines with a vertical axis of several hundreds of meters high, where the entire structure rotates, could eliminate the need for large and expensive bearings.

Disadvantages of turbines with a vertical axis of rotation

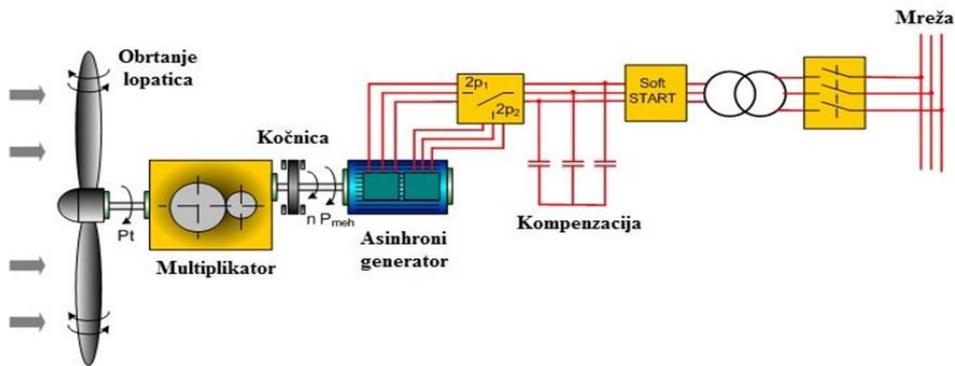
- Most have an efficiency in the range of 50% of the efficiency of turbines with a horizontal axis of rotation. This is mostly due to the added drag that occurs as the blades rotate into the wind.
- Most must be placed on relatively flat ground, so many sites that can benefit from VSHO turbines are simply too steep.
- Most have very little starting torque, so they need an external energy source to start spinning.
- Although most of their parts are located on the ground, which is certainly an advantage, they are still burdened by the great weight of the structure above them, which in the case of insufficiently good design significantly complicates the replacement of parts.

4.1.1.1. Wind turbines according to the type of wind generator

According to the type of wind generators, we can divide them into wind turbines with an induction cage wind generator, with a synchronous machine and a variable-speed turbine, with a double-sided fed induction machine and with a multi-pole synchronous machine with direct drive

Wind turbine with induction cage wind generator

The principle scheme of this wind turbine is given in the picture



VA with induction cage wind generator

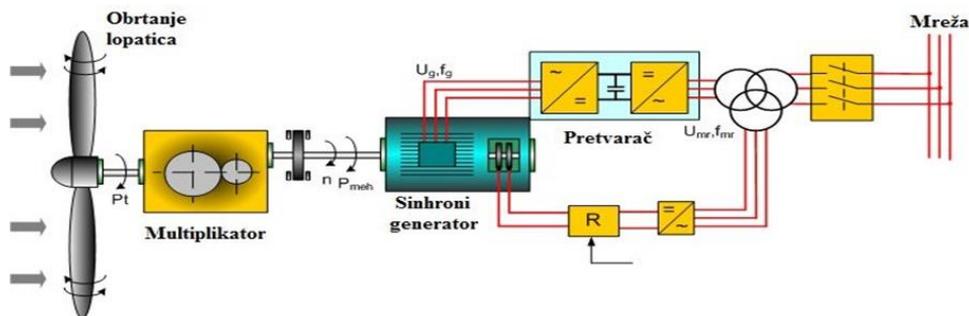
With these wind turbines, it is not possible to change the rotation speed of the wind turbine. Due to the stiffness of the torque-speed characteristic of the asynchronous machine, the wind turbine operates at speeds that are slightly different from the synchronous speed dictated by the network to which it is connected. This operation is partially alleviated by making a double stator winding (as in the washing machine motor), the winding designed for lower power has a larger number of pole pairs (3-4), while the nominal power winding has a smaller number of pole pairs (2-3). This way of working leads to an increase in the degree of utilization of wind turbines. A device for limiting the starting current and torque of the machine, the so-called soft starter, is attached to the stator connections, and it protects the turbine and reducer from impact torque. After reaching speed, the soft starter is short-circuited and the generator is directly connected to the grid. Between the turbine rotor and the asynchronous generator, the multiplier is selected so that a 4-pole or 6-pole three-phase asynchronous cage generator can be used. Such a generator is very simple, it is connected directly to the 50 or 60 Hz network with the use of a device that reduces the magnitude of the short circuit current. The load on the generator is limited by the aerodynamic design of the turbine blades, the so-called stall principle", and the speed of the entire turbine drive train + multiplier + generator changes very little around the nominal speed of the generator. The slip of the generator is about (1-2) % so that the losses in the rotor of the generator are within tolerable limits.

The asynchronous cage machine consumes reactive power, so in these wind turbines, reactive energy is compensated using capacitor batteries. This type of wind turbine is not suitable for locations with gusty winds, because due to the stiffness of the mechanical characteristics, the torque of the wind turbine is sharply transmitted to the shaft, and the gears in the reducer may be damaged. In the event of a failure on the electrical network, the wind generator easily loses stability, and due to large power variations that cause voltage fluctuations, this type of wind generator is not recommended for connection to a weaker distribution network. The advantage of this wind turbine is in the price, because it uses a robust induction machine that is directly connected to the grid. A variant of the cage asynchronous motor with a variable number of poles is often used, usually for two rotation speeds according to the figure.

Wind turbine with synchronous machine and variable speed turbine

Classic synchronous generators designed for a constant synchronous speed of rotation, dictated by the driving machine, have a DC excitation current on the rotor. These are aggregates (generator + driving machine), generally the main sources of electricity in power plants, for 50 or 60 Hz systems. If, due to better energy efficiency of the aggregate or another reason, it is necessary to regulate the rotation speed of the turbine and the synchronous generator during operation, and to connect that generator to the fixed-frequency energy system, this can be done by using a frequency converter located between the windings of the synchronous generator and the fixed-frequency energy network, according to the illustration in the picture. The power of the converter is equal to the power of the generator.

An excitation current in the rotor winding and a voltage regulation system or permanent magnets are required.

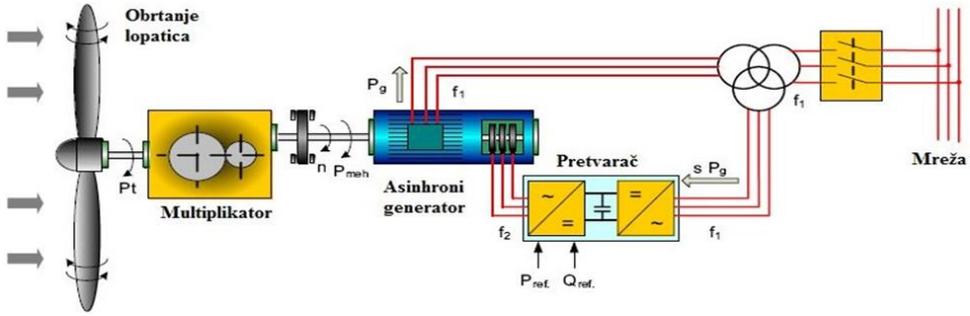


VA with wind generator-double sided induction machine

Wind turbine with wind generator - powered by induction machine on both sides

The characteristic of this wind generator is that it is used with wind turbines of high power. It enables a speed change in a wide range around the synchronous speed, thus ensuring a high degree of utilization of the wind turbine for a wide range of wind speeds. The change in the rotation speed of the wind turbine is from 10 to 25 rpm, so a mechanical reducer is needed to adjust the speed. The principle scheme of this wind turbine is given in the picture.

The stator winding is directly connected to the grid, and the rotor winding is connected to the grid via slip rings, the inverter-rectifier group and the transformer. Changing the active and reactive power of the generator is done by changing the frequency and phase of the current that supplies the rotor winding. The machine can operate in a wide range of speeds in both supersynchronous and subsynchronous mode, which allows full adjustment of the speed.

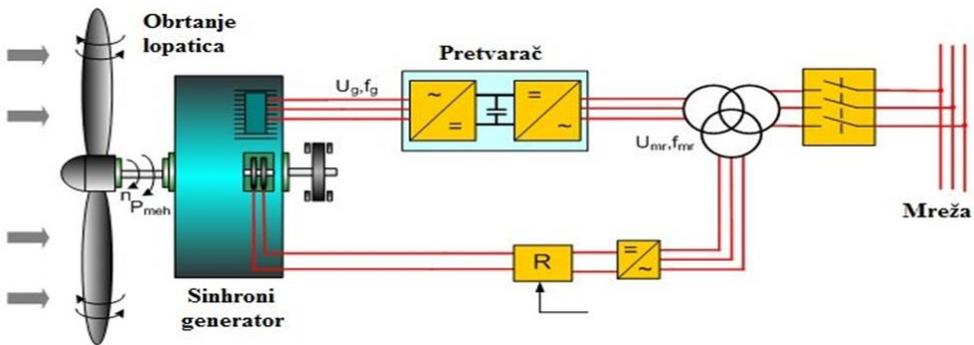


VA with wind generator-double sided induction machine

A double-sided induction machine can also generate reactive energy, but usually the wind generator is designed to work with a power factor of $\cos\phi=1$, because the generation of reactive energy additionally loads the converter in the rotor circuit. However, if it is necessary to stabilize voltages in the distribution network, the wind generator can generate reactive power at the expense of reducing active power. The double-sided powered induction machine is installed in wind turbines of the highest power, in those designed for operation on land (onshore), as well as in models for coastal sea belts (offshore). Such wind turbines have a higher degree of utilization, can generate reactive power, have lower impact mechanical stresses, because the characteristic of the generator is adaptive, they work more stably and generate less noise. The disadvantages are: relatively high price due to power electronics, they are more sensitive to atmospheric overvoltages, increased losses in the generator, generate more harmonics. The limiting factor for wind turbines of the highest power is the reducer, which suffers high stresses.

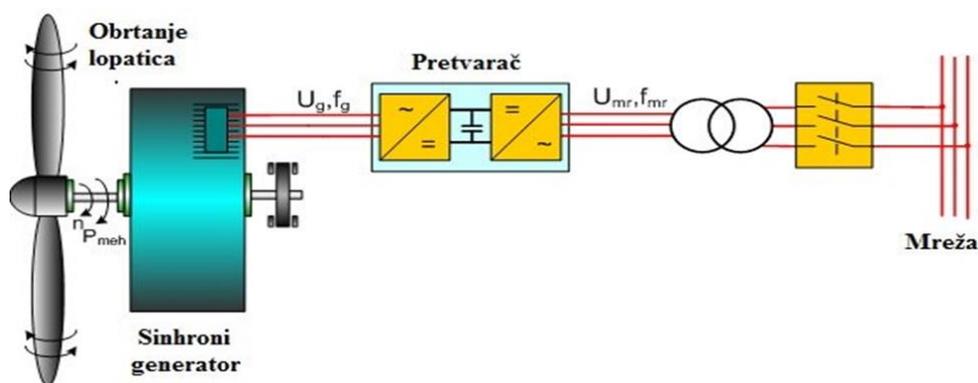
Wind turbine with wind generator - multi-pole synchronous machine with direct drive

The main drawback of the wind turbines shown so far is the use of a reducer between the turbine and the generator. This drawback is avoided with a concept with a slow-speed multipole synchronous generator that is directly connected to the wind turbine. The principle scheme of this wind turbine is shown in the picture. Unlike an asynchronous generator, it is possible to use a synchronous generator for very low turbine rotation speeds (5-30 rpm). A synchronous generator with a large number of poles (60 or more) in a construction with classical excitation or permanent magnets can be directly connected to the turbine without a multiplier (direct-drive), and the connection to the network is via a frequency converter. The power of the frequency converter is equal to the power of the generator. Due to the large number of poles and the low rotation speed, the generator must develop a high torque, its dimensions and mass are relatively large, they have a decisive influence on the construction and dimensions of the power plant.



VA with wind generator-multipole synchronous machine with classic excitation system and direct connection to the turbine

The wind generator works with variable speeds, so it must be frequency separated from the grid, which is achieved with AC-DC-AC converters. The power and speed of the wind turbine is regulated by turning the rotor blades. AC-DC-AC converters must have wind generator power, which is a drawback of this concept. Due to the limitation of the power of the converter, the wind generator is designed to work with the nominal power with a power factor of $\cos\phi=1$, but it is possible to generate reactive power at the expense of reducing the active power when necessary. One such wind generator is shown in the picture.



VA with wind generator-multipole synchronous machine with permanent magnets

Wind turbines with slow-rotating synchronous wind generators are used both for low power units (300 kW) and for wind turbines of the highest power. German wind turbine manufacturer Enercon produces wind turbines with slow-rotating synchronous wind generators. This manufacturer offers a wind turbine with a nominal power of 4.5 MW, with a wind turbine with a diameter of 114 m and a support column with a height of 124 m. The working range of wind speeds for this turbine is 2.5 to 34 m/s. The rotation speed of the wind turbine rotor is 8 to 13 rpm, with the peripheral speed of the tip of the blade reaching a speed of 270 km/h. A wind turbine with a slow-rotation synchronous wind generator has similar characteristics as a wind turbine with a wind generator - a double-sided powered induction machine. Its disadvantage is its high price, due to the use of a non-standard machine and a high-power converter. Due to the large number of poles, the generator has a large mass and diameter. The advantage compared to the previous solutions is the direct coupling of the wind generator with the wind turbine, i.e. there is no reducer.

4.2.2.3. Wind turbines according to the autonomy of the operating mode

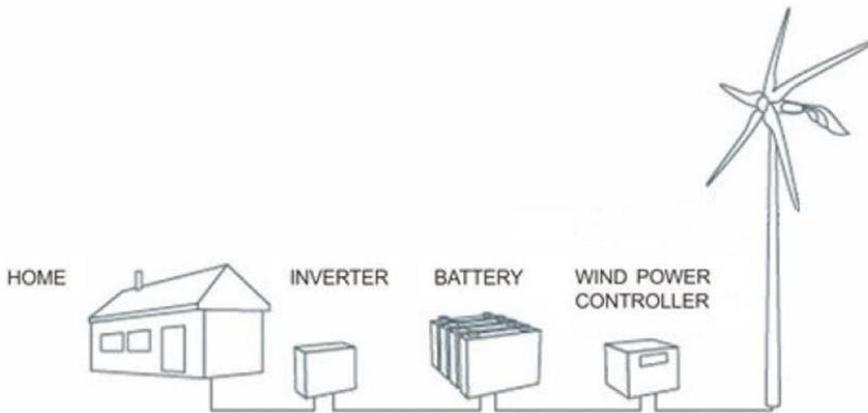
According to the autonomy of the operating mode, wind farms are divided into on-grid wind farms (wind farms connected to the power grid), off-grid (independent wind farms or wind farms that are not connected to the power grid) and hybrid wind farms (wind-solar, wind-diesel, wind farms with an energy storage system).

