



**CZECH TECHNICAL UNIVERSITY IN PRAGUE**

**Faculty of Electrical Engineering**

**Power Engineering Department**

**Distribuční sítě s rozptýleným zdroji**

**Distribution systems with renewable sources**

Bachelor's Thesis

Study program: Electrotechnika, energetika a management

Specialization: Applied Electrical Engineering

Supervisor: Ing. František Vybíralík, CSc.

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Czech Technical University in Prague  
Faculty of Electrical Engineering

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# BACHELOR PROJECT ASSIGNMENT

Student: **Dauren Karimov**

Study programme: Electrical Engineering, Power Engineering and Management  
Specialisation: Applied Electrical Engineering

Title of Bachelor Project: **Distribution system with renewable energy sources**

Guidelines:

- 1) General information on distributed energy sources, types of power plants utilizing renewable energy sources, specifically photovoltaic power plants.
- 2) Describe the rules for connecting dispersed energy sources to the distribution system.
- 3) A case study for the selected part of the medium voltage distribution system.

Bibliography/Sources:

- [1] Distribution network codes.
- [2] eVlivy application manual.
- [3] SCHLABBACH, J, BLUME a T STEPHANBLOME. Voltage quality in electrical power systems. London: Institution of Electrical Engineers, c2001, x, 241 p. IEE power and energy series, 36. ISBN 978-085-2969-755.

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Prague, February 20, 2017

**Declaration**

I hereby declare that this thesis is the result of my own work and all the sources I used are in the list of references, in accordance with Methodological Instructions of Ethical Principle in the Preparation of University Thesis.

In Prague, 26.05.2017

Signature.....

### **Acknowledgement**

I would like to thank everyone that were involved in the development of this thesis, especially my supervisor Ing. František Vybíralík, CSc. and Ing. Jan Kyncl, Ph.D. for their continuous guidance and support, also E-Vlivy for the experience and knowledge it has given me on Distribution Power Systems.

### **Abstract**

This thesis is about the general information on distributed energy sources, types of power plants, specifically photovoltaic power plants (constraints, laws, standards and requirements), the rules for connecting dispersed energy sources to the distribution system, voltage characteristics before and after connection to a consumption network.

### **Key Words**

Distribution system, generation, power plants, solar cells, renewables, power quality.

### **Abstrakt**

Tato práce pojednává o obecné informace o distribuovaných energetických zdrojů, typů elektráren, zejména fotovoltaických elektráren (jeho omezení, zákonů, norem a požadavků), pravidla pro připojení rozptýlených zdrojů energie k distribuční soustavě, charakteristika napětí před a po připojení k spotřeba sítí.

### **Klíčová slova**

Distribuční soustava, generace, elektrárny, solární články, obnovitelné zdroje, kvalita elektrické energie.

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# **1 Introduction:**

## **1.1 Distributed power (DP) generation.**

Nowadays energy is playing one of the main parts in people life. Humanity has traveled the path from bonfire to nuclear power plants. Today, the world's energy sector is based on non-renewable sources of energy. The main energy carriers are oil, gas and coal. Scientists warn of the possible exhaustion of resources such as oil and gas, the depletion of other important resources: iron and copper, nickel, manganese, aluminum, chromium, etc. For half a century after the Second World War, mankind used as much mineral raw materials, as in the entire previous history. Of course, it is too early to talk about the complete depletion of resources, but we are already looking for ways to solve this problem. One of them is the usage of alternative energy sources, which due to their renewability and that it is environmentally friendly. Such sources include: solar energy, wind energy, hydro, geothermal plants, tidal and wave energy conversion, fuel cell, solar-thermal-electric conversion, biomass utilization thermoelectric and thermionic, etc.

Distributed generation most commonly involves solar photovoltaic, but can also include small hydroelectric, small-scale biomass facilities, and micro-wind.

## **1.2 Advantages and disadvantages of DP:**

The bulk of the economic benefits of widely distributed, locally controlled, and locally produced clean energy can go directly to ratepayer-generators and property owners through mechanisms such as the feed-in tariff, a generous per-kilowatt-hour payment made to taxpayers who generate clean power on their homes and businesses. Because of local redundancies and geographic diversity, a well-designed local grid with distributed power production and adequate storage can reliably provide critical energy in times of emergencies with less disruption and pollution than conventional solutions. Perhaps most importantly, millions of acres of healthy, intact ecosystems are left undisturbed when generation is sited within the built environment.

Extent and growth are not captured properly in energy statistics. This is due mainly to the smaller size and the more distributed nature of renewable installations compared to fossil ones. Renewable energy generated and consumed at the residential level is often not measured, because it does not feed into the power grid, is not part of a larger heating system, or is sourced outside formal markets. As all these factors imply, measuring the contribution of renewable energy sources is more complicated, and the resulting statistics more uncertain

# **Types of renewable energy sources**

## **2 Solar energy:**

Solar energy is the energy produced from the sun. The sun has produced energy for billions of years. It is the most important source of energy for all life forms. It is counted as a renewable source of energy opposed to fossil fuels, which are non-renewable sources. Solar energy technologies use the sun's energy to light and heat homes, produce hot water and electricity.

On average, sun irradiates on the every square meter of Earth's surface approximately 164 [W] of solar energy. In other words, we could put some device, such as table lamp on every square meter of Earth and light up the whole planet's surface with this energy. The energy of the Sun arrives on Earth as a mixture of light and heat, but the point is that we cannot directly use either of them to run a machine or device. We have to find some way of converting solar energy into other forms of energy, such as electricity, that we can use more easily. And that's exactly what solar cells are used for.