On-grid wind farms

On-grid wind farms are wind farms that are directly connected to the national or regional power grid. These wind farms generate electricity that is sent to the grid and distributed to end users. The produced energy is sent directly to the grid via electric lines, and the energy is used to power households, industry and other users. These wind farms usually operate at high capacities and generate stable and continuous energy production that is available for integration into the grid. When connected to the grid, on-grid wind farms can help maintain grid stability, as they are able to adjust their operation depending on the grid's needs. They can reduce or increase production depending on consumption conditions.

Off-grid wind farms

Off-grid wind farms are not connected to the power grid and are used to supply energy in areas that do not have access to the grid or where connecting to the grid is not economically viable. These wind farms produce energy that is used locally, often to supply remote areas, households or specific industrial facilities. Since these systems are not connected to the grid, the energy they generate must be stored to be available when the wind is not present. Batteries or other energy storage technologies are used for this. These systems operate autonomously and may include automation components to ensure smooth operation in variable wind conditions. Off-grid systems do not depend on external energy sources and can function in areas without electricity infrastructure. They can be used in remote areas, on farms, on ships or in research stations.



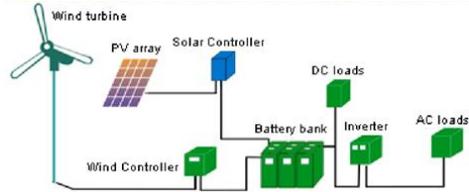
Off-grid power plant overview

Hybrid wind farms

Hybrid wind farms are decentralized systems for the production of electricity. These systems combine wind turbines with other energy sources such as solar panels, diesel generators or energy storage systems to ensure a constant supply of energy and optimize production.

Wind-solar hybrid wind power plants

These wind farms combine wind turbines and solar panels into one system. Using both technologies allows greater flexibility and stability in energy production because wind and solar often have different production patterns. Solar panels produce energy when there is no wind (on sunny days), while wind turbines work better when it is cloudy or windy, the Sun does not shine at night, while the wind may be present and so on.



View of the wind-solar hybrid power plant

Wind-diesel hybrid wind power plants

These power plants use wind turbines in combination with diesel generators. Wind turbines produce energy when conditions are favorable, while diesel generators take over production when wind is not available. Using wind turbines reduces the need for diesel fuel, thus reducing operating costs and CO2 emissions.

Wind farms with energy storage systems

These wind farms use batteries or other energy storage technologies (such as hydrogen-based systems or compressed air) to store excess energy produced during periods of high wind. The stored energy is used when the wind blows less or during peak consumption periods. Energy storage enables a constant supply of energy and reduces the need to connect to the power grid and enables optimization of the use of produced energy and reduces losses.

4.2.2.4. Wind turbines by location

Wind turbines can be used in locations where the average wind speed is higher than 4.5 m/s. An ideal location should have a constant wind flow without turbulence and with minimal probability of sudden storm gusts of wind. Locations are first selected based on the wind map, and then practical measurements are made. Average wind speed is one of the main factors for choosing the location of wind turbines. Types of wind farms according to location: on land (onshore wind farms), at sea (offshore wind farms - floating and coastal) and high-altitude wind farms.

Locations on land (onshore wind farms)

Onshore installations of wind turbines are most often located in hilly areas at least 3 kilometers away from the coast. They are most often placed at the top of a hill or slope, because in this way they take advantage of the so-called topographical acceleration that the wind gets when passing over the elevation. That extra wind speed makes a significant difference in electricity production. Special attention must be paid to the correct placement of the turbines, because sometimes a small height difference can have a significant impact on the production of electricity. Often the problem is that some locations that are suitable for wind turbine installation have great natural beauty or are ecologically significant. The installation of onshore wind farms is usually cheaper than offshore, as it does not require offshore technology, specialized platforms or similar infrastructure requirements. Given the lower initial costs, onshore wind farms often have a faster return on investment. Onshore wind farms are easy to access, which means lower maintenance and repair costs, and the infrastructure (roads, power lines, etc.) already exists on land. A

disadvantage may be space, as in urbanized areas or in dense settlements, installation space may be limited and they are often located far from main consumption centers, which may require additional investment in transmission infrastructure. Also, there may be conflicts with other sectors, such as agriculture or tourism.

Locations at sea (offshore wind farms)

These are those locations that are more than 10 km from the mainland and where the wind installations are less offensive in appearance and noise. The fact that water (especially deep) has a smaller surface "roughness" than land has a strong influence on wind speeds, which are much higher at sea. Power factors are much higher in such installations. At sites with extended shallows, wind farms are easy to install, which is not the case at sites that do not have such characteristics. In general, offshore wind turbine installations are generally more expensive than land-based ones because their towers are taller when the underwater part is taken into account. The produced electricity is transmitted to land via a submarine cable. Care must also be taken to protect against corrosion, which is why additional coatings and cathodic protection are often added. Such turbines are the largest turbines in operation and further growth in their size and installed power is predicted. Offshore wind farms can have more than 100 wind turbines.

These wind farms can be in shallow or deep sea areas, and are divided into two main types: offshore and floating.



VIDEO

How do offshore wind turbines work?
<https://www.youtube.com/watch?v=HqCVgRbPQcg>

Coastal (bottom-fixed) offshore wind farms

Coastal locations are located within a radius of 3 km from the sea or at sea within 10 km from the mainland. These wind farms are placed on the bottom of the sea and fixed at the bottom (often up to 60 meters deep). They are placed on the sea surface, but strengthened by structures that connect to the seabed.

Offshore wind farms often take advantage of steadier and stronger winds than onshore ones, which increases efficiency. They do not interfere with population, agriculture or other human activities on land, but there are issues related to bird migration and the impact on marine life. Installation is very expensive as it requires the construction of special platforms, transport ships and other infrastructure while the technical challenges related to offshore construction and maintenance as well as access are increased.

Floating offshore wind farms (FOW - floating offshore wind)

These wind farms are installed on floating platforms that do not depend on the seabed. Floating turbines can be placed in deep waters where conventional offshore wind farms are impractical, i.e. they can be placed in areas of the sea that are too deep for traditional offshore wind farms. Floating wind farms can increase overall energy production, as the installation space is almost unlimited as they can be placed at greater distances from the coast, where the winds are strongest and freshest, reducing possible disturbance to the coast.

Installation and maintenance of floating wind farms are more expensive than traditional offshore wind farms and require specialized vessels for transport and installation, and there is a risk of damage due to hostile sea conditions (storms, waves).

High-altitude wind farms

High-altitude wind farms use winds at higher altitudes, usually above 200 meters, to harness stronger and more stable wind. There are several types of high-rise wind farms, including those on tall buildings and flying wind turbines. Flying turbines can be located in the upper layers of the atmosphere. Aerial platforms that "flutter" in the air or advanced drones that create wind farms in motion can be used. High-altitude wind farms can use very stable and strong winds that are not present on the surface of the earth. These turbines can be used in areas where land space is limited or where ground installations are more difficult to implement. At present, high-rise turbines have not been commercially developed for widespread use and still represent a large investment and their long-term profitability and safety is still uncertain.

Each of these types of wind farms has its own advantages and challenges. Onshore wind farms are the most widespread, because they are easier to implement, while offshore wind farms enable larger capacities due to stronger and more stable winds. High-altitude wind farms are still in the development phase, but have the potential to revolutionize the use of wind at higher altitudes. The choice of technology depends on local conditions, energy needs, available resources and investments.

4.2.2.5. Wind turbines by power

Wind farms can be classified according to power, where power often refers to the capacity of an individual wind turbine or the entire wind farm. The main categories are small wind farms and large wind farms (wind farms).

Small wind farms

Small wind farms usually include individual wind turbines or small wind farms with a total installed capacity of up to 10 MW. These power plants are usually used for local or industrial energy consumption, and are rarely used for large-scale commercial production.

One turbine in a small wind power plant usually has a capacity of several hundred kilowatts to several megawatts, that is, wind turbines with a capacity of 100 kW to 2 MW are the most common.

Small wind farms are often used for specific, smaller energy needs. These can be homes, farms, commercial buildings, industrial zones or small settlements and are usually built as distributed sources which means they do not require complex transmission networks. Installation of small wind farms is usually faster and cheaper, and due to their smaller dimensions, they can be placed in locations that are not suitable for large wind farms.

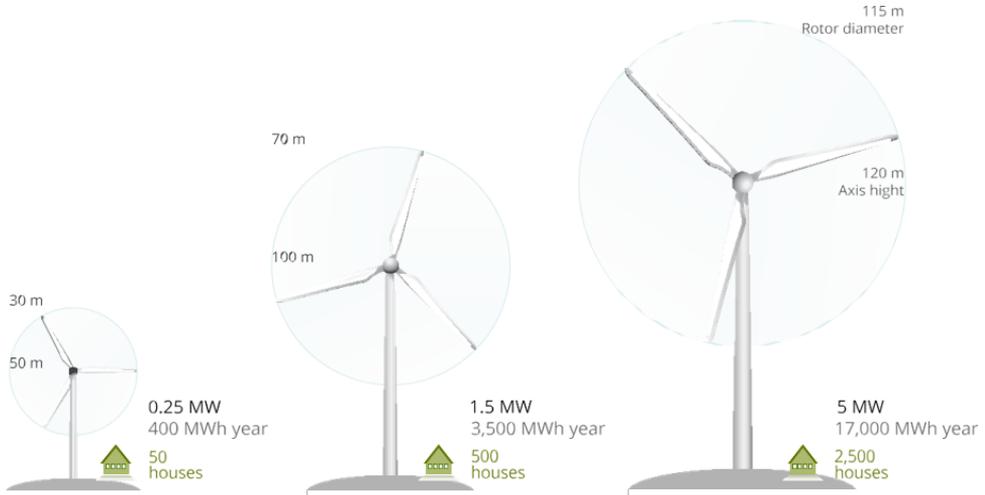
Some small wind farms are placed on the roofs of residential or commercial buildings to reduce energy costs. These power plants usually have a smaller capacity (up to 100 kW), but can significantly contribute to savings.

Large wind farms

Large wind farms, or wind farms, include projects with a total capacity of more than 10 MW, and usually include a large number of wind turbines. These wind farms can have capacities of up to several hundred megawatts (MW) and are used to produce energy for the national or regional grid. In large wind farms, wind turbines with a capacity of 2 MW to 6 MW (or more) are most often used. Given the number of turbines and their power, these wind farms can produce significant amounts of energy. For example, wind farms like London Array or Horns Rev in Europe have capacities from 500 MW to 1,200 MW.

These power plants mainly serve for the commercial production of energy that is sold on the market and can be distributed over wide areas. They require developed infrastructure, including transmission lines and transmission networks, so that the generated energy can be transported to consumers. Many wind farms are located at long distances from large urban centers.

Due to their large scale, large wind farms can be more economically viable, with lower production costs per megawatt-hour (kWh), making them more competitive with other energy sources.



Growth of wind turbine parameters depending on power



EXERCISE

Study the construction of wind farms in your region.

4.2.3. Wind farm structure

The structure of the wind farm includes various systems that enable efficient production, transmission and distribution of energy. Each of the systems has a specific function in the process of converting wind energy into electricity, and in connecting it to the power grid. The structure of the wind power plant consists of the wind turbine system, the wind power grid connection system (the wind power grid connection, the electrical network inside the wind power plant, the distribution plant at the point of connection to the grid), the management and control center, the energy storage system, and the condenser-filter plant.

Wind turbine system

A wind turbine is the basic component of a wind power plant that converts the kinetic energy of the wind into electrical energy. Each wind turbine consists of several key parts such as a rotor with blades, a generator shaft that transmits mechanical energy to the generator, a generator that is usually asynchronous or synchronous, a gearbox, a control system for controlling the operation of the wind turbine and a supporting structure. Each of these parts will be described in more detail later.

Wind power grid connection system

This system enables the transmission of the produced electricity from the wind farm to the electricity grid. It consists of several key parts.

Network connection of the wind turbine

- Converters (inverters): They convert the electricity produced by the generator into electricity, which is compatible with the grid system. In the event that DC (direct current) energy is used, inverters convert it into AC (alternating) energy that can be transmitted to the grid.
- Protection and regulation: The network connection must be protected against overload and short circuits, and the regulation system ensures voltage and frequency stability and synchronization with the network.

The electrical network inside the wind farm

- Cable system: Used to transfer energy from each wind turbine to the distribution plant. These cables are connected to all wind turbines in the wind farm and enable centralized energy distribution.
- Switchgear: Includes switches, fuses, and other electrical components that help distribute power and maintain network security.

Substation at the point of connection to the grid

- Transformers: They are used to raise the voltage of electricity to the level required for transmission over longer distances to final consumers or input to the wider power grid.
- Switchgear and switches: These devices enable the control and protection of the flow of energy to the network. The switches allow the interruption of the power supply in the event of a malfunction and ensure the safety of the system.

Command and control center

The control center is a key component that enables monitoring and optimizing the operation of the wind farm. This system monitors the condition of all turbines and systems within the wind farm (speed of rotation, energy production, wind conditions, temperature, equipment condition and more) and automatically adjusts the operation of the wind turbines, optimizing performance depending on wind conditions and grid requirements.

The control center enables remote monitoring and management of the wind farm, even from other locations, which is important for large wind farms or offshore projects.

Energy storage system

Depending on the type of wind farm and the specifics of the local energy network, an energy storage system may be present to ensure stability and balance between production and consumption. The batteries can store excess energy produced during days when the wind is strong, and release the energy later during periods of lower winds. In some larger systems, the use of water systems for energy storage (Pumped Hydro Energy Storage) can be a way to store energy in high reservoirs when wind energy production is high, and later to release energy in times of need.

Condenser-filter plant

Condenser-filter plants are used to improve the quality of electricity that the wind farm delivers to the grid. Capacitors serve to compensate for reactive power, thus reducing the voltage drop and increasing the efficiency of electricity distribution. Filters can be installed to remove interference in the electrical signal and ensure voltage and frequency stability, thereby preventing negative impact on the power grid.

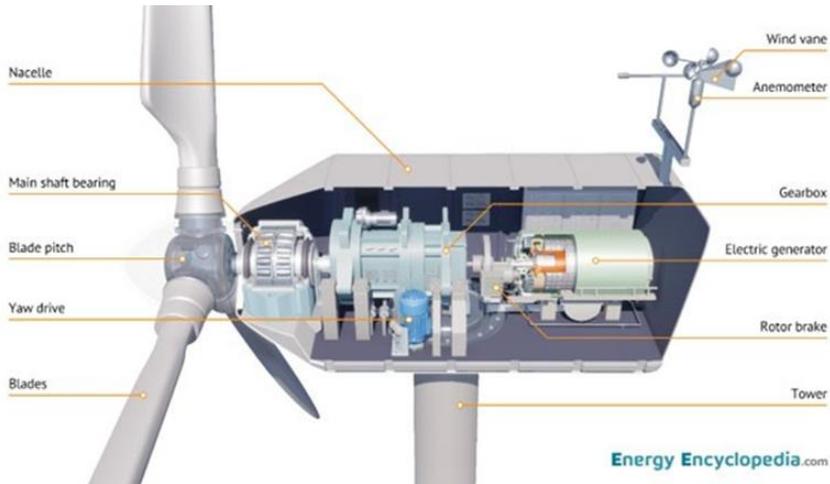
All these components enable wind farms to contribute to the energy grid and help reduce CO2 emissions.

4.2.4. Wind turbine elements

Wind turbine elements: rotor (blades, head, shaft), blade rotation system (sensors, drive mechanism, control), brake system (mechanical, electric, hydraulic brake), power transmission (multiplier), generator (asynchronous-induction, synchronous, direct), anemometer, wind vane, monitoring and control system (manipulation, measurement, regulation, protection, supervision and monitoring, control, communication), nacelle rotation system, power electronics devices (DC/AC and AC/DC converters), capacitor battery, nacelle, tower, network connection (power cable, distribution cabinet, transformer), fire protection system (fire detectors and alarms, fire extinguishers, ventilation, automatic shutdown), foundation, grounding, etc.

For the proper and safe functioning of the entire wind turbine-generator system, the generator, as well as other parts of the wind turbine, must meet certain requirements.

The wind turbine-wind generator system is given in the figure



Wind turbine parts

Description of the key elements of the wind turbine:

Rotor

The VA rotor consists of blades, a rotor head and a shaft. Blades are components that capture wind energy and convert it into mechanical work. They are usually made of light but strong materials. The central part of the rotor is the rotor head that connects the blades to the shaft. The head allows the blades to rotate under the influence of the wind. The shaft transfers mechanical energy from the rotor to the generator. It includes the main shaft, which is connected to the rotor, and the shaft that connects the generator.

Blade rotation system

The main component of this system are sensors. They measure wind speed and direction, helping the system to optimize blade angle for maximum efficiency. The propulsion mechanism controls the rotation of the blades in the direction of the wind (yaw system) and usually uses electric motors or hydraulic systems. The steering helps regulate blade angle to optimize power generation, prevent overload and ensure safety.

Brake system

The brake system consists of a mechanical, electric and hydraulic brake. A mechanical brake physically blocks the rotation of the rotor, usually via brake discs, when it is necessary to stop the wind turbine. An electric brake slows the rotation of the rotor by using a generator or an electric motor as a dynamic brake, while a hydraulic brake provides a stronger braking torque through a hydraulic system and is usually used for safety stopping in extreme conditions.

Power Transmission (Multiplier)

In gear systems, the multiplier increases the rotational speed of the rotor before that energy reaches the generator, because the generator must operate at much higher speeds.

Generator

As we mentioned earlier in the manual, several types of generators are used in VE wind turbines. The asynchronous induction generator is the most commonly used generator in wind farms and can operate in various wind conditions. The synchronous generator is less often used in wind turbines, because it requires synchronization with the grid frequency. In specific cases, a DC generator is also used, when DC voltage production is required, such as an off-grid system.

Anemometer

An anemometer is a device that measures wind speed and sends data to a control system that then adjusts the operation of the wind turbine.

Direction indicator - wind vane

This small device measures wind direction, helping the nacelle and blade rotation system to point the wind turbine in the most favorable wind direction.

Monitoring and management system

This is a more complex system that performs manipulation operations, i.e. management of mechanical parts, such as the rotation of blades and nacelles, then measurement and monitoring of parameters such as wind speed, temperature, voltage and current values, and regulation and optimization of wind turbine operation in order to achieve maximum efficiency. This system ensures protection against overload, excessive wind speed and other hazards by monitoring the condition of all components of the wind turbine in real time and connecting the VE to external systems for remote monitoring and control.

Gondola rotation system

A nacelle yaw system ensures that the nacelle (the central part of the wind turbine that contains the generator) faces the direction of the wind, usually using electric motors or hydraulic systems.

Power electronics devices

The generator of the wind turbine usually produces alternating current (AC) which is not always in accordance with the grid requirements, so an inverter (if a change from DC to AC is required) or a converter is used to transform the current into a suitable form for the grid. The inverter ensures that the production of electricity from the wind turbine is synchronized with the voltage, frequency and phase of the power grid. Inverters can also perform tasks such as power control and voltage stabilization.

Capacitor battery

This battery is used to compensate for reactive power in the system and stabilize the voltage to maintain power quality.

Gondola

The nacelle is the central part of the wind turbine that contains the generator, transmission systems, brakes and turning system. It is located at the top of the tower. The nacelle is very heavy, usually weighing between 70 and 120 tons, depending on the size of the wind turbine. The nacelle enables the efficient transfer of kinetic energy from the rotor to the generator and further into electrical energy that is sent to the grid.

Tower

The structure that supports the nacelle and the rotor is the tower. The tower must be tall enough to reach areas with strong winds and its height can be up to 150 meters. It is usually made of steel or concrete. Larger towers allow for better utilization of the wind.

Network connection

The connection to the grid represents the physical connection between the wind turbine and the power grid. This includes all the necessary cables, junction boxes, distribution cabinets, measuring equipment and other components that enable the transmission of electricity from wind turbines to the grid.

Transformer

The transformer is a key component that allows the voltage generated by the wind turbine to be changed to match the voltage levels of the grid. The energy generated by the wind turbine generator is usually of low voltage, and the transformer raises that voltage to a level suitable for transmission through the grid.

Fire protection system and safety devices

Safety devices ensure that the wind turbine is protected from damage due to electrical faults, short circuits, overloads or other accidents. Protective relays and switches enable automatic shutdown of the system in the event of an emergency, which protects the equipment and prevents the spread of faults in the network. Fire detectors and alarms detect the beginning of a fire and send an alarm for a timely response. Ventilation must be designed to maintain optimal conditions in the gondola and prevent the accumulation of flammable gases. In the event of a fire or other critical problem, the system automatically shuts down the wind turbine to prevent damage.

Foundation

The foundation is the structure that provides the stability of the wind farm, usually made of concrete and steel, which supports the tower.

Grounding

Grounding of wind turbines is a key component of the safety system in wind farms. Considering the size and power of wind turbines, proper grounding is necessary to protect people, equipment and electrical parts from potential electric shocks, short circuits and other hazards resulting from electrical faults. Grounding allows electrical faults, such as a short circuit or lightning strike, to be directed to the ground instead of passing through sensitive wind turbine components or the power grid, thus preventing the risk of electric shock to people or animals.



VIDEO

Simulation of wind turbine operation:

<https://www.youtube.com/watch?v=TXHAKe6I0rE>.



QUIZ

Quiz 3: Wind turbine elements:

<https://forms.office.com/e/he6v3JvUPD>.

4.2.5. Material, tools, equipment and devices for work on the construction and maintenance of wind farms

For high-quality and safe construction, assembly and maintenance of wind farms, 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-corrosion paints, coatings, mastics), sealing materials, screws and nuts, marking and signaling material, building materials, etc.

Examples of power cables

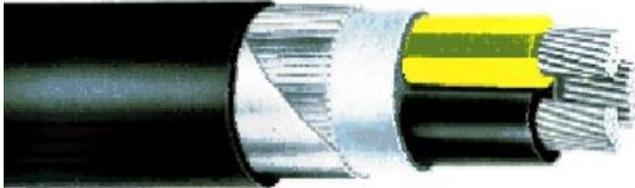


PP00



PP40

Use: 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

Use: 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 slanting laying as well as on slippery surfaces.

Control and signal cables



Control and signal cables

Use: For connecting signal and control devices in industry, thermal, hydropower, 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.

Cable accessories for installation cables



Heat shrinkable cable cap



Cable joints and branches



Various types of cable lugs



Cable heads



Various types of coupling sleeves



Examples of pipes



PVC installation pipes



Installation metal pipes and connectors

Tools: insulating pliers, compression pliers, wire cutters, metal saws, screwdrivers, wrenches, files, hammers, electric locksmith tools, hydraulic tools (hydraulic presses, guns, etc.), manual lifting equipment, scissors and knives for cutting insulation material, sheet metal shears, saws, soldering tool, sheet metal bending tool, profile bending tool, punching tool, cutting tool, cutting tool cutting, threading tool, measuring and control tool, welding tool and accessories, spirit level, etc.



Tools for crimping, stripping insulation, measuring instruments

Hydraulic tool

Equipment and devices: portable grounding device, insulating pole, portable transformer, portable generator, drill, grinder, high-voltage voltage indicators, multimeters, devices for diagnostics and testing, megaohmmeter, temporary structures and facilities (scaffolding, work platforms, shelters, etc.), lifting hooks, supports, anchors, crane with isolation platform, etc.



Working platforms

High-voltage voltage indicators are key tools for the construction and maintenance work of wind farms. These devices allow technicians to safely check the presence or absence of high voltage in electrical installations, thereby reducing the risk of electric shock.



High-voltage voltage indicators

Specialized machines and vehicles: For the construction and maintenance of wind farms, specialized machines and vehicles adapted to work in difficult conditions are often used. These include large-capacity telescopic cranes for lifting and mounting wind turbines, all-terrain vehicles for transporting equipment and materials over inaccessible terrain, self-propelled scaffolding and platforms for working at height, as well as specialized drills and trenchers for laying foundations and cable installations. These vehicles and machines enable the safe and efficient execution of all construction and electrical works on wind farms.



Specialized vehicles

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



A specialized aircraft for transporting wind turbine blades



VIDEO

Specialized aircraft for the transport of wind farm equipment:

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



PRACTICAL EXERCISE

Task 1: Using hand and power tools

Material and tools:

- Basic hand tools (pliers, screwdrivers, scalpels, knives for removing insulation),
- Power tools (drill, sander, 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 properly 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.
 - Use a tester to check the correctness of 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 safety rules when working with power 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 the use of the tool and suggest improvements.



PRACTICAL EXERCISE

Task 2: Identification and analysis of materials

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.

5. INSTALLATION AND DISASSEMBLY OF ELECTRICAL EQUIPMENT IN WIND POWER PLANTS

5.1. Preparation of the terrain for the installation of power equipment in wind farms

The preparation of the ground for the installation of power equipment is crucial for the stability and long-term functionality of the wind farm. This process includes making foundations for wind turbines, preparing trenches for cable infrastructure, installing power connections and ensuring technical conditions for the operation of electrical installations.

Importance and procedure of site investigation - wind speed measurement

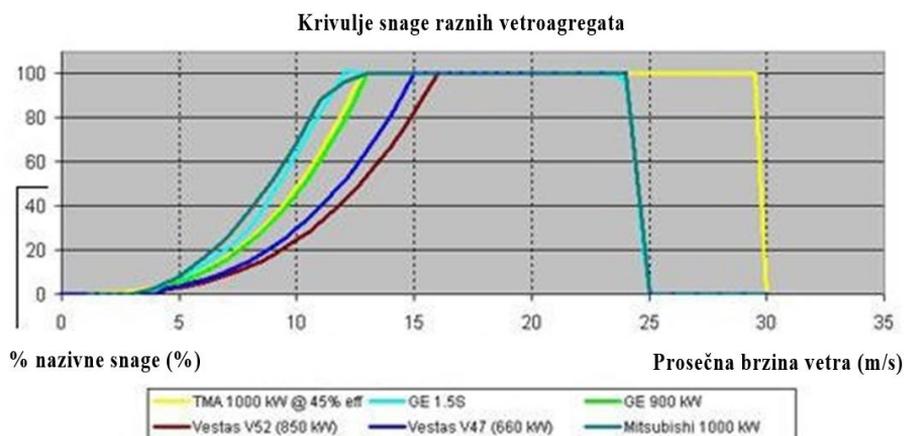
Before starting the construction of the wind farm, it is necessary to carry out multi-year measurements of wind speed and direction in order to assess the profitability of the project and optimize the distribution of wind turbines.

Accurate estimation of energy production enables realistic calculations and reduces investment risks. Optimizing the layout of the turbines reduces turbulence and increases the efficiency of the system, while the analysis of seasonal variations enables better planning of production and maintenance.

The critical wind speeds for starting and stopping wind turbines depend on the design and type of turbine, but generally fall within the following limits:

- Cut-in speed - Usually between 3 – 4 m/s. This is the lowest wind speed at which the wind turbine starts producing electricity. Below this value, the wind does not have enough power to move the blades.
- Nominal wind speed (Rated speed) - Usually between 12 - 15 m/s. This is the optimum wind speed at which the turbine achieves its maximum power output. The turbine continues to produce the same maximum power even at higher wind speeds up to the cut-off limit.
- Maximum wind speed for operation (Cut-out speed) - Usually between 20 – 25 m/s (72 – 90 km/h). If the wind speed exceeds this limit, the system automatically shuts down the turbine to prevent damage.
- Survival wind speed - Usually over 50 – 70 m/s (180 – 250 km/h). This is the maximum wind speed that the turbine can physically withstand before permanent damage. In extreme conditions, the turbine activates the braking system and turns the blades into a "feathering" state to reduce the area exposed to the wind.

These values may vary depending on the manufacturer and type of wind turbine (onshore or offshore). Each manufacturer of wind generators has made a diagram of utilization depending on the wind speed. Power curves of various wind turbines.



Power curves of various wind turbines

Wind speed measurement procedure:

- Installation of the meteorological measuring station - It is installed at the height of the planned nacelle of the wind turbine (80-140 m) and is equipped with anemometers, weather vanes and sensors for temperature and humidity.
- The use of LIDAR and SODAR technology - LIDAR (Light Detection and Ranging) and SODAR (Sonic Detection and Ranging) make it possible to measure the wind profile up to a height of several hundred meters without the need for physical poles.
- Long-term data collection (12-24 months) - Continuous recording of wind speed and direction for reliable analysis.
- Analysis and optimization – Software tools are used for simulation and modeling of wind energy potential. Extreme winds, changes in turbulence and seasonal fluctuations are identified. Optimization of the placement of turbines in the wind farm is being carried out in order to minimize turbulence and maximize energy production.
- Decision-making - Based on the results, a final feasibility study is made and the technical specifications of the equipment are defined.

The types of foundations for wind turbines can be concrete, steel and floating, depending on the location and the base on which the power plant is built. Concrete foundations are most often used in onshore wind farms due to their high stability and resistance to weather influences. They are made in the form of large reinforced plates or columns that take the load of the wind turbine and transfer it to the ground. Steel foundations are used in offshore power plants, where it is necessary to ensure resistance to corrosion and strong sea currents. Floating foundations are used for wind farms in deep waters, where classic fixed structures are not possible.

When laying the foundations, special attention is paid to the production of power connections, which must be installed in the concreting phase in order to facilitate the connection of electrical installations later. This includes running electrical conduits, installing grounding and securing connections for switchboards and transformers.



Examples of wind turbine foundations

In addition to the foundation, it is necessary to prepare trenches for laying power cables. Trenches must be dimensioned in accordance with the project and technical standards in order to ensure the safe installation of cables and their long-term protection against mechanical damage and adverse weather conditions.