**2.1 The photoelectric effect** is the phenomenon of the emission of electrons under the action of light. It was discovered in 1887 by G. Hertz, who discovered that a spark discharge can occur in the air gap when it is close to a different spark discharge. Hertz experimentally showed that this is due to ultraviolet radiation of the second order. In 1889, J. Thomson and F. Lenard found that when illuminated in a pumped-out vessel, it emits electrons. Continuing these studies, Lenard demonstrated in 1902 that the number of electrons emitted from the metal is proportional to the intensity of light, at the moment when their energy depends only on the light wavelength, i.e. colors. These facts contradicted the conclusions of Maxwell's theory of the mechanism of emission and absorption of light. According to this theory, the intensity of light serves as a measure of its energy and, of course, it must influence the energy of the emitted electrons. [14] Under certain conditions, the photoelectric effect is possible in gases and atomic nuclei, from which photons with a sufficiently high energy can knock out protons.

## **2.2 Solar cell:**

A solar cell is a solid-state electrical device which directly converts sunlight into electricity. Incident light on the solar cell produces both a current and a voltage in order to generate power. This process needs the next criteria: first of all, a material in which the absorption of light excites an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. After that, the electron loses its energy in the external circuit and goes to the solar cell. In practice nearly all photovoltaic energy conversion uses semiconductor materials that have a p-n junction. This junction is formed by joining p-type (high concentration of hole or deficiency of electron) and n-type (high concentration of electron) semiconductor material. Because of this junction, excess electrons from n-type try to diffuse with the holes of p-type whereas excess hole from p-type try to diffuse with the electrons of n-type. The movement of electrons to the p-type side exposes positive ions in the n-type side, while the movement of holes to the n-type side exposes negative ion cores in the p-type side, resulting in

an electric field at the junction and forming the depletion region

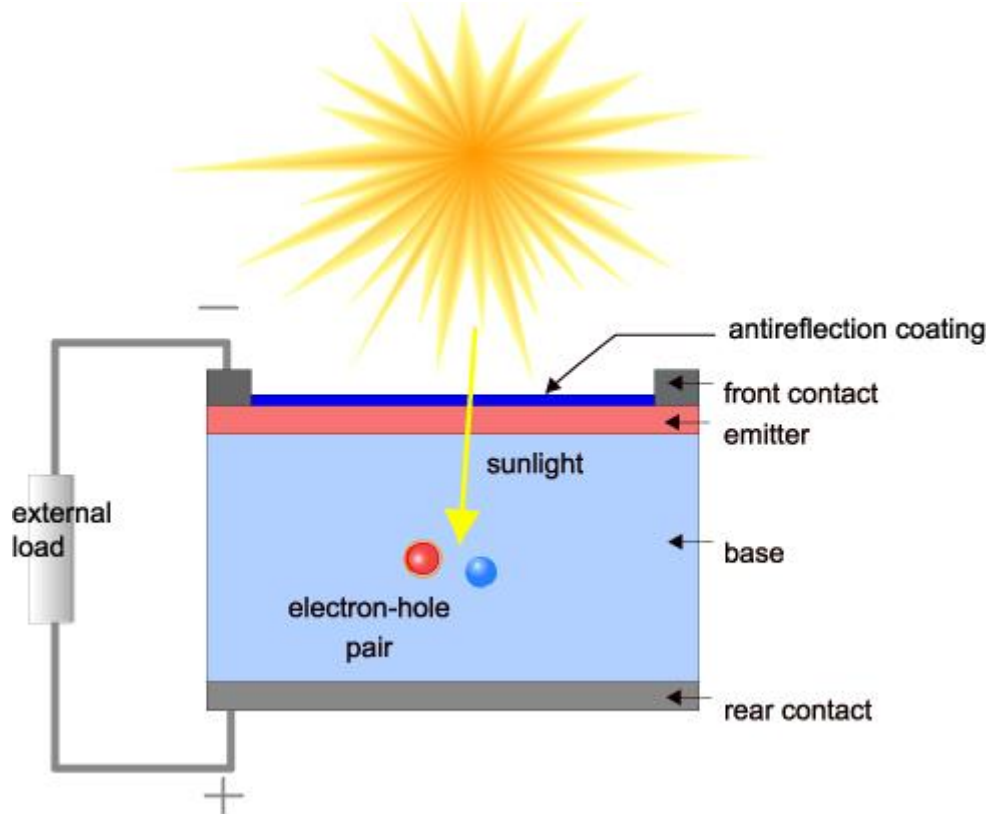


Figure 1.1: Cross section of a solar cell.

### **Diode equation:**

The diode equation gives an expression for the current through a diode as a function of voltage.

The "Ideal Diode Law" expressed as:

$$I = I_0 \left( e^{\frac{qV}{kT}} - 1 \right)$$

(1)

$I$  = the net current flowing through the diode.

$I_0$  = "dark saturation current", the diode leakage current density in the absence of light.

$V$  = applied voltage across the terminals of the diode.

$q$  = absolute value of electron charge.

$k$  = Boltzmann's constant.

$T$  = absolute temperature (K).



### Non-Ideal Diodes:

For actual diodes, the expression becomes:

$$I = I_0 \left( e^{\frac{qV}{nkT}} - 1 \right)$$

Where:

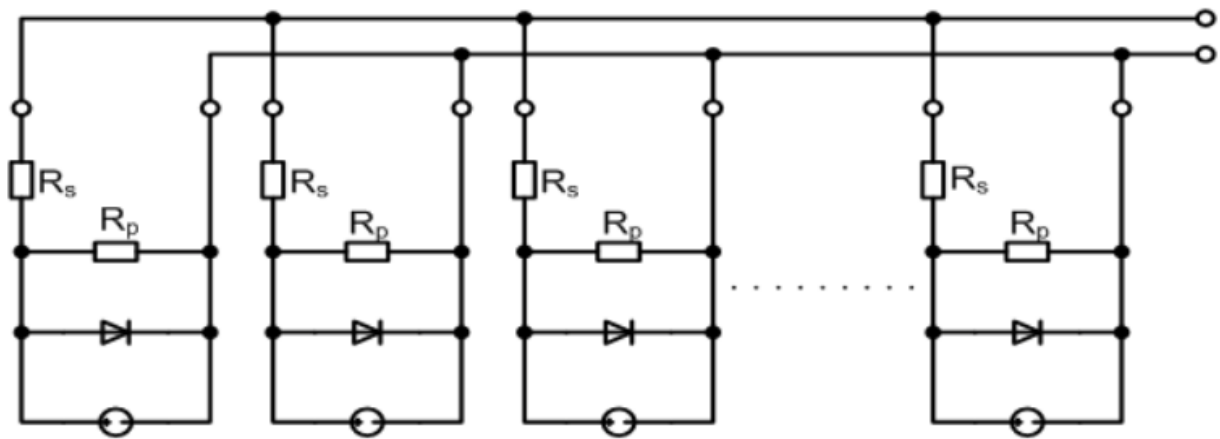
$n$  = ideality factor, a number between 1 and 2, which typically increases as the current decreases.