For onshore wind farms, trenches are dug according to the geological characteristics of the terrain and installation requirements. The depth of the trench depends on the voltage level of the cables and the specific conditions of the site, but usually it is from 0.8 to 1.5 meters. After excavation, a protective layer of sand or other material is placed on the bottom of the trench to prevent direct damage to the cables. The cables are then carefully laid, secured and covered with protective elements such as plastic covering strips or concrete slabs. After that, the trenches are filled with layers of earth, with mandatory marking of the cable route for easier future maintenance and inspection.

In offshore wind farms, trenches for energy cables must be additionally protected against hydrodynamic forces, waves and sea currents. Cables are usually laid using specialized equipment that enables their safe placement on the seabed, and in certain cases they are additionally covered with protective materials to reduce the impact of abrasion and mechanical damage.

After laying the cables, tests and inspections are carried out to ensure the correctness of the installations. Testing includes checking the continuity and insulation of cables, as well as the resistance of joints to mechanical and electrical influences. These checks are crucial because they ensure the safety of the system and prevent potential failures after the plant is put into operation.

In addition to trenches and foundations, it is necessary to prepare stands for power equipment, including transformer stations, distribution cabinets and connection points. These stands must be properly leveled and secured to support the weight of the equipment and ensure the stability of the system.

The final stage of site preparation includes the installation of grounding and conductive paths for protective conductors. Proper grounding is of key importance for protection against overvoltage and ensuring the safety of the power system.

When all the preparatory work is completed, a final inspection is carried out, which checks whether the foundations, trenches, grounding and energy connections are made in accordance with the project and standards. Only after that can the installation of power equipment and connection of the wind power system to the grid begin.

5.2. Assembling and disassembling the assembly structure of equipment in wind power plants

Prefabricated structures in wind farms represent key elements that enable the installation of various equipment and infrastructure facilities required for the operation and safety of the wind farm itself. Each structure has a specific function and must be designed to ensure stability, durability and safety, taking into account technical requirements, external conditions and intended use.

Tower and nacelle of wind turbines - characteristics important for assembly and disassembly

Assembly and disassembly of the tower and nacelle of wind turbines are key stages in the installation and maintenance of wind farms. These processes require precision, specialized equipment, safe working conditions and strict technical guidelines due to the height, weight and complexity of these elements.

As we mentioned, the tower is the main vertical element of the wind farm that supports the nacelle, rotor (blades) and all related components. The tower must be strong and stable to withstand the forces generated by the wind and the rotation of the wind turbine. Towers can be between 60 and 150 meters high, depending on specific site conditions. The most common are steel towers, but concrete foundations or combinations of steel and concrete can also be used. Steel towers can be tubular (cylindrical) or segmented (composed of several parts). The tower must be strong enough to withstand different weather conditions (wind, snow, rain) and vibrations caused by the operation of the turbine. In addition, it must allow for the installation of nacelles, rotors and other important systems.

The nacelle is the key component of the wind turbine that is placed on top of the tower. The weight of the gondola is usually between 70 and 120 tons. Inside the nacelle there is a generator, a transmission mechanism, a system for turning the turbine (yaw system), a wind monitoring system, an electronic control system and various sensors, and it is extremely important to take special care of lifting the nacelle and connecting it to the tower.

Assembly and disassembly of wind turbine towers and nacelles require specialized equipment, experience and high precision to ensure the safety of all workers and reliable installation of all components. Dismantling is also a technical challenge, but with proper precautions, it can be done safely and in compliance with regulations.

The tower assembly procedure takes place in several steps.

The first step is the preparation of the construction site, which begins with the thorough preparation of the land. The ground on which the tower will be placed must be stable. The foundations (concrete or steel) on which the tower will stand are being built. The foundation must be buried deep enough to support the weight of the entire turbine. After that, a geodetic and technical inspection of the foundation is carried out to ensure the correct height and direction of the tower.

After that, the assembly of the parts of the tower is carried out. Tower components (segments) are transported to the construction site by specialized vehicles (trucks or ships for offshore projects). Assembly of the tower usually starts with the lower segments. Each segment of the tower is lifted by a large crane (mobile crane, telescopic crane or aerial crane, depending on the location and conditions). Each segment of the tower is connected using screws and fastening mechanisms. Partial assembly continues until the tower reaches the required height. Then the tower is fixed. At the top of the tower, channels and supports are placed that enable the installation of the gondola.

The gondola assembly procedure also takes place in several steps.

First, the equipment is prepared. Before assembling the gondola, it is necessary to secure the necessary lifting equipment, such as high-capacity cranes (usually mobile cranes with a crane). Before lifting, all

components inside the nacelle, generator, transmission system and turning system, must be carefully checked and secured. The gondola is lifted by a crane towards the top of the tower by a crane. It is a critical stage that requires great precision as the nacelle must be correctly positioned on the top of the tower. A crane is used to lift, and field workers monitor all aspects of the lift. After that, the gondola is attached to the tower. When the gondola reaches the top, it is attached to the supports at the top of the tower, and all joints and safety mechanisms are checked. After assembling the nacelle, the rotors (blades) are mounted on the main shaft of the generator. Depending on the size of the wind turbine, the blades can be mounted individually or in groups. Sometimes the mounting of the blades on the main shaft is done on the ground, so that system is lifted together and mounted on the nacelle. Finally, an electrical and mechanical check is performed. All electrical connections, control systems, transmission mechanism and nacelle turning system are tested.

Procedure for dismantling the tower and nacelle of the wind turbine

Dismantling of wind turbines (tower and nacelle) is usually carried out during the maintenance phase or after the wind farm stops working, e.g. due to end of life or removal of old turbine.

The process of dismantling the tower begins with stopping the wind turbine. First, all electrical and mechanical components are turned off. Depending on the type of wind farm, it is necessary to remove all cables and electrical installations that connect the wind farm to the grid. Then the security is checked. Before the start of dismantling, an assessment of safety conditions is carried out, including an inspection of the terrain and the use of protective equipment. When all the conditions have been checked, the parts of the tower are dismantled. The tower components are gradually being removed. The segments are lowered using cranes, starting from the upper parts. After lowering, the removed parts are transported from the construction site in an appropriate manner.

The dismantling of the nacelles begins with the lifting of the nacelles. As with assembly, the gondola is lifted by a large crane and lowered to the ground. Under the nacelle, the generator, transmission mechanism and other components installed in the nacelle are separated. After the nacelle is safely placed on the ground, all parts are dismantled and transported to a designated or recycling location.

Supports and bases of elements of electrical installations

The process of mounting and dismantling the pedestals and supports for installing elements of electrical installations and safety equipment in wind farms is a very important part of infrastructure construction and maintenance.

Bases and supports have an important function in power systems because they enable the correct placement of switches, transformers, electrical cables and other power systems. Their role is to ensure the stability, safety and protection of installations from external factors. In addition, they are used for the installation of security equipment, such as security cameras, meteorological sensors, beacons and sound alarms, which contribute to the safety of the wind farm. Structures must be designed to withstand external influences, such as rain, wind, snow, high temperatures and corrosive conditions, especially in offshore wind farms.

The procedure for mounting the pedestal and support

Installation of supports and bases begins with laying the foundation. If a concrete footing is used, it shall be poured according to specifications, unless it has been placed in previous stages of construction. Bases that are mounted on foundations are made of steel or aluminum, depending on the type of installation. They are attached with screws, nails or other fastening materials, and in the case of steel supports, it is necessary to control the quality of welded joints and fastenings.

In case the mounts are used for devices that must be placed at a certain angle or height, such as weather sensors, cameras or beacons, an adaptive design is chosen that allows for position adjustment. Considering

the outdoor conditions, the stands are designed to provide maximum stability and resistance to windy conditions.

After the brackets and pedestals have been installed, appropriate power devices, such as switches, sensors and cables, are mounted on them. The electrical installation is connected according to the technical specifications, and security devices, such as cameras or beacons, are connected to energy sources and energy storage systems and connected to the central system of the wind farm. When all the elements are mounted, the stability control is carried out. This includes checking fastening mechanisms and fixtures, as well as testing each device installed to ensure proper operation.

Procedure for disassembling the stand and support

Before starting the disassembly of all electrical components, it is necessary to turn off the power supply. Devices connected to stands or supports, such as security cameras or transformers, must be turned off to ensure worker safety. A safety check is then carried out to ensure that the working conditions are safe, using protective equipment such as helmets, gloves and safety suits.

Dismantling begins with the removal of power equipment. All devices, including switches, cables, security cameras and weather sensors, are carefully removed to avoid damage. This is followed by the disassembly of the support and the base, during which all fastening screws and load-bearing parts are removed. If the stands are made of steel or aluminum, they are disassembled into smaller components for easier transport and recycling.

If the supports were placed on concrete foundations, the foundations are removed or moved to free up space. Depending on the size and weight, it may be necessary to use specialized equipment, such as cranes or hydraulic tools. After disassembly is complete, all removed parts, including stands, brackets, and electrical equipment, are transported to an appropriate disposal, recycling, or service facility. All materials must be properly separated for further processing or reuse.

Assembly and disassembly of stands and supports for electrical installations and safety equipment in wind farms require careful planning, precision and appropriate safety equipment. During installation, the focus is on stability, accuracy of installation and proper connection of power and safety devices. On the other hand, dismantling requires safe removal of equipment and structures, with careful handling of all parts to avoid damage and ensure safe and efficient recycling or reuse of materials.



VIDEO

Installation procedure of the wind farm:

https://www.youtube.com/watch?v=f16BMVw_B-Y,
<https://www.youtube.com/watch?v=vjqdJ8QSmRA>,
<https://www.seetaoe.com/details/129354.html>.

Constructions for meteorological equipment and security cameras

Constructions for meteorological equipment are used to install devices such as anemometers, barometers and sensors for measuring temperature and humidity. These devices monitor wind and environmental conditions and enable optimization of the wind power plant's operation. On the other hand, security camera structures are used to monitor the wind farm and protect the equipment.

These structures can be made of light steel or aluminum, but must be strong enough to withstand outdoor conditions, including high winds, rain and snow. When it comes to height and accommodation, structures for meteorological instruments usually include poles or masts that allow the equipment to be placed at the appropriate height, thereby ensuring accurate measurements. The assembly of structures is performed in a way that allows simple adjustment of the position and orientation of the equipment, thus ensuring their maximum efficiency.

Containers for transformer stations and electrical energy storage system

Assembly and disassembly of container structures for installation of power equipment of wind farms are an important part of the process of construction, maintenance and optimization of wind farms.

Container structures play a key role in protecting power equipment, ensuring a stable working environment that protects against weather, mechanical damage, dust and moisture. Their primary purpose is to house high-voltage and low-voltage power equipment, including transformers, distribution cabinets, protection-control systems and energy storage systems. In addition to protection, container structures allow mobility and flexibility, which means that they can be transported and placed in different locations within a wind farm or between several energy facilities. Also, they serve for the integration and modular expansion of power systems, which facilitates management and maintenance.

Installation procedure of container constructions

Installation of the container begins with its lifting and placing on the prepared foundation. The foundation must be designed to withstand static and dynamic loads caused by the weight of the container and internal equipment, as well as external forces such as wind, vibrations and electromagnetic interference. The stability of the structure is ensured by fastening with anchor bolts, steel supports or concrete bases, whereby additional protection can be provided in areas with extreme weather conditions.

Power components are placed inside the container according to engineering specifications and safety requirements. Equipment such as medium- and low-voltage distribution cabinets, transformers, uninterruptible power supply systems (UPS), switchgear and protection-control units are carefully placed and connected in accordance with the appropriate electrotechnical standards. Components are installed on metal supports, insulated bases or inside specialized compartments to ensure optimal heat dissipation and electromagnetic compatibility (EMC).

Cabling inside the container plays a key role in connecting power equipment with external systems. High-voltage, medium-voltage and low-voltage cables must be properly dimensioned, marked and laid in cable ducts with appropriate mechanical protection. In addition, appropriate grounding and surge protection systems are implemented to ensure the safety of the installation and the reliability of the equipment.

After the assembly is completed, testing of the power systems inside the container is carried out. This procedure includes measurement of insulation resistances, testing of continuity and functionality of switchgear, testing of protective relays and checking of parameters of transformers and battery systems. Only after all parameters meet technical standards and regulations, the container can be put into operation and connected to the power grid.

Dismantling procedure of container structures

Dismantling of containers is carried out when the equipment has reached the end of its useful life, during the modernization of the system or when moving the equipment to a new location. The first step is to safely shut down the power systems, where the power supply is interrupted and all active electrical circuits are turned off. Before the start of the work, a test of the absence of voltage is carried out and adequate protection against electrostatic discharge (ESD) is ensured.

Inside the container, the power equipment is carefully dismantled according to established procedures. Transformers, distribution cabinets, protective relays and switchgear are gradually removed, taking into account the sequence of disassembly to avoid the possibility of short circuits and unexpected electrical discharges. Cables are separated, labeled and disposed of in a safe manner to prevent damage and ensure proper recycling or reuse.

After all equipment has been removed, the container is prepared for transport using a crane or specialized vehicle. If it is moved to a new location, it is necessary to ensure proper mechanical connections and secure transport conditions to prevent damage during transport. In cases where the container is permanently removed, the foundations and anchoring elements are also dismantled, adhering to the standards of disposal of construction waste.

Transport and disposal of equipment

After dismantling, the containers and power equipment are transported to designated locations for recycling, disposal or reuse. Depending on the type of equipment, it may be necessary to use specialized transportation services to safely transport high-voltage components, batteries, or other sensitive electrical devices. The recycling of copper conductors, insulating materials and metal parts is carried out in accordance with ecological standards in order to reduce the negative impact on the environment and ensure the reuse of valuable materials.

All these prefabricated structures must be designed and built in accordance with safety standards and regulations, taking into account the specifics of wind farms (eg offshore or onshore, different weather conditions, technical requirements). Installation must be precise, as any installation errors can have a serious impact on wind farm performance, personnel safety and the environment.