### Cells in parallel

#### **Parallel wiring:**

For practical use it is necessary to have cells in series connection to obtain a source of a higher voltage.

All cells have same voltage, currents sum up (*Figure 1.3*).



*Figure 1.2: cells in parallel*

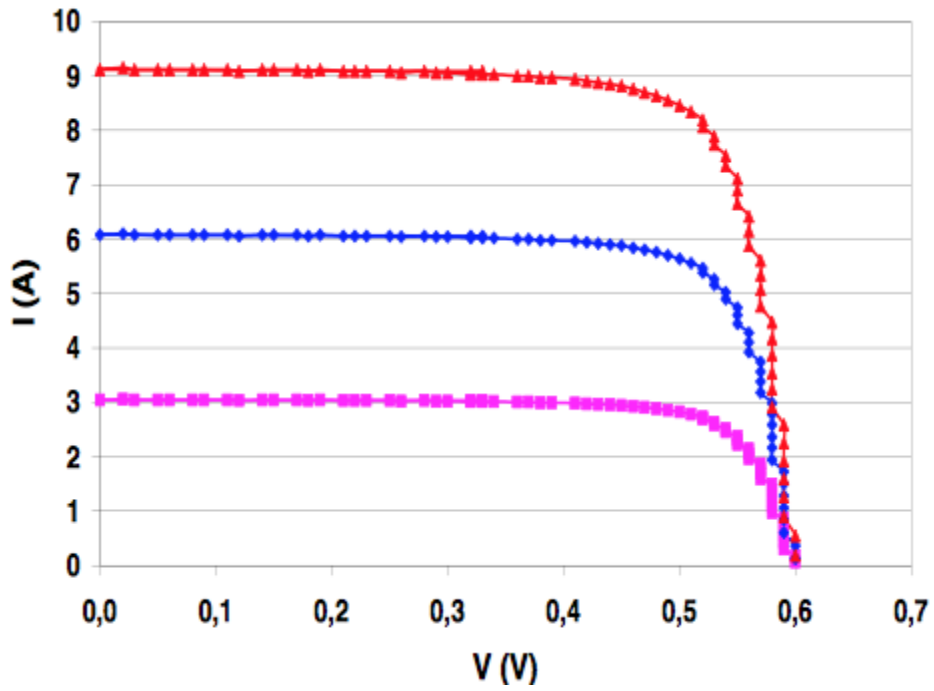


Figure 1.3: I-V curves stack on each other.

**Cells in series:**

**Series wiring:**

Parallel connection increases the output of a current (amperes) whereas keeping voltage the same. All cells have same voltage, currents sum up. (Figure 1.5)

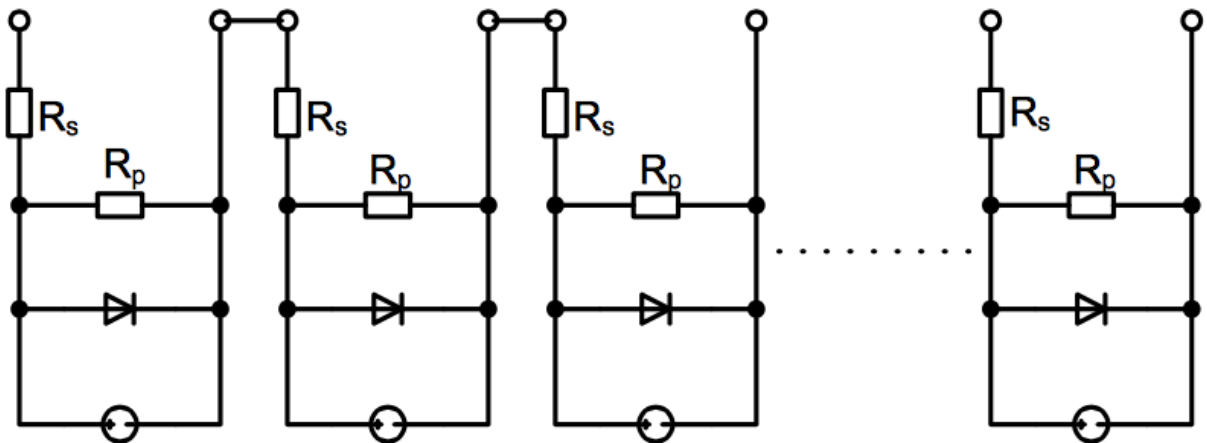


Figure 1.4: cells in series

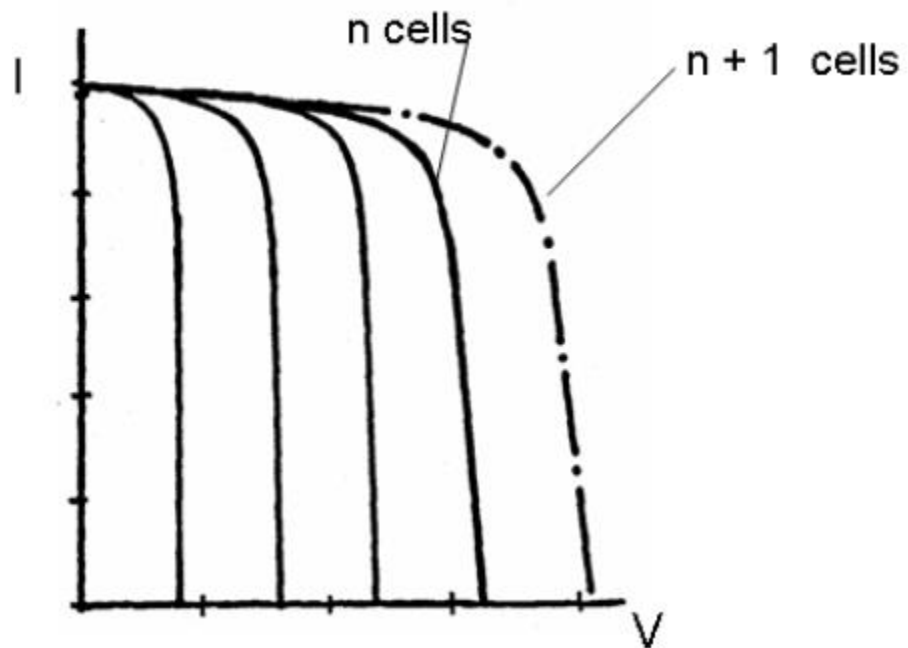


Figure 1.5: I-V curve of series wiring.

### **2.3 Working principles of solar cell:**

The energy conversion in a photoconductive device is based on the photoelectric effect that occurs when solar radiation is exerted on inhomogeneous semiconductor structures. The heterogeneity of the Semiconductor Photoelectric Converters (SPC) structure can be obtained by doping the same semiconductor with various impurities (creating pn junctions), or by joining different semiconductors with an unequal band gap-the electron detachment energy from the atom (creating heterojunctions). The conversion efficiency depends on the electrophysical characteristics of the inhomogeneous semiconductor structure, as well as the optical properties of the photoconductivity, among which photoconductivity plays the most important role.

## **2.4 Types of solar cells:**

### **Monocrystalline silicon:**

The most effective and widespread for general consumption are monocrystalline silicon elements. For manufacturing such elements, the silicon is purified, melted and crystallized in ingots, from which thin layers are cut off. Externally, single-crystal elements look like a monochromatic surface of dark blue or almost black color. There is a grid of metal electrodes going through the silicon. The efficiency of this element is from 16 to 19% under standard testing conditions (direct sunlight, +250 °C). The lifetime of such panels is usually 40-50 years. The productivity for every 20-25 years of service is gradually reduced by about 20%

### **Polycrystalline silicon:**

The technology is not fundamentally different from monocrystalline elements, but the difference is that the silicon which is used for manufacturing is less pure and cheaper. The surface is not monotonous, it has a pattern of many crystals. The efficiency of this element is from 14 to 15%.

### **Ribbon silicon:**

Generally speaking, ribbon silicon is the same as the aforementioned types, but is different only by the fact that the silicon is not cut from the crystal, but is built up by a thin layer in the form of a tape. Anti-reflective coating gives an iridescent color to such panels.

### **Amorphous silicon:**

In this type, crystals are not used, but the thinnest layers of silicon sputtered in vacuum onto plastic, glass or metal. This type is the cheapest in production, but has a serious drawback. The layers of silicon burn out in the light much faster than the previous types. Decrease in productivity by 20% can happen in two months.

### **Cadmium tellurium (CdTe):**

This type of thin-layer solar cells has a potentially greater efficiency and uses tin oxide as a conductive component. The efficiency is 8-11%. These elements are not much cheaper than mono- and polycrystalline silicon and have the problem of containing cadmium, which is toxic.

## **2.5 Concentrated solar power (CSP):**

### **Solar Tower (ST):**

These power plants are based on the principle of obtaining water vapor using solar radiation. There is a tower in the center of the station with a height of 18 to 24 meters (depending on the power and some other parameters, the height can vary), on top of which there is a reservoir of water. This reservoir is covered in black to absorb heat radiation. Also in this tower is a pumping group that delivers steam to a turbogenerator that is outside the tower. Around the tower, heliostats are located at some distance. Heliostat is a mirror with an area of several square meters, fixed on a support and connected to a common positioning system. Depending on the position of the sun, the mirror will change its orientation in space. The main and most time consuming task is to position all mirrors of the station so that at any time all the reflected rays from them hit the tank. During a clear sunny weather, the temperature in the tank can reach 700°C. Such temperatures are used in most conventional thermal power plants, so standard

turbines are used to generate energy. In fact, these stations can reach a relatively high efficiency (about 20%) and a high power.



*Figure 1.6: Solar tower.*

### **Solar Dishes (SD):**

This type uses the principle of generating electricity, similar to ST, but there are differences in the design of the station itself. The station consists of separate modules. The module consists of a support on which the truss structure of the receiver and reflector is attached. The receiver is at some distance from the reflector, and the reflected rays of the sun are concentrated in it. The reflector consists of mirrors in the form of plates (hence the name), radially located on the farm. The diameters of these mirrors reach 2 meters, and the number of mirrors is several tens (depending on the power of the module). Such stations can consist of either one module (standalone) or several dozen (work in parallel with the network).



*Figure 1.7: Solar dishes.*

### **Parabolic trough (PT) :**

Parabolic troughs work on the principle of heating of the coolant to suitable parameters so that a turbogenerator can be used. PT construction: a parabolic mirror of a large length is installed on a truss structure, and a tube is installed in the focus point of the parabola, along which the coolant flows (most often oil). Passing all the way, the coolant warms up and the heat exchanger heats the water, which turns into steam and goes to the turbogenerator.



*Figure 1.8: Parabolic trough.*

## **2.6 Solar collectors:**

Solar collectors are devices designed to collect the heat energy of the Sun. Unlike solar panels that produce electricity directly, the solar collector generates heat-transfer material. There are several types of solar collectors. Among them: flat, vacuum and focused collectors-concentrators.