EXERCISE

Research task - examples of different constructions of wind turbine towers.
Research and compare the different types of towers used in wind farms (steel tubular



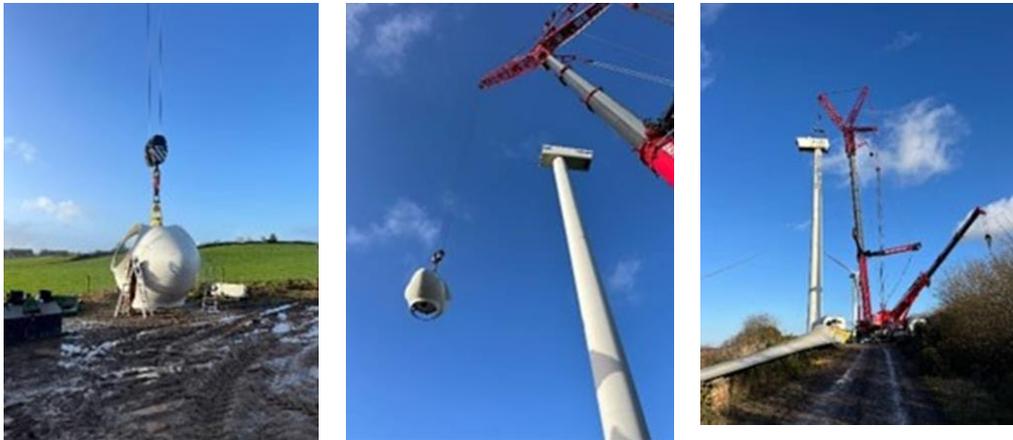
QUIZ

Quiz 4 - Checking knowledge about prefab structures in wind farms:
<https://forms.office.com/e/H4qvBw4qju>.

5.3. Assembly/disassembly and connection of power equipment in wind power plants

Installation and connection of power equipment in wind farms includes a series of technical procedures that ensure proper operation of the system. The process includes installation of the nacelle with factory-integrated equipment, installation and connection of additional electrical components, routing and laying of cables, and integration of energy storage systems.

Nacelle assembly with factory-integrated mechanical and electrical equipment The nacelle of the wind turbine is supplied with key components already installed, including the generator, main shaft, transmission system and electrical control modules. The assembly of the nacelle is carried out by a high-capacity crane, which lifts and places the nacelle on top of the wind turbine tower. During assembly, a specialized coupling system is used, which ensures precise alignment of the generator shaft with the main turbine shaft. After installation, the nacelle is mechanically fixed using high-strength screws and safety rings.



Gondola lifting procedure

Mounting and dismounting of monitoring and control systems

In addition to factory-installed components, additional equipment for monitoring and control is installed in the nacelle. These include temperature and vibration sensors, meteorological instruments, remote control and communication systems. Installation of these systems requires precise connection of sensors and control units with the central control module.

During disassembly, all connections are carefully disconnected, and sensitive devices are packed in protective containers for transport and reinstallation.

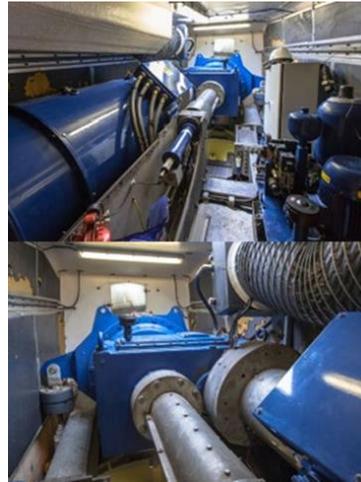


Examples of mounting parts of equipment on the gondola

Connecting the electrical components inside the nacelle of the wind turbine

Connecting the electrical components inside the nacelle of the wind turbine requires precision and expertise and is a key step in the final assembly phase, as it ensures the functionality of the system for the production, regulation and distribution of electricity. This process includes the connection of generators, converters, protection and control systems, as well as other electrical equipment necessary for the efficient operation of wind turbines.

After successful connection and testing, the wind turbine is ready for grid integration and regular operation.



Interior of wind turbine nacelle with shaft, gearbox, clutch and cooling system

Connecting the generator to the converter system

The generator is the heart of the wind power system and its primary function is the conversion of mechanical energy obtained from the wind into electrical energy. Depending on the type of wind turbine, the generator can be synchronous or asynchronous, with direct or indirect power transmission.

Connecting the generator involves the following steps:

- **Checking electrical connections-** Before connecting, the compatibility of the generator connections with the electrical system of the wind farm is checked. All connections must comply with technical specifications and insulation standards.
- **Connecting the generator to the converter-** The output lines of the generator are connected to the converter system, which converts the produced electricity from a variable frequency to a stable and synchronized frequency suitable for distribution in the network. Wiring is done using high-voltage cables resistant to temperature changes and mechanical stress.



Connection of wind turbine generators

- **Generator grounding**– The generator is connected to the grounding system of the wind turbine to ensure protection against overvoltage and electrostatic charging.
- **Phase sequence check**– After connection, a phase sequence test is performed to ensure proper matching of output power with network requirements.

Installation and connection of the control system

The management system of wind turbines is responsible for monitoring and optimizing the operation of all components. It consists of various sensors, control units and systems for communication with the central operating center of the wind farm.

- **Sensor connection** – Sensors are installed inside the nacelle to measure generator temperature, bearing vibration, rotor speed, voltage and current. These sensors send data to the control system to optimize operation and prevent breakdowns.
- **PLC Controller Installation** – The Programmable Logic Controller (PLC) is a key component for managing the operation of the turbine. It connects to the generator, protection systems and communication interfaces to enable remote control and automated power regulation.
- **Braking System Integration** – The electrical and mechanical braking system connects to the control module, allowing for immediate turbine shutdown in the event of excessive wind speeds or technical problems.



Figure: Connection of wind turbine control system, including sensors, PLC controller and braking system

Connection of protection and security systems

Protection of power components from overvoltage, short circuits and overloads is essential for the safety and longevity of the system.

- **Installation of protective relays** -Relay protection includes devices that recognize network faults and automatically shut down the system in case of need. These devices are connected to the key nodes of the electrical network of wind turbines.
- **Installation of surge protectors** -Varistors and gas arresters are installed to protect electrical components from lightning strikes and surges.
- **Connecting the safety grounding system**- Grounding is realized by connecting all metal parts and electrical devices to the grounding line, which reduces the risk of electric shock and overvoltage.

Laying and connecting power cables inside the gondola

The cable system inside the nacelle enables the distribution of the produced energy towards the distribution cabinet and further network. Power cables must be properly laid and protected from mechanical damage and vibrations that occur during the operation of the wind turbine.

- **Selecting and routing cables**– Flexible and temperature-resistant cables are used, which are passed through the cable channels inside the gondola.
- **Cable fastening**- Cables are attached using cable ties and special supports that prevent their wear and tear during operation.
- **Connection to the distribution cabinet**- The main energy lines are connected to the distribution cabinet, where further distribution of energy to the network is carried out. The connection is made according to single-wire schemes, with a check of the insulation and continuity of the connections.
- **Cable testing**- After connection, insulation resistance test, continuity check and load test are performed to ensure the reliability of the connection.



Laying and connecting power cables inside the nacelle of the wind turbine

Final testing and verification of the system

After all the electrical components are connected, the final tests are carried out, which include:

- **Visual inspection of joints and cable installations**– All connections are inspected to ensure there are no loose connections or insulation damage.
- **Measurement of electrical parameters**– Voltage, current and insulation resistance are checked to ensure that the system is functioning according to technical specifications.
- **Wind turbine test run**- Under controlled conditions, a test operation of the turbine is started to ensure the proper functionality of all connected electrical systems.
- **Setting up the operating system**– Optimization of turbine operating parameters, including rotor speed, generator power and protective limits, is performed using software tools and a communication interface.

The system for storing electricity in the wind farm and the installation/disassembly procedure

In modern wind farms, a system for storing electricity is increasingly used, most often in the form of battery storage or supercapacitors. Assembly of the storage system involves the installation of battery modules in specially designed containers, their connection with inverters and integration with the power grid. During disassembly, it is necessary to disconnect the storage system from the network, perform a safety discharge of the battery cells and carefully disassemble the modules for transport or replacement.

After the completion of all assembly works, a final inspection and testing is carried out to ensure the functionality of the power system and its readiness to work in the network.



An example of a system for storing electricity in a wind farm



EXERCISE

Task: Write a seminar paper on the procedure for connecting electrical components inside the nacelle of a wind turbine.



QUIZ

Quiz 5 - Knowledge check on assembly and connection of power equipment:
<https://forms.office.com/e/85wh4EzhsW>.

5.4. Selection of protective equipment and equipment for assembly and disassembly of wind farm elements

In the previous chapters of the manual, the tools, equipment and devices used in the construction and maintenance of wind power plants, as well as the basic protective equipment for work in power plants, were discussed. In this chapter, the focus is on specific protective equipment and measures that are applied during the assembly and disassembly of wind farm elements.

Installation and dismantling of wind farm elements are among high-risk tasks that require the use of adequate protective 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 hazards and is mandatory for everyone who participates in the assembly and disassembly of wind farm elements. Equipment includes:

- Protective helmet - Protects the head from impacts, falling objects and electric shocks. The helmet must have a safety strap to keep it stable while working at height.
- Safety harness and lanyards (system for work at height) – All workers working on a tower or gondola 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 for working with electric power components, dielectric gloves are used that prevent electric shock.
- Protective clothing and footwear - Workers must wear antistatic and flame retardant 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 chemical agents, 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
							



Example of safety lashing for fixed points for work at height

Collective protective equipment

In addition to personal protection, collective protective equipment is also installed at the wind farm construction site, which reduces risks for all workers.

- Safety barriers and safety nets – Placed around critical areas to prevent tools and materials from falling from a height.
- Systems for protection against lightning strikes - Installation of wind turbines 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.
- Signaling and marking of work zones - Marking hazardous areas with reflective strips and safety signs reduces the risk of accidents and collisions with heavy equipment.
- Assistive systems for lifting and handling loads - Includes cranes, winches, cranes and specialized systems for transporting heavy components, to reduce the physical effort of workers and the risk of injury.



An example of a safety barrier mounted directly on top of the nacelle

Emergency measures and evacuation plan

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

- Gondola and Tower Evacuation Plan – In the event 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.
- Rescue from height training - All workers working on the turbine must be trained in the use of evacuation equipment, such as self-lowering ropes or special baskets for lowering the injured.

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



EXERCISE

Personal or collective protective equipment in wind farms.

Write a seminar paper on personal or collective protective equipment used on wind farm construction sites.



QUIZ

Quiz 6 - Checking knowledge about protective equipment and equipment:

<https://forms.office.com/e/f2iVZFZD6V>.

6. PERFORMANCE OF ELECTRICAL INSTALLATIONS OF WIND POWER PLANTS

6.1. Types and basic elements of electrical installations of wind farms

The execution of electrical installations of wind farms includes a wide range of systems and components necessary for the stable and safe operation of the plant. These installations include power installation, control, management and signaling installation, earthing and lightning protection installation, lighting installation, fire protection installation, surveillance camera installation and access control systems.

Various elements are used in electrical installations, including conductors and cables, switches, switches, fuses, sensors, measuring instruments, protective devices, controllers, grounding and lightning protection elements, light indicators, electronic locks and identification devices. Each of these elements has a specific role in the functioning of the system and must be properly installed and connected to ensure the reliability and safety of the plant.

Types of conductors and cables used in wind farms include non-insulated conductors, energy-insulated conductors, low-voltage power cables (up to 1kV), control and signal cables, and grounding conductors. For their correct assembly, various cable accessories are used, such as cable caps, cable heads, cable connectors, cable forks, cable lugs and cable ties.

In addition, the execution of electrical installations requires the use of appropriate installation materials, including distribution boxes, conduits, protective pipes, clamps, ties, connectors, clamps and screws. Proper organization and installation of cable lines are key to efficient system operation, and for this purpose, cable constructions such as cable channels, cable shelves, flexible cable pipes, cable bridges, cable holders and cable bundles are used.

6.2. Installation of cable structures and laying of cables of electrical installations of wind power plants

Procedure for mounting cable structures

Installation of cable structures begins with planning the route and position of the cables. It analyzes the terrain, avoids obstacles and ensures that cables will not be exposed to hazards such as corrosion or physical damage. Based on the needs of the wind power plant, the type of cables and the type of cable structures (ducts, underground installations, connection boxes) are designed.

The preparation of materials includes the selection of cables according to the needs of energy transmission, taking into account the voltage levels and the specifics of the terrain. Appropriate supports, ducts, pillars and other structures are used depending on the type of installation (above ground or underground).

The preparation of cables and supports involves cutting the cables to the required length, cleaning and protecting them from weather conditions. If the cables are placed on supports or in ducts, the necessary supports or concrete and metal structures are mounted.

Cable laying can be underground or above ground. In the case of underground laying, trenches are dug on the planned route, while respecting the minimum depths in order to protect the cables from external influences. Cables are laid in trenches, ensuring a minimum distance between different types of cables. In the case of overhead laying, the cables are attached to supports or poles with appropriate spacing and weather protection.

The connection of cables is performed in joint boxes or distribution boxes with the use of waterproof connectors and insulators, ensuring quality connections according to electrical installation standards.

Testing and verification includes testing insulation, continuity and voltage levels to ensure system integrity. This is followed by finishing works such as installing protections at the joints, marking the cables and documenting the installation.

Cable laying and marking procedure

Before laying the cables, it is necessary to make a proper selection of the types of cables according to their function:

- Power cables transmit high-power electricity.
- Control cables enable monitoring and control of system operating parameters.
- Control cables connect wind turbine control and automation systems.
- Signal cables are used for data transmission between different system components.

The laying of cables begins with checking the prepared cable structures. The cables are then placed in cable ducts, racks, bridges or flexible pipes, taking care to protect them from physical damage.

Cable marking is essential for identifying and maintaining installations:

- **Cable color and markings-** each type of cable has specific colors that allow easy identification (eg power cables are black or brown).
- **Tags and labels-** cables may have permanent markings with information on the type, voltage value and function of the cable.
- **Markings on connections and junction boxes-** clearly marked entry and exit points for easier maintenance and troubleshooting.
- **Markings on the ground for underground installations-** the use of colors, tapes or signs to indicate the presence of underground cables.

After laying and marking, voltage levels, signals and continuity are tested to ensure proper functioning of the system. These procedures ensure the long-term reliability and safety of wind power installations.

Making cable terminations for energy, control and signal cables in wind farms is a very important step because it ensures the correct transmission of electricity and signals between different system components, as well as the safety and reliability of the entire power system. Cable terminations are made in a way that ensures solid, safe and reliable electrical connections. When crimping cable ends, power dissipation, i.e. energy losses due to the electrical resistance of the connection, plays a key role in the efficiency and safety of power installations. Poorly executed connections can cause increased transient resistance, which leads to heating of the contact point and potential failures in the system.

Effect of transient resistance on system performance:

- **Increased heat dissipation**- A poorly crimped joint creates localized heating, which can cause degradation of the insulation and accelerated aging of the material.
- **Reduced efficiency of electricity transmission**- Greater resistance in the joints means additional energy losses, which can negatively affect the operation and stability of the wind farm.
- **Risk of mechanical weakening of the connection**- Insufficiently tightened or inadequately performed crimp joints can weaken over time due to vibrations and thermal cycles, which increases the possibility of conductor breakage.
- **Increased risk of fire**– High temperatures at poor connections can lead to overheating and potential fire of the cables.

Recommendations for proper crimping:

- Using the correct crimping tool in accordance with the manufacturer's recommendations.
- Application of appropriate connection elements (cable lugs, connectors) made of materials compatible with the conductor.
- Measurement of junction resistance after crimping is complete to ensure minimal energy dissipation.
- Application of thermal inspection (e.g. thermal cameras) to detect possible problematic connections during system exploitation.

Properly executed cable terminations guarantee safe and efficient operation of the power system of wind farms, reducing losses and extending the life of the equipment.

An example of the procedure for making cable terminations for energy cables by steps.

With power cables, it is important that the ends are strong, properly insulated and protected from external factors.



PRACTICAL EXERCISE

Task 1: Make the termination of the power cable by observing the correct steps of preparing, processing and connecting the conductors.

Material and tools:

- Power cables of appropriate section,
- Insulation removal tool (cable knife, insulation stripping pliers),
- Cable clamps and lugs,
- Crimping tool,
- Heat shrink tubing or insulating tape,
- A multimeter or continuity tester,
- Protective equipment (gloves, safety glasses).

Procedure:

1. Workplace preparation
 - Check that the workplace is clean and well lit.
 - Prepare all necessary tools and materials.
2. Downloading outer insulation (sheath)
 - Carefully remove the outer sheath of the cable in a length of 3 to 4 cm using the insulation stripping tool.
 - Be careful not to damage the internal conductors.
3. Removal of conductor insulation
 - On each conductor, remove the insulation to the length required for the installation of the connection clamps (usually 1 to 2 cm).
 - Check that there is no damage to the cores of the cable.
4. Installation of lugs or connection clamps
 - Place appropriate lugs or clamps on the bare ends of the conductors.
 - Use a crimping tool to ensure a tight fit.



PRACTICAL EXERCISE

5. Joint insulation
 - Cover the joints with heat shrink tubing or insulating tape to ensure protection against moisture and mechanical influences.
 - Check that the insulation is well attached and does not leave exposed metal parts.
6. Testing connections
 - Use a multimeter or continuity tester to check the correctness of the connections.
 - Ensure that the connections are tight and there is no loss of contact.
7. Proper storage of the surrounding material
 - Sort different types of waste.
 - Properly package, label and store waste in accordance with environmental standards.
8. Store used tools in a suitable place

Final check:

- Perform a visual and functional joint control.
- Ensure that cable terminations meet safety and quality standards.

Connecting power, control and signal cables in wind farms must be done very carefully in order to ensure the reliability and safety of the entire power system. This process involves different types of connections and the use of specialized components for each type of cable

Connecting power cables

Connecting power cables is a key step in ensuring stable power transmission. The first step in this process is to prepare the necessary tools and materials, including medium or high voltage power cables, connection terminals, clamps, scraping and crimping tools, and waterproof boxes and insulating materials.

When removing the outer insulation, a suitable stripping tool is used to remove the insulation to the required length, usually between 10 and 15 centimeters, depending on the specifics of the joint. It is important to take care not to damage the internal insulation or the conductor. After that, the inner insulation is removed from the conductor, usually about 1 to 2 centimeters, leaving enough wire for later connection to the connector.

Connections are placed on the bare conductors, which can have different shapes, such as round or plate openings. These connections ensure a safe and stable electrical contact between the conductor and the connection. Their fastening can be done by crimping or screwing. If crimping joints are used, they should be crimped with a suitable tool to ensure a tight mechanical connection. In the case of screw joints, fastening is done by tightening the screw, where it is important to avoid excessive tightening in order not to damage the conductor.

After the joints are attached, they are insulated with suitable materials such as PVC or silicone pipes, which protect the joint from external influences such as moisture and chemicals. In addition, the joints can be secured with silicone or thermofoils to ensure long-term protection against water penetration.

The final step in the procedure is to test the connection using an electric multimeter or other suitable device, in order to check the continuity and correctness of the connection, thus ensuring the reliability and safety of the energy system.



Connecting power cables

Connection of signal and control cables

Connecting signal and control cables is crucial to ensure stable and accurate transmission of low-voltage signals that control system operation. The first step in this process involves preparing the necessary tools and materials, including multi-wire signal and control cables, clamps and connectors for small conductors, stripping and crimping tools, and protective materials to insulate the joints.

The outer insulation is removed using a tool for removing the insulation, whereby the insulation is removed from the cable sheath on a length of 3 to 5 centimeters. After that, the inner insulation is removed from the individual wires inside the cable, leaving enough bare conductors for connection.

Connection of signal and control cables is done using small clamps or connectors adapted for thin conductors. These connectors, which can be in the form of wire clips or small connectors, allow wires to be connected to a control device or switch. When the wires are placed in the connectors, a crimping tool is used to ensure a tight connection between the conductor and the connector. In the case of screw connectors, the wires are attached by screwing, where it is important to ensure good contact without excessive tightening.



Connection of signal and control cables

After the connection is completed, the joints are insulated with PVC or silicone sheaths to ensure protection against external influences. The final step in the process involves testing the functionality of the signal and control systems to verify correct response to the signal connections. Testing is carried out using devices for measuring signals and voltages, which ensures the reliability and stability of the entire system.

Cable splicing in wind farms requires careful and precise execution to ensure long-term reliability of the system. Power cables, control and signal cables have different requirements, but all connections must be made safely, protected from external influences and tested to ensure correctness.

6.3. Installation of distribution and control panels, cabinets and counters of electrical installations of wind power plants

Distribution and control panels, cabinets and counters of electrical installations in wind farms play a key role in the management, control and protection of all power systems within the wind farm. Their purpose and functionality are of essential importance for the proper functioning of the system, safety and reliability of work.

Distribution boards and cabinets

Switchboards (or distribution cabinets) in wind farms serve as a central point for the distribution of electricity within the wind farm system. These components enable the safe and efficient management of electricity produced in wind turbines, in order to distribute the energy to other parts of the system.

The purpose of switchboards is to distribute electricity. They receive electricity from wind turbines (or other sources) and distribute it to various consumers within the system, such as electric motors, generators, heating, control systems, and more. Switchboards contain protective devices such as fuses, switches, relays, and circuit breakers that prevent overloads, short circuits, and other safety incidents. Also, they enable monitoring of system status. They often include monitoring and control systems (e.g. SCADA systems) that allow remote monitoring of the state of electrical components, as well as remote switching on or off of certain parts of the system.

Control panels and cabinets

Control panels and cabinets in wind power plants enable the management and monitoring of the operation of wind turbines and supporting systems. Through them, operators can manually control and monitor the operation of the plant, while at the same time they are integrated with automated systems and remote control. Using switches, buttons and displays, the control panels allow turning wind turbines on and off, setting operational parameters and monitoring system performance.

Control cabinets are connected to sensors and measuring devices that monitor key parameters such as wind speed, generation power, equipment temperature, voltage and current. In addition, they are equipped with signal systems that warn of potential malfunctions or irregularities through sound alarms, light indicators or messages on the screen.

Automated systems such as SCADA platforms are often used for efficient management of wind farms, which enable real-time monitoring and control. In this context, the control panels serve as an interface between the operator and the system, enabling precise and safe control of the plant's operation, which enables a quick response to changes and difficulties in the system.



Control cabinets and panels



Desks and control stations

Control panels or control stations are used for more complex monitoring and control functions, especially in large wind farms or those that are part of a larger energy-connected system. These desks enable centralized management and monitoring of all wind farm systems.

The consoles serve as a central system for monitoring and managing all functions of the wind farm, including turning on and off wind turbines, monitoring operational parameters, managing the energy balance, and adjusting energy production. Control stations enable remote control and monitoring of the wind farm, which is especially important for wind farms located in remote or hard-to-reach areas.

These consoles allow operators to access diagnostic information regarding the condition of the equipment and can enable problems to be recognized before they become serious, aiding in preventive maintenance.



Control station

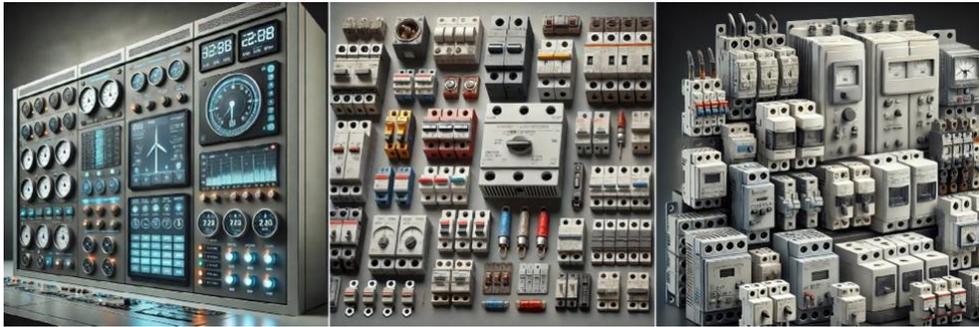
Safety and security

Both distribution and control panels, cabinets and counters must be designed to ensure a high level of safety and protection. This includes:

- **Overload and short-circuit protection:** By including safety devices such as circuit breakers and fuses.
- **Protection from external conditions:** The equipment must be protected from moisture, dust, extreme temperatures and chemicals, and can have housings with appropriate IP standards (eg IP65) for protection from external influences.
- **Physical security:** Using locks and other security measures to prevent unauthorized access.

Switchboards and control panels, cabinets and counters in wind farms enable efficient management, distribution and monitoring of electricity, as well as protection of the system from breakdowns and malfunctions. These components allow operators to quickly react to changes in the system, maintain safety and reliability, and optimize the operation of the wind farm, thereby ensuring maximum efficiency in energy production and reducing potential risks.

Basic electrical installation elements that are installed in switchboards and control panels, cabinets and counters are switches, switches, fuses, contactors, measuring devices (voltage, current, power, energy, frequency), sensors (temperature, vibration, noise), surge arresters, protective relays, control devices (PLC, softstarters, regulators), signal devices (LED indicators, audible alarms) and others.



Measuring devices

Switches, switches, fuses, contactors

Surge arresters, protective relays



Signaling devices

Control devices

Sensors

The installation of switchboards and control panels, cabinets and counters, and the connection of electrical installation elements in wind farms is important from the aspect of ensuring proper operation, safety and efficiency of power systems. This procedure includes mounting the equipment, connecting the wiring components, and testing all systems to ensure reliable operation of the entire system.

Installation of distribution and control panels, cabinets and counters

Preparation for the installation of distribution and control panels, cabinets and counters begins with the selection of a suitable location. The space must be dry, easily accessible and protected from external influences such as dust and moisture, with sufficient space for placing all the necessary elements. Key factors in site selection include adequate ventilation to prevent equipment overheating, safety requirements that allow safe and unhindered access for technical personnel, and protection from external factors, whereby, depending on the environment, protective enclosures with appropriate IP protection are used, e.g. IP65 for outdoor installation.

After site preparation, installation of basic electrical installation elements begins. Switchboards are placed in such a way as to allow easy access to all components, and their installation includes the installation of wiring boxes for fuses, switches, switches and other devices necessary for the protection and distribution of energy. Control devices, such as relays, automated switches, monitoring and control systems and a remote control interface, are installed in the control cabinets. Desks and control stations are placed in central locations so that operators can effectively manage all functions of the wind farm. These elements include displays, buttons, switches and communication devices required for monitoring and control.

The final part of the assembly includes the installation of doors and enclosures on each panel, cabinet or counter, which ensures safe access to internal components, but at the same time prevents unauthorized entry. Depending on the type of device, the door may have glass windows for visual surveillance, protection against dust and moisture, and alarm systems that signal attempts at unauthorized opening. This protective measure contributes to the safety and reliability of electrical installations in wind farms.



PRACTICAL EXERCISE

Task: Participants must assemble the switchboard and/or control panel according to the given technical specifications

Material and tools:

- Distribution/control panel,
- Electrical installation elements (switches, fuses, switches, contactors, measuring devices, sensors, surge arresters, protective relays, control devices, signaling devices),
- Screws, dowels and fastening material,
- Tools for drilling and assembly (drill, screwdrivers, keys),
- Insulating material (insulating pipes, tapes),
- Multimeter for checking the correctness of connections,
- Protective equipment (gloves, safety glasses)

Execution procedure:

1. Workplace preparation
 - Ensure that the installation location is dry, ventilated and easily accessible.
 - Check the technical documentation and assembly plan.
 - Prepare all necessary tools and materials.
2. Installation of switchboard/control panel
 - Mark the exact position where the board will be mounted.
 - Use a drill to drill holes for fasteners.
 - Place the board and fasten it with appropriate screws and dowels.
3. Installation of electrical installation elements
 - Install protective switches, fuses and switches according to the given scheme.
 - Install measuring devices (voltage, current, power, energy, frequency).
 - Install sensors and protective elements (surge arresters, relays).
 - Install control devices (PLC, soft starters, regulators).
 - Install signal devices (LED indicators, sound alarms).
4. Connection of electrical installation elements
 - Connect power supply, control and signal lines according to technical specifications.
 - Ensure proper wiring and organization of cables inside the panel.
 - Check the correctness of the connections and ensure proper insulation.



PRACTICAL EXERCISE

5. Installation of protective covers and doors
 - Install covers and protective panels to ensure system safety.
 - Check that all elements are properly attached and closed.

6. Testing and verification
 - Use a multimeter to check the continuity and correctness of the connections.
 - Test protective and control components.
 - Simulate the operation of the system in order to check the functionality of all elements.

Final check:

- Visually inspect all joints and attached elements.
- Document the procedure and register any irregularities.
- Ensure that all safety standards are met.

6.4 Connection electrical installation elements in distribution and control panels, cabinets and counters

Connection of electrical installation elements in distribution and control panels, cabinets and counters must be performed according to safety and technical standards. It is important to ensure proper connection of all components, establish power connections and implement protection and control systems.

Planning and preparation of electrical installations begins with checking technical drawings and connection schemes, which clearly describe the arrangement of devices, switches, switches, relays, terminals and other electrical installation elements. The selection of suitable conductors is crucial for the reliability of the system, taking into account the maximum load, the type of installation and the protective measures.

Connection of protective devices includes proper installation of fuses, switches and switches to prevent overload or short circuits. Fuses are placed at the entrance to the switchboard to protect against short circuits and overloads, while automatic switches enable automatic disconnection of the power supply in case of irregularities in the system. Also, overvoltage protections reduce the risk of equipment damage due to voltage surges.

Connecting the power and control lines means connecting the main power source to the main switch or fuse, from where the power is distributed to the various components via the appropriate cables. Control lines connect signal and control devices in the control panel, enabling remote control and automatic switching to different operating modes.

Control devices, such as relays, switches, and sensors, are connected to control and signal lines to enable automatic system state changes based on operating parameters. Sensors are integrated with monitoring and control devices, enabling monitoring of key parameters such as temperature, voltage, current and wind speed.

Each switchboard or control panel must be equipped with a suitable conductor connected to the grounding system of the wind farm. This component ensures the safe removal of voltage surges or electrical faults to ground, thus improving the safety of the system.