### **Flat collector:**

A flat collector consists of an element absorbing solar radiation, a transparent coating and a thermal barrier layer. The absorption element is called the absorber. It is connected with the heat-conducting system. A transparent element is usually made of tempered glass with a low metal content. Flat collectors are able to heat water up to 190-200 °C. The more incident energy is transferred to the heat carrier flowing in the collector, the higher is its efficiency. The efficiency can be increased by applying special optical coatings that do not radiate heat. The standard solution to improve the efficiency of the collector is the use of an absorber from copper sheet because of its high thermal conductivity.

### **Advantages:**

- High efficiency at summer;
- Relatively simple design, ability to install from any angle
- Excellent price / performance ratio for southern latitudes and warm climate
- Possibility of effective operation throughout the year; the ability of self clearing from snow and frost

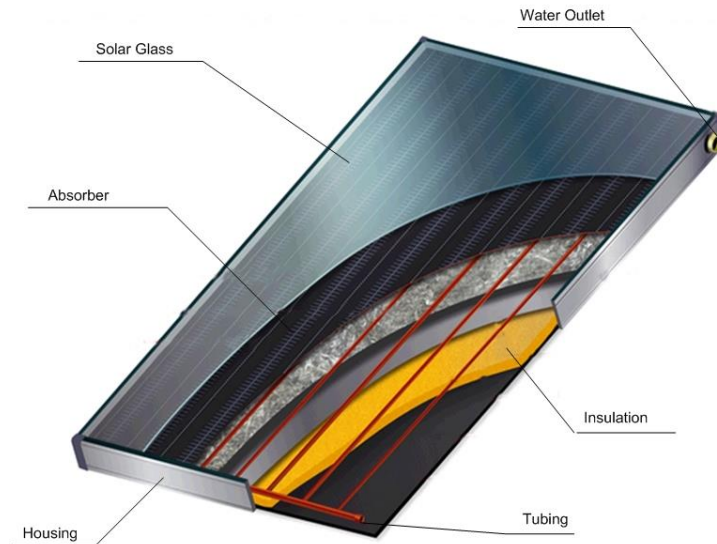
-Long service life.

**Disadvantages:**

-High heat losses

-Low working capacity in the cold season

-The complexity of installation, associated with the need to deliver to the roof of the collected reservoir



*Figure 1.9: Flat collector.*

**Vacuum collector:**

The main component of the vacuum tubular solar collector is the glass vacuum tubes. Each vacuum tube consists of two glass tubes. The outer tube is made of transparent heavy-duty borosilicate glass, which withstands the impact of hail with a diameter of 25 mm. The inner tube is also made of transparent borosilicate glass coated with a special selective coating that provides heat absorption with minimal reflection. In order to avoid heat losses, air is evacuated from the space between the two pipes and a vacuum is created. The cylindrical absorber allows capturing and the use of diffused solar energy three times more effectively in comparison with flat solar collectors.

**Advantages:**

-Low heat loss

-Working capacity in the cold season up to 30°C

-Ability to generate high temperatures

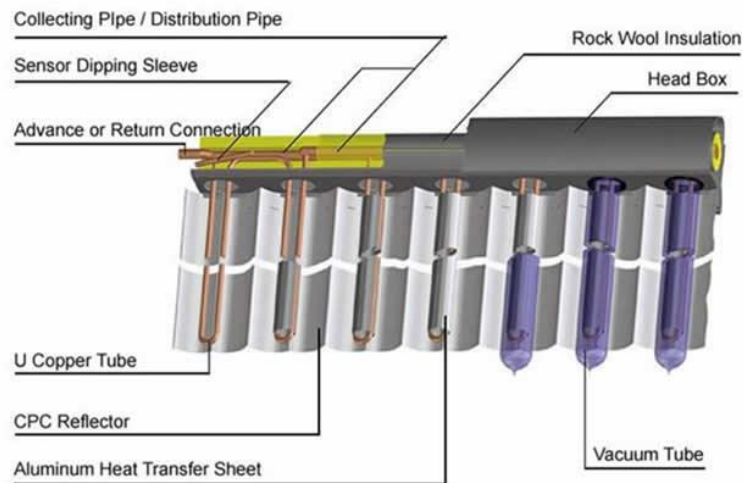
-Long period of work during the day

-Easy installation

-Excellent price / performance ratio for temperate latitudes and cold climates

**Disadvantages:**

- Inability to self-clean from snow
- Relatively high initial cost of the project
- Working angle not less than 20°



*Figure 1.10: Vacuum collector.*

**Focused collectors:**

Focused collector-concentrators use mirror surfaces for the concentration of solar energy on the heat receiver. The temperature reached by them is much higher than on flat collectors. However they can concentrate only direct solar radiation, which leads to poor indicators in foggy or cloudy weather. Hubs work best when they face the Sun. Tracking devices are used, for turning the collector towards the Sun during the day. To accurately concentrate the direct stream of parallel rays, the reflecting surface in the section must have the form of a regular parabola. If large lenses made of a thick layer of glass are used as concentrators for solar radiation, then they will be heavy and very expensive, so usually Fresnel lenses are used for this purpose, in which the profile of grooves, like those of plates, is obtained by embossing.

**Advantages:**

- Installation of the axis of the parabolic-cylindrical mirror along the "east-west" axis. If you fix the angle of inclination in accordance with the movement of the Sun by the seasons, then the need for hourly tracking of the Sun will disappear and it will be necessary to manually change the angle of inclination in accordance with the season.
- The interior of the mirror image is deeper than the paraboloid, which increases the area of the heat-sensing surface, meaning that all the sun's rays diverging from the main axis fall on the same point on the surface.

**Disadvantages:**

- Focusing collectors are much more expensive than flat ones



- For heating and cooling systems, as well as hot water supply of houses, high temperatures are not needed, therefore, these advantages are not realized in this case
- Collectors with concentrators collect only direct solar radiation, since only parallel beams can be concentrated in this way; these collectors do not focus scattered radiation.

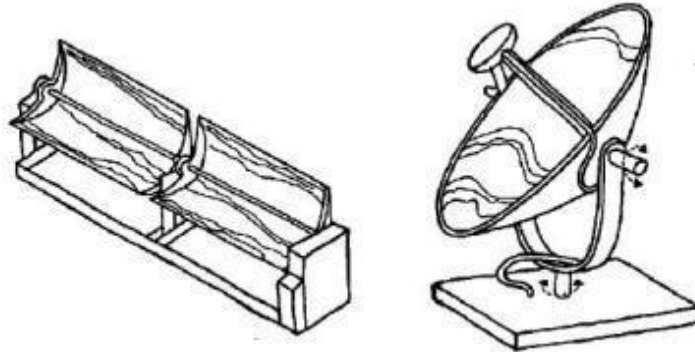


Figure 1.11: Focusing collector.

### **3 Wind energy**

Wind energy is an energy sector specializing in converting the kinetic energy of air masses in the atmosphere into electrical, mechanical, thermal or any other form of energy. Such conversion can be carried out by such units as a wind generator (for generating electric power), a windmill (for conversion into mechanical energy), a sail (for use in transport), and others.

Wind energy refers to renewable energy, since it is a consequence of the activity of the Sun. Some countries in particular, are developing wind power intensively. Large wind power plants are included in a common network; smaller ones are used to supply electricity to remote areas. Unlike fossil fuels, wind energy is almost inexhaustible, universally available and more environmentally friendly.

#### **3.1 Working principle:**

The principle of operation of a wind power plant is based on the conversion of wind energy into rotational motion of a turbine. This happens with the help of blades (rotor). The wind follows the contour of the blade, leading them into rotation. Modern wind power stations have three blades. Their length can reach 56 meters. The speed of rotation is within the range of 12-24 rpm. Gearboxes are used to increase the speed of rotation. The capacity of modern wind generators can reach 750 [kW].

#### **3.2 Components of wind turbine:**

-A wind turbine installed on a mast, with extensions and a rotor or blades.

-Power generator.

The received electric power is supplied to:

-The battery charge controller connected to the batteries (usually for 24 [V]).

-The inverter (=24 [V] -> ~ 220 [V] 50 [Hz]) connected to the circuit.

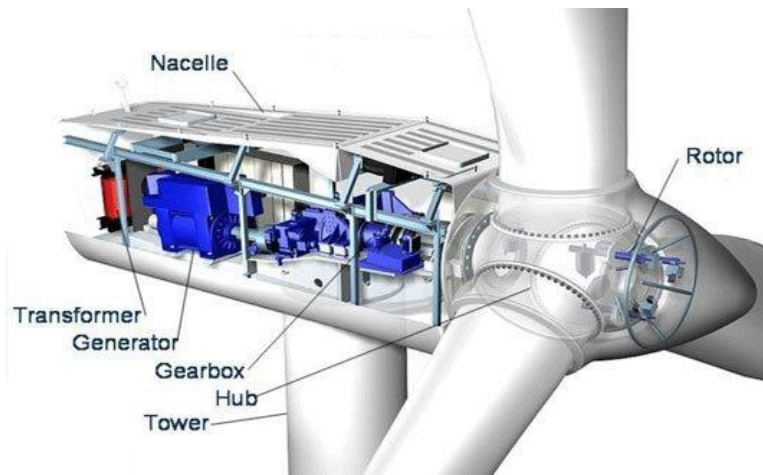


Figure 2.1: Wind power plant components.

- The rotor converts wind energy into rotational energy. Most modern rotors of wind turbines consist of three blades.
- Nacelle - located atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake assembly.
- Gear box: connects the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 30 – 60 rotations per minute (rpm), to about 1000 – 1800 rpm; this is the rotational speed required by most generators to create electricity. The gear box is a costly, heavy part of the wind turbine and engineers are exploring “direct-drive” generators that operate at lower rotational speeds and do need gear boxes.
- The generator uses magnetic fields to convert the resulting rotational energy into electrical energy.
- The tower of the wind generator is made of steel pipes, although trellised towers are still used in some countries. The towers for modern wind farms can be from 60 meters to 100 meters in height.
- The transformer converts the voltage that is required for the electrical network. The transformer can be built into the tower or located at the base of the tower.
- The hub consists of two parts – hub housing and a pitch system.
- Hub housing – blades of wind turbine are mounted on hub housing for structural strength, making the equipment lighter in terms of total weight
- Pitch system: turns the blades out of the wind to control the rotor speed, and to keep the rotor from turning in winds that are too high or too low to produce electricity.
- An anemometer and a weather vane are located on the rear side of the wind turbine housing and the wind speed is measured. The collected information is used by the control system in order to generate the maximum amount of energy. These wind speeds are also used to monitor the operation and allow the operating system to start and stop the turbine. A modern wind power plant starts generating power at a wind speed of 4 [m/s] and stop at a speed of about 25 [m/s]. The yaw mechanism rotates the rotor into the prevailing wind direction.

### **3.3 Types of wind turbines:**



Figure 2.2: a) Horizontal axis wind turbine; b) Vertical axis wind turbine.

### **Horizontal axis wind turbine (HAWT) (Figure 2.1a)**

Wind turbines with a horizontal axis of rotation can use lifting force or resistance force to convert wind energy. Devices using the lifting force are preferable because they can develop a greater force by several times than devices with direct action of the resistance force. The latter, cannot move at a speed exceeding the speed of the wind. Due to this, the blades on which the lifting force acts (the wind wheel) can be more rapid (speed - the ratio of the circumferential velocity of the surface element to the wind speed) and have a better power-weight ratio at a lower cost per unit of installed capacity. A wind wheel can be made with a different number of blades. From single-bladed wind generators with counter-loads to multi-bladed (with a number of blades up to 50 and more). Wind wheels with horizontal axis of rotation are sometimes fixed in one direction, i.e. they cannot rotate about a vertical axis perpendicular to the direction of the wind. This type of wind turbines is used only in the presence of a single, dominant wind direction. In most cases, the system on which the wind wheel (so called the head) is mounted, is made rotary, orienting in the direction of the wind. Tail units are usually used for small wind generators, while for large ones, electronics control the orientation. To limit the speed of the wind wheel at high wind speed, there is a number of methods, including the installation of blades in the vane position, the use of valves mounted on or rotated with the blades, as well as devices for removing the wind wheel from the wind with a side plan located parallel to the plane of rotation of the wheel.