Interior of a wind turbine nacelle

After the connection is complete, testing and checking the connections are key steps in ensuring the correctness of the system. Electrical testing involves checking the continuity, insulation and correctness of all connections using a multimeter or specialized devices. The visual check includes an inspection of all

connections and wiring to ensure correctness of the installation, strength of the connections, neatness and safety of the entire electrical installation system.

6.5. Installation of grounding and lightning protection of wind power plants

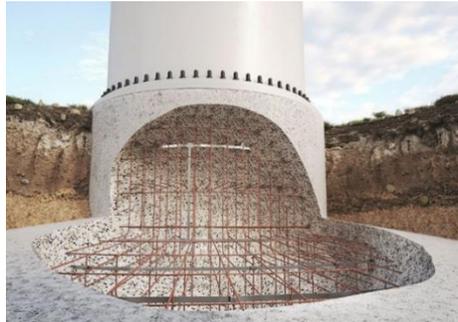
In wind farms, grounding systems play a key role in the safety, stability and protection of power equipment and people. The grounding system enables the safe removal of electric currents in the event of a fault, reduces the risk of electric shock and ensures the proper functioning of the system. There are different forms of grounding systems, each designed for a specific function within a wind farm.

Grounding system of wind turbines (wind turbines)

The grounding system of the wind turbine is of great importance for the safety of the turbine itself, equipment and people. The main function of wind turbine grounding is to ensure safe current flow in the event of a fault (eg short circuit or lightning strike).

Wind turbines usually have a grounding device built into the foundations of the turbine. This is usually achieved by connecting metal parts of the foundation to the grounding system. The foundation grounding system can use steel rebars in concrete or metal pipes placed in the ground, which are connected to the metal parts of the turbine (eg frame or generator housing).

In a wind turbine, a ground wire connects metal parts (such as the generator housing and associated equipment) to the foundation's grounding system. Wind turbines often have a lightning protection system that includes grounding electrodes connected to the metal parts of the turbine and the grounding system.



Wind turbine grounding

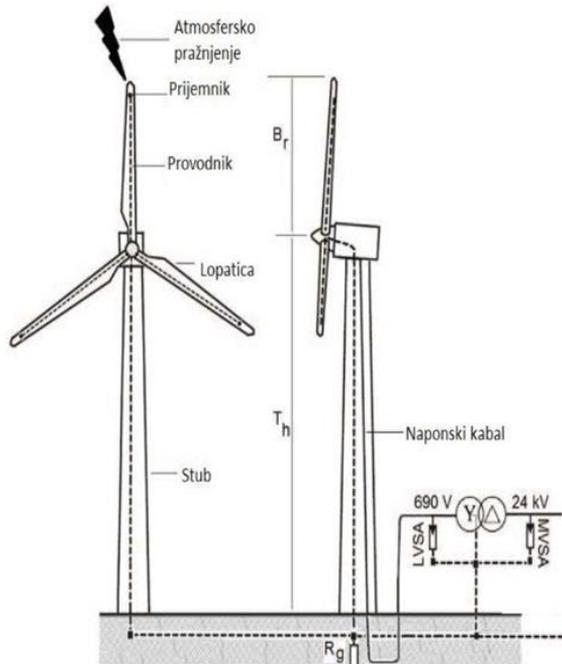
Grounding system of transformer stations

Transformer stations in wind farms are used to transform the voltage of electricity in order to enable correct distribution to the electricity grid. The grounding system of transformer stations ensures the safety of the equipment, protection against failure and stability of the system.

An earthing system is used in transformers and other devices inside the station, which ensures safe current flow in the event of a fault. Usually the soil is used as the ground, and metal rods or plates are placed in the ground around the station. The metal parts of the transformer (such as metal frames and casings) are connected to the grounding system by wiring that goes to grounding electrodes (steel rods or grids) in the ground.

In large transformer stations, it is often necessary to use multiple earthing electrodes to distribute the energy in the event of a short circuit and reduce the risk of overload. The substation grounding system also helps protect equipment from surges that may occur due to lightning or other disturbances.

Due to the prominence of wind turbines at high altitude locations, it is necessary to provide comprehensive protection against atmospheric discharges and surges. The probability of being hit by an atmospheric discharge increases linearly with height, so protection is of great importance for wind turbines of great power and at the same time of great heights.



Grounding system in case of direct lightning strike

The grounding system of the electrical network of the wind power plant

The electrical network of the wind farm connects wind turbines, transformer stations and other equipment and enables the distribution of the produced energy towards the public grid. The grounding system of the electrical network ensures the stability and safety of the entire system.

In wind farms, there may be a centralized grounding system that connects all system components (wind turbines, transformer stations, lines and devices) to a common grounding system. Electrical installations and equipment in the network are connected to the earth by means of earth conductors. These conductors serve to ensure a safe current path to earth in the event of a fault.

Grid earthing devices usually consist of multiple grounding electrodes, such as metal rods, plates, and grids placed in the ground. Depending on the size of the wind farm, these grounding devices can be placed along the entire length of the facility.

The grid's grounding system also includes protection against electric shocks (lightning) by means of surge protectors, which enable the safe direction of voltage shocks to the ground. The earthing system must be regularly tested to ensure that all connections are correct, and earth continuity testing devices are used in this connection.

Types of electrodes in grounding devices

In all of the above systems, different types of grounding electrodes are used. Some of the more common types of electrodes include:

- Metal rods: Steel rods placed in the ground, which are well connected to the system.
- Metal plates: Plated metal grounding devices embedded in the ground, often used in areas with poor soil conductivity.
- Grid systems: In some cases, a grid system of steel wires, steel strips or plates installed in the ground is used.

Surge protection

Apart from basic grounding, surge protection is also very important in wind farms, as the systems must be protected from high voltage surges, especially due to lightning. Devices such as surge protectors (SPDs) are used. These devices reduce the transfer of overvoltage to the equipment and direct the excess energy into the grounding system.

Grounding systems in wind farms, including the grounding of wind turbines, transformer stations and electrical networks, play a key role in ensuring the safety of people and protecting equipment from failure and damage. Depending on the size and specifics of the wind farm, grounding systems can be very complex, but they must always be designed and executed according to strict safety standards to ensure system reliability and minimize the risks of electric shock and other electrical hazards.

6.6. Measurement and control of the performance of wind turbine components

Measuring and controlling the performance of wind turbine components is essential for efficient system operation and failure prevention. The process includes testing technical parameters during operation and after installation to ensure optimal system performance and safety.

Measurement of technical parameters of wind turbine components

- **Wind speed and blade performance**– Anemometers and wind vanes measure the input parameters of the wind in order to optimize the aerodynamics of the blades.
- **Rotor vibrations and stability**- Vibration sensors monitor the balance of the rotor and indicate possible mechanical damage.
- **Bearing and generator temperature**– Thermal sensors detect overheating of critical parts.
- **Generator voltage and current**- Analysis of electrical parameters ensures stable energy production.
- **Transmission system efficiency**– Measurement of torque and power enables optimization of gearbox and generator operation.
- **Braking and safety system**– The functionality of the hydraulic and mechanical brakes is tested.

Commissioning and testing of installed components is done in several steps.

- **Visual inspection**- Correctness of joints, fastenings and structural integrity is checked.
- **Electrical measurements**– Voltage, current and conductor continuity are tested.
- **Functional testing**- The monitoring and control system is activated, checking the reactions of the turbines to different operating conditions.
- **Load test**- Work under maximum load is simulated to ensure production stability.
- **Data analysis and system tuning**- Based on the obtained results, final settings and work optimization are made.

Continuous performance monitoring and testing ensure long-term, reliable and efficient operation of wind turbines, reducing the risk of unplanned breakdowns and downtime.

7. EQUIPMENT MAINTENANCE AND MONITORING IN WIND POWER PLANTS

7.1. Types of maintenance and activities in the maintenance of wind power plants

Maintenance of wind farms is crucial for ensuring their uninterrupted and long-term operation, reducing the risk of breakdowns and optimizing electricity production. There are two basic types of wind farm maintenance: preventive and corrective maintenance. Preventive maintenance includes regular activities aimed at preventing breakdowns and extending the service life of equipment. As part of this maintenance, visual inspections, planned replacements of consumable parts and periodic testing are carried out. Corrective maintenance refers to activities that are undertaken after detecting a malfunction or irregularity in the operation of the system, and the goal is to quickly diagnose and eliminate the malfunction in order to return the system to optimal working condition.



Monitoring the operation of wind power plants involves measuring and analyzing various parameters. Electrical quantities monitored include current, voltage, frequency, power, electrical energy, and resistance. In addition to electrical quantities, it is important to monitor non-electrical parameters such as temperature, wind speed and direction, air flow, vibration and noise, as they directly affect system performance and indicate possible problems.

Preventive maintenance includes a series of activities that contribute to the long-term and reliable operation of wind turbines. Visual inspections allow timely detection of signs of wear, damage or irregularities in operation. Preventive work includes lubrication of moving parts, cleaning of the system and replacement of consumable parts before failure occurs. In addition, preventive tests of the condition of the elements are carried out, including testing of the electrical and mechanical characteristics of the equipment, which can predict potential failure.



Visual inspections

Corrective maintenance is carried out when there is a malfunction or problem in the operation of the system. Fault diagnosis includes problem identification, fault location and root cause analysis. After that, troubleshooting or replacement of defective components is undertaken. Upon completion of the repair, it is necessary to test the functionality of the system to ensure correctness, after which the wind turbine is put into operation.

Different measuring devices are used for precise monitoring of the operation of wind turbines. Electrical quantities are measured using digital multimeters, oscilloscopes, network analyzers, megohmmeters, wattmeters and frequency meters. Non-electric quantities are monitored using thermometers, thermal imaging cameras, anemometers, wind vanes, orientation sensors, vibration sensors and pyranometers.

Every performed visual inspection, preventive work or testing must be documented in the test protocol. This document contains basic information about the inspection, including the date and time of the inspection, the name of the wind farm and equipment information. It also contains a description of the observed problems, the measurements performed and the values of the measured parameters. Finally, the protocol provides recommendations for future maintenance activities, thus ensuring the long-term reliability and safety of system operation.

7.2. Preventive maintenance works of wind power plant elements

Preventive maintenance of wind farms is key to ensuring their long-term and reliable operation. These activities enable timely detection of potential problems and prevention of malfunctions that could lead to unplanned downtime or serious system damage.

Visual inspections represent the first step in preventive maintenance and are aimed at early detection of signs of wear, corrosion, deformations and other irregularities. During the inspection, the foundations are examined in order to detect any cracks or changes in the structure that could threaten the stability of the tower. The tower is checked for corrosion, mechanical damage and loose connections. The nacelle is analyzed for possible oil leaks, deformations and irregularities in the operation of mechanical components. The blades are examined for the presence of cracks, erosion and other mechanical damage that may affect their efficiency. The braking system is checked to ensure that it can stop the turbine in emergency situations. The transmission system is analyzed for possible problems with bearings and shafts, while the generator, electrical connections, cables and transformers are checked for possible breakdowns, interruptions in electrical connections and overheating.

Preventive works include lubrication of bearings and mechanical parts, replacement of worn or damaged parts, cleaning of elements, operation check and calibration of sensors, measuring devices and control systems, tightening of joints and contacts, and renewal of anti-corrosion coatings. All these activities are aimed at maintaining the system in optimal condition and extending its working life.

Preventive examinations of the condition of elements are essential for early detection of potential problems. Ultrasonic and vibration tests of blades enable the detection of internal damage that is not visible to the naked eye. Insulation, vibration and grounding tests of the generator ensure its safe and efficient functionality. Checking active alarms on the remote control system enables quick response in case of irregularities. Examining the transformer's insulation, oil condition, and noise helps assess its current condition and predict potential problems.



Preventive maintenance of the wind turbine

Safety measures when performing preventive maintenance include the use of protective helmets, gloves, safety glasses, safety belts and specialized clothing for working at height. In addition to personal protective equipment, collective protection measures such as protective fences and warning signs are also used. All measurements of electrical and non-electrical quantities are performed using appropriate measuring devices, under controlled conditions to ensure the accuracy of the results.



PRACTICAL EXERCISE

Task 1: Visual inspection of wind farm elements

Perform a visual inspection of the key elements of the wind farm in order to detect possible damages and irregularities.

Material and tools:

- Maintenance documentation,
- Inspection lamp,
- Camera for documenting damage,
- Protective equipment (helmet, gloves, safety belt).

Procedure:

1. Prepare inspection report and inspection plan.
2. Inspect the foundation, tower, nacelle and vanes for cracks, corrosion and deformation.
3. Inspect the braking system, transmission system, generator, cables and transformer for possible faults.
4. Document observations and prepare a report with recommendations.

Task 2: Measurement of electrical and non-electrical quantities

Perform measurements of the characteristic parameters of the wind power plant.

Material and tools:

- Digital multimeter,
- Anemometer,
- Thermal imaging camera,
- Measurement protocol.

Procedure:

1. Place the measuring devices at the appropriate points.
2. Measure voltage, current, frequency and power.
3. Measure the temperature of key components.
4. Enter the results in the measurement protocol and analyze the values.

These practical exercises can be carried out in cooperation with the local company that maintains the wind farm.

7.3. Corrective maintenance works of wind power plant elements

Corrective maintenance is carried out when a system failure occurs, and its goal is to quickly eliminate the malfunction and restore the wind farm to its correct operating condition. The most common causes of failure include mechanical damage to the blades due to extreme weather conditions, cable damage that can lead to power interruptions, automatic control system failures that affect the proper functioning of wind turbines, as well as the activation of protections that can shut down the system due to network instability.

Troubleshooting requires appropriate material resources, including replacement parts, electrical leads, fuses, sensors, lubricants, and specialized repair tools. Fault diagnosis includes the analysis of data from the remote monitoring system, the use of diagnostic devices for electrical and mechanical parameters, and a physical examination of the system to determine the cause of the problem. Once a fault is identified, its elimination is attempted, which may include repairing damaged components, replacing faulty elements, and retuning the automatic control system.



Examples of failures for corrective maintenance

After eliminating the fault, it is necessary to carry out a functional test and check the operation of all key elements. Electrical and mechanical components are tested using appropriate measuring devices, while safety systems are checked under controlled conditions to ensure that they respond correctly in the event of future problems. When all the tests confirm the correct operation, the wind turbine is put into operation again, with continuous monitoring of its parameters to ensure that there are no additional irregularities.

The combination of preventive and corrective maintenance ensures reliable operation of wind farms, reduces unplanned downtime and extends the life of key system components.



PRACTICAL EXERCISE

Task: Fault diagnosis

Identify system failure using diagnostic tools. Material and tools:

- Basic system documentation,
- Multimeter and oscilloscope,
- Protective equipment.

Procedure:

1. Collect failure data and review system errors.
2. Use a multimeter to check electrical parameters.
3. Analyze the results and identify the cause of the problem.