### **Vertical axis wind turbine (VAWT) (Figure 2.1b)**

Wind turbines with a vertical axis of rotation with such rotors have important advantages over wind turbines with a horizontal axis arrangement. They do not need the orientation to the wind, the structure is simplified, and gyroscopic loads are reduced, causing additional stresses in the blades, transmission system and other elements of installations with a horizontal axis of rotation. These devices include devices with plates, cup-shaped or turbine elements, as well as Savonius rotors with S-shaped blades, which are also acted upon by the lifting force. Devices of this type have a large initial moment, but less speed and power compared to a conventional rotor.

In 1920, in France, Darrieus proposed a new type of rotor, which has been intensively developed since 1970. The Darrieus Rotor refers to wind generators using a lifting force that appears on curved blades with a wing profile in cross section. The rotor has a relatively small initial moment, and a high speed, due to this, a relatively large specific power, attributed to its mass or cost. Such rotors have different shapes ( $\Phi$ -,  $\Delta$ -, Y- and rhombus-shaped) with one, two or more blades. The propeller wings should be lightweight and at the same time strong enough. They are made of wood, steel or artificial materials - such as fiberglass.

### **Calculation of wind power:**

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

Where

**P** is power output [W]

**ρ** is the denser the air, the more energy gets turbine. Temperature and elevation have large impact on air density. [ $kg/m^3$ ]

**A** is also called “capture area”, the output power of the wind turbine is directly associated to area covered by its blades [ $m^2$ ]

**V** is the amount of energy in the wind is changeable with the cube of its speed [mph]

### **Disadvantages of wind energy:**

-Expensive

-People complain about loud noises, which spread hundreds of meters around (a wind generator can be seen already at a distance of 200-250 meters from the house).

- The wind is not always predictable - sometimes there are periods without wind for several days

-Land for wind generators near the coast is usually not cheap

## **4 Hydropower plant (HPP):**

For utilities, the most attractive among renewable sources of energy is electricity obtained from the use of water. Its economic feasibility has been successfully proven. Power plants with a capacity of up to 10 [GW] were built. In Europe, the main hydropower potential has already been realized: 98% of the energy consumed in Norway is generated from hydropower, and the German government has stated that there are no more places to accommodate the HPP in the country. Considering the global spread of hydropower, it can be noted that today about 10% of existing hydro resources.

### **4.1 Operational principles:**

In the HPP, the kinetic energy of the falling water is used to generate electricity. The turbine and the generator convert the energy of water into mechanical energy, and then into electricity. Turbines and generators are installed either in the dam itself or next to it. Sometimes a pipeline is used to bring water under pressure below the dam level or to the water intake of the hydroelectric power station. The power of the hydropower plant is determined primarily by the function of two variables: the water flow expressed in [ $m^3/s$ ], and the hydrostatic head, which is the difference in altitude between the initial and final points of water fall. The station design can be based on one of these variables or both.

In terms of energy conversion, hydropower is a technology with very high efficiency, often exceeding more than double the efficiency of conventional thermal power plants. The reason is that the volume of water falling vertically has a large kinetic energy, which can easily be converted into mechanical (rotational) energy needed to produce electricity. The equipment for hydropower engineering is quite well developed, relatively simple and very reliable. Since no heat is present in the process (in contrast to the combustion process), the equipment has a long service life, failures rarely occur. The service life of the hydroelectric power station is more than 50 years. Nowadays, considerable experience has already been accumulated on the operation of hydroelectric power stations with a capacity from 1 [kW] to hundreds of megawatts [MW]

### **4.2 Types:**

HPP technologies can be divided into two types:

-traditional

-hydro accumulated using a pumping system.

There is another classification of HPP, depending on:

- Nominal power (large or small HPP);
- Water pressure level (low, medium and high-pressure HPP);
- Type of turbine (Kaplan, Francis, Pelton);
- Location and type of dam, reservoir.

#### **4.3 Components of hydroelectric power stations:**

Traditional HPPs (Figure 3.1) consist of the following components:

- Dam. Controls the flow of water
- Reservoir. This is the storage of water that builds up behind many dams. The stored energy that is contained in the reservoir is converted into kinetic energy once the control gate opens and the water flows through it
- Intake: The section of the reservoir immediately in front of the control gate where water is drawn into the penstock due to the gravity
- the penstock is long pipe where water travels from the intake, forcing it to run through the turbine.
- Turbine. Rotates under the pressure of water falling on the blades. Kinetic and potential energy of water are converted into rotational energy of the turbine
- Generator. It is connected to a turbine and, by spinning, produces electricity.
- Transmission lines. They transfer electric current from the hydroelectric power station to the electric distribution system.

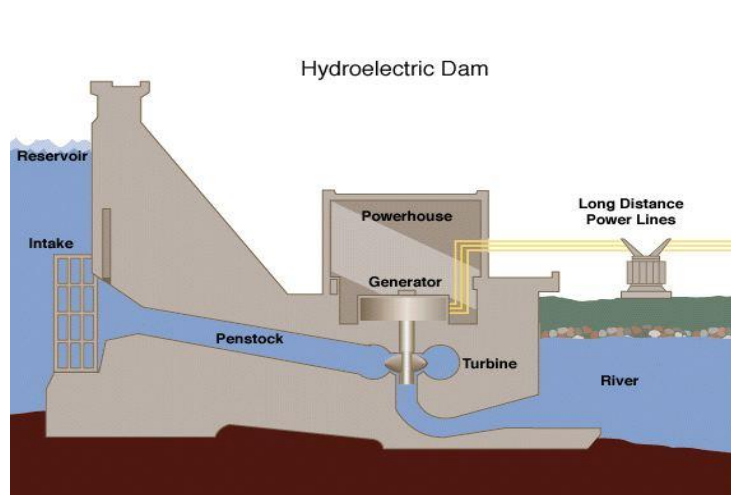


Figure 3.1: Hydropower plant components.