These practical exercises can be carried out in cooperation with the local company that maintains the wind farm

7.4. Maintenance works of electrical installations of wind power plants

Maintenance of electrical installations of wind power plants includes a series of activities aimed at ensuring the reliable and safe operation of power systems. Preventive maintenance of electrical installations includes inspection of all cables, connections and connections to detect possible damage or overloads. Regular cleaning and replacement of worn components reduce the risk of breakdowns and ensure power supply stability.

Special attention is paid to the maintenance of the grounding system and lightning protection. The correctness of the grounding, resistance to corrosion and the quality of the connections are checked, and any identified problems are immediately removed to ensure the safety of the system in the event of a lightning strike.

Preventive maintenance of the distribution cabinet and mains connection panel includes inspection of all electrical connections, replacement of worn fuses and testing of the functionality of protective devices. Any malfunction can cause system interruptions, therefore regular testing and maintenance is necessary.

Insulation and grounding resistance measurements are key steps in assessing the condition of electrical installations. These tests are performed using specialized devices such as megohmmeters and ground resistance testers, ensuring proper operation and reducing safety risks.

Eliminating faults in electrical installations involves precise diagnostics, replacement of faulty components and testing the functionality of the system before putting it back into operation. Any intervention must be carried out in accordance with safety standards to ensure reliability and safety of work.

These practical exercises can be carried out in cooperation with the local company that maintains the wind farm.



PRACTICAL EXERCISE

Task 1: Inspect distribution cabinets and cables to determine possible faults.

Material and tools:

- Installation documentation,
- Inspection lamp,
- Protective equipment.

Procedure:

1. Inspect the condition of joints, connections and protective devices.
2. Identify signs of overheating or mechanical damage.
3. Document findings and suggest necessary corrective measures.



QUIZ

Quiz 7: Maintenance of equipment in wind farms:

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

7.5. Collection, processing and storage of data in wind power plants

Monitoring and monitoring of system parameters in wind farms are becoming increasingly important segments in the renewable energy industry. The development of technology has enabled more accurate and reliable data collection, which improves the operation and efficiency of wind turbines, and at the same time optimizes their maintenance. The increasing use of smart sensors, analytical software and cloud solutions contributes to better control of plant operation and reduction of the risk of breakdowns.

It is expected that the demand for technicians specialized in data monitoring and analysis will increase significantly in the future. The role of these experts will be crucial in monitoring the performance of wind farms, implementing new technologies and improving operational efficiency. It is for this reason that this manual takes a brief look at monitoring systems and related technologies so that students/attendees can gain basic knowledge about this growing field.

Key elements of the parameter monitoring system and their role in plant operation:

Data Manager(Data Management Module)

- **Description:** A central device or software platform that enables the collection, processing and analysis of wind farm data.
- **Function:** Integration and management of data from sensors, weather stations, inverters and other system components. It also enables remote performance monitoring and fault detection.
- **Application:** It is used to optimize the operation of wind turbines, predictive maintenance and improve the efficiency of electricity generation.

Communication cable

- **Description:** Cable for data transmission between different wind farm components.
- **Function:** Enables the connection of sensors, Data Managers, servers and other monitoring and control systems. It can be optical or copper, depending on the system requirements.
- **Application:** Used for secure and reliable data transfer between wind turbines, meteorological stations, control systems and remote control centers.

Server

- **Description:** Centralized computer or cloud platform for storing and analyzing data from the wind farm system.
- **Function:** Archiving data, processing information and enabling remote access to users and operators. It can be a local server in the plant or a remote server in the cloud.
- **Application:** Used for long-term storage of operational data, analytics, report generation and system performance forecasting.

Wind farm management software

- **Description:** Comprehensive software solutions for management and optimization of wind power plants.
- **Function:** Data visualization, performance analytics and decision support for operators.
- **Application:** Used for real-time monitoring, maintenance planning and maximizing energy production.

Environmental monitoring systems

- **Description:** Systems for monitoring the environmental impact and conditions in the wind farm environment.

- **Function:** Monitoring noise levels, wildlife activity and habitat changes.
- **Application:** Ensures compliance with environmental regulations and reduces the environmental footprint of the wind farm.

A series of specialized equipment is used in wind power systems for data collection, processing and storage, which enables efficient system management, performance analysis and optimization of work. In addition to the Data Manager, communication cable and server, the following equipment is also used:

Sensors and measuring devices

- **Anemometer**– It measures wind speed, which is crucial for optimizing the operation of wind turbines.
- **Wind vane**– Shows wind direction and helps in automatic nacelle steering (yaw system).
- **Temperature sensors**- They monitor the temperature of the environment, generator, bearings and other components.
- **Vibration sensors**- They monitor the condition of bearings, rotors and other mechanical parts in order to detect possible failures.
- **Humidity and pressure sensors**– They are used to monitor weather conditions and protect equipment from corrosion.

Communication and network equipment

- **Industrial Ethernet Switch**- Enables connection of various components in the wind farm network, such as Data Manager, SCADA systems and server infrastructure.
- **4G/5G or satellite modems**- They enable remote communication between the wind farm and the operation center.
- **Optical or copper communication cables**– They are used for safe and fast data transfer between turbines, control systems and servers.
- **Wireless communication modules**- Enable data transmission via Wi-Fi, Zigbee or other wireless protocols within the wind farm.

SCADA (Supervisory Control and Data Acquisition) system

- **Description:** Software and hardware that enables remote monitoring and management of the wind farm.
- **Functions:**
 - o Collection of data from turbines and sensors in real time.
 - o Fault detection and performance analysis.
 - o Automatic optimization of system operation.
- **Application:** Enables centralized control of the operation of the wind farm from the command center.

Data storage and analysis systems

- **Data Logger**– A device that records data from sensors and measuring devices for later analysis.
- **Local servers**- They provide fast data processing and storage of operational information on site.
- **Cloud-based platforms**– They are used for long-term data storage, enabling analytics and predictive processing through AI algorithms.

UPS (Uninterruptible Power Supply) systems

- **Description:** Battery or generator systems that provide uninterrupted power to key communication and control equipment in the event of a power failure.
- **Function:**
 - o Protects data and systems from data loss due to power failure.
 - o Maintains continuity of operation of server and SCADA systems.

Cybersecurity equipment and software

- **Firewall devices**- They provide protection of the wind farm network against cyber attacks.
- **VPN (Virtual Private Network) systems**- Enable secure remote access to data and wind farm systems.
- **Antivirus and IDS/IPS**(Intrusion Detection/Prevention Systems) – Prevent unauthorized access and security incidents.

Cameras and security systems

- **Thermal cameras**– They are used to detect overheating or other anomalies in the equipment.
- **IP surveillance cameras**- They enable the monitoring of wind turbines and the protection of wind farm facilities.
- **Drones with cameras and sensors**– They are used to inspect blades, supports and other hard-to-reach parts of turbines.

8. CONCLUSION AND RECOMMENDATIONS

Installation and maintenance of power equipment in wind farms is a key segment in the development and application of renewable energy sources. This manual enables the acquisition of the necessary knowledge and practical skills that are essential for quality and safe performance of work in this area.

Through consideration of the theoretical foundations, technical characteristics of wind power plants, the specifics of assembly and disassembly of power equipment, as well as through a detailed presentation of safety and protection measures at work, users are trained for safe and efficient work in the wind energy sector. Also, special attention is paid to preventive and corrective maintenance, which extends the life of the system and ensures the reliability of its operation.

The future of power systems is based on the increasing use of renewable energy sources, and wind farms play a central role in that process. The development of new technologies, increasing the efficiency of the system and improving security procedures open wide opportunities for progress and professional development in this area. Therefore, continuous education, monitoring of innovations and adoption of modern work techniques are imperative for everyone who wants to be part of this perspective sector.

The importance of education in the field of wind energy cannot be emphasized enough, given that the demand for experts in this field is growing rapidly. The global trend of switching to renewable energy sources creates a huge need for a qualified workforce that can successfully meet the technical and operational challenges of installing, maintaining and managing power equipment in wind farms. Workers with specialized knowledge in this area will not only be in demand on the domestic market, but will also have opportunities to work in international projects around the world.

Therefore, educational programs and professional trainings become a key factor in training a new generation of technicians and engineers who will play a key role in the further expansion of wind farms. Proper education not only contributes to the professional development of an individual, but also increases the safety and efficiency of work, reducing risks and raising industry standards.

This manual not only provides basic knowledge, but also motivates users to explore further, develop critical thinking and actively participate in the advancement of the wind energy industry. Their role in preserving energy stability, protecting the environment and applying innovative solutions will be of crucial importance in the coming years.

We hope that this material will serve as a safe basis for the successful application of acquired knowledge and skills and contribute to the further development of renewable energy sources.

Literature and used sources

- Ackermann, T. (2012). *Wind Power in Power Systems*. John Wiley & Sons.
- Barac, K., Radić, L. (2006). *Safety and health when working on electric power facilities with reference to European standards*. EDB, Belgrade.
- Boyle, G. (2004). *Renewable Energy: Power for a Sustainable Future*. Oxford University Press.
- Burton, T., Sharpe, D., Jenkins, N., & Bossanyi, E. (2011). *Wind Energy Handbook*. John Wiley & Sons.
- Čalasan, M., Čalasan B. (2013). *Electrical installations and lighting*. Institute for textbooks and teaching aids, Podgorica.
- Čalasan, M., Čalasan B. (2015). *Electrical installations and lighting*. Institute for textbooks and teaching aids, Podgorica.
- Freris, L., & Infield, D. (2008). *Renewable Energy in Power Systems*. John Wiley & Sons.
- Gasch, R., & Twele, J. (2011). *Wind Power Plants: Fundamentals, Design, Construction and Operation*. Springer.
- Gippe, P. (2004). *Wind Power: Renewable Energy for Home, Farm, and Business*. Chelsea Green Publishing.
- Howe, E. (2013). *Wind Turbines: Fundamentals, Technologies, Application, Economics*. Springer.
- Heier, S. (2014). *Grid Integration of Wind Energy: Onshore and Offshore Conversion Systems*. John Wiley & Sons.
- Janković, S. (2019). *Electric power systems and renewable sources*. University of Belgrade.
- Lekić, M. (2017). *Renewable energy sources*. University of Montenegro.
- Manwell, JF, McGowan, JG, & Rogers, AL (2010). *Wind Energy Explained: Theory, Design and Application*. John Wiley & Sons.
- Mathew, S. (2006). *Wind Energy: Fundamentals, Resource Analysis and Economics*. Springer.
- Milovanović, Z. (2021). *Technical regulations in the power industry*. Faculty of Civil Engineering, Belgrade.
- Rajković, D. (2011). *Energy production and conversion*. Zagreb.
- Ristić, B. (2018). *Basics of electrical engineering with application in renewable energy sources*. University of Nis.
- Stevanović, V. (2020). *Wind power plants - design and implementation*. Academic book, Novi Sad.
- Škuletić, S., Braletić, M. (2022). *Introduction to energy, textbook*. Institute for textbooks and teaching aids, Podgorica.
- Škuletić, S., Sekulić, Z. (2019). *Electricity production, textbook*. Institute for textbooks and teaching aids, Podgorica.

Organizations and standardization sources:

- European Wind Energy Association (EWEA) – www.ewea.org
- Global Wind Energy Council (GWEC) – www.gwec.net
- IEEE Power & Energy Society - www.ieee-pes.org
- International Electrotechnical Commission (IEC) – www.iec.ch
- International Electrotechnical Commission (IEC). (2019). IEC 61400-1: Wind Turbines - Design Requirements
- International Energy Agency, Paris, France. (2017). World Energy Outlook Special Report
- International Renewable Energy Agency (IRENA) – www.irena.org
- Occupational Safety and Health Administration (OSHA). (2017). Guidelines for Wind Energy Workers - Safety and Best Practices
- Working from a height; General measures for safety and health at work during work at height Instructions for work at height and working platforms: UBR.11. 01/2015; I-1, R-0:
- VDE - Association for Electrical, Electronic & Information Technologies – www.vde.com
- <https://ieeexplore.ieee.org/document/8467935>
- <https://www.energyencyclopedia.com/>
- <https://www.engie.com/en/activities/renewable-energies/wind-energy/recycling-wind-turbines>
- <https://epa.org.me/wp-content/uploads/2023/09/DOKUMENTACIJA-ZA-ODLUCIVANJE-O-POTREBI-IZRADE-ELABORATA-PROCIJENE-UTICAJA-NA-ZIVOTNU-SREDINU.pdf>
- <https://univdatos.com/news/offshore-wind-market-2>
- https://labvolt.festo.com/solutions/3_fluid_power/89-8075-50_wind_turbine_training_system
- <https://www.extrica.com/article/20178>
- <https://www.windsystemsmag.com/maintaining-a-maintenance-plan/>

Sites from which images were downloaded:

- European Network for Renewable Energy Sources (EU Renewable Energy Network) - www.eurener.org
- Global Wind Atlas - www.globalwindatlas.info
- National Renewable Energy Laboratory (NREL) – www.nrel.gov
- Pexels – www.pexels.com
- PTRK – Telescopic crawler cranes <https://www.prangl.com/services/mobile-cranes/telescopic-crawler-cranes>
- Renewable Energy World - www.renewableenergyworld.com
- Unsplash – www.unsplash.com
- Wikimedia Commons – www.commonswikimedia.org
- WindEurope – www.windeurope.org
- <https://www.innotech-safety.com/en/safety-systems-wiki/renewable-energy-and-fall-protection-systems>
- <https://www.energyencyclopedia.com/en/renewable-energy/wind-energy>
- <https://read.aviationnewsjournal.com/articles/windrunner-aims-to-transform-wind-turbine-transport>
- <https://en.wind-turbine-models.com/fotos?p=50>
- <https://businessinwind.com/gamesa-versus-vestas-ireland/>
- <https://www.prangl.com/services/mobile-cranes/telescopic-crawler-cranes>
- <https://elektrovat-enel.rs/shop/page/4/>

Links to suggested video material

- <https://www.youtube.com/watch?v=8sPp8G8a48E>
- <https://www.youtube.com/watch?v=nA9oC--tq50>
- https://www.youtube.com/watch?v=qSWm_nprfqE
- <https://www.youtube.com/watch?v=HqCVgRbPQcg>
- https://www.youtube.com/watch?v=fl6BMVw_B-Y
- <https://www.youtube.com/watch?v=vjqdJ8OSmRA>
- <https://www.energyencyclopedia.com/en/free-downloads/videos/types-of-res-and-the-use-of-renewable-56>
- <https://www.energyencyclopedia.com/en/free-downloads/videos/comparison-of-renewable-energy-source-55>
- <https://www.youtube.com/watch?v=bNBQKIht6rg>
- <https://www.engie.com/en/activities/renewable-energies/wind-energy/recycling-wind-turbines>
- https://labvolt.festo.com/solutions/3_fluid_power/89-8075-50_wind_turbine_training_system
- <https://www.energyencyclopedia.com/>