#### **Calculating the hydroelectric power:**

$$P = \eta \rho Q g h$$

##### **Where**

**P** is power in watts [W]

**$\eta$**  is the dimensionless efficiency of the turbine

**$\rho$**  is the density of water in kilograms per cubic meter [ $kg/m^3$ ]

**Q** is the flow in cubic meters per second [ $m^3/s$ ]

**g** is the acceleration due to gravity [ $m/s^2$ ]

**h** is the height difference between inlet and outlet in meters [m].

### **Disadvantages:**

- The main reason that HPPs are not built everywhere is the high cost of their construction.
- The need for large water resources in proximity to human settlements.
- Other problems associated with the construction of hydropower plants include: the impact of dams on river ecosystems
- Social problems, in particular, related to resettlement of residents.

## **5 Biomass. Biofuel classification.**

In many countries, much attention has been paid on finding ways to use the energy that plants accumulate through photosynthesis for technical needs, in particular to replace traditional fuel oil on vehicles with biofuel (ethanol and biodiesel). As it is known that biomass is usually used to designate all organic substances of both plant and animal origin, the source of which is the present biosphere of our planet. Annually on Earth with the help of photosynthesis there are about 120 billion tons of dry organic matter, which is equivalent to more than 40 billion tons of oil.

### **What can be done from biomass?**

#### **5.1 Biogas.**

In total, about sixty types of biogas technologies are currently used or developed in the world. The most common method is anaerobic digestion in metatanks, or anaerobic columns. Biomass (excrement of farm animals, straw and other crop waste) is fermented as a result of the vital activity of methanobacteria, resulting in biogas and by-products (fertilizer).

#### **5.2 Biodiesel fuel.**

Biodiesel is an environmentally friendly fuel for diesel engines, obtained by chemical treatment of vegetable oil or animal fats, which can serve as an additive to diesel fuel or completely replace it. Biodiesel, as shown by experiments, when it gets in water, does not cause damage to plants and animals. In addition, it undergoes almost complete biological decomposition: in soil or water, microorganisms process 99 % of biodiesel for 28 days, which makes it possible to talk about minimizing pollution of rivers and lakes.

#### **Method for direct conversion of biomass to fuel**

One method is the selection of catalytic pyrolysis of cellulose, the result of which is the formation of aromatic compounds (naphthalene, toluene, ethyl benzene, etc.), among the byproducts - solid carbon material, CO, CO<sub>2</sub> and water. The reaction was carried out at 600 °C on a ZSM5 zeolite catalyst. The process was completed in just two minutes. The starting reagent was a purified cellulose powder. Representations of the mechanism of the process include several elementary reactions - the decomposition of cellulose to form organic compounds containing oxygen, then the reactions of these compounds within the pores of the catalyst, where dehydrogenation, decarbonylation, oligomerization and other chemical transformations take place.

#### **5.3 Algae cultivation and processing:**

Special cultivation of biomass in the form of microscopic algae and its subsequent conversion to alcohol or methane makes it possible to create an artificial analog of the process of formation of organic fuels, which exceeds the speed of natural processes. Unicellular botryococcus algae are of great interest, the hydrocarbon content of which reaches 80 % of the dry weight. The composition of the hydrocarbons produced by the botryococcus allows them to be used as an energy source or as a raw material in the petrochemical industry (directly or after partial cracking). After hydrocracking, 65 % of gasoline, 15 % of aviation fuel, and 3 % of residual oil are produced

#### **5.4 Cyanobacteria:**

Scientists have changed the genome of cyanobacteria, adding the genes responsible for cellulose production, taken from acetic bacteria *Acetobacter xylinum*. As a result, the modified bacteria began to produce cellulose in the form of gel, which is very convenient, as it is easier to split into glucose and sucrose - simple sugars, which are the main source for the production of ethanol. What is also important, according to scientists, is that cyanobacteria can be grown on non-arable land and use salt water for irrigation, which cannot be used for drinking or watering plants.

### **6 The rules for connecting dispersed energy sources to the distribution system.**

While renewable energy systems are capable of powering houses and small businesses without any connection to the electricity grid, many people prefer the advantages that grid-connection offers.

A grid-connected system allows you to power your home or small business with renewable energy during those periods (daily as well as seasonally) when the sun is shining, the water is running, or the wind is blowing. Any excess electricity you produce is fed back into the grid. When renewable resources are unavailable, electricity from the grid supplies your needs, eliminating the expense of electricity storage devices like batteries.

In addition, power providers (i.e., electric utilities) in most states allow net metering, an arrangement where the excess electricity generated by grid-connected renewable energy systems "turns back" your electricity meter as it is fed back into the grid. If you use more electricity than your system feeds into the grid during a given month, you pay your power provider only for the difference between what you used and what you produced.

#### **Connection conditions [9],[10]**

Connection of small power plant (distributed sources) to the distribution network may be at low voltage level (0.4 kV) and at medium level (22, 35 kV), depending on the total power of the power plant, the nominal power of the generator, the circumstances of the distribution network, the power plants operation mode and other factors.

Connection capacity to distribution network:

- A power plant up to 50 kW - at the low voltage line or low voltage buses of 22 / 0.4 kV substation,
- A power plant up to 100 kW - at the medium-voltage network (22, 35 kV):
- A power plant up to 1000 kW - at the medium voltage line,
- A power plant over 1000 kW - at the medium or high voltage line, input-output system.

A possible way of connecting the power plant to the distribution network is determined by a detailed techno-economic analysis to define the optimal solution in terms of connection costs and the impact of production facilities on the distribution system. The final evaluation of the capabilities and mode of connection of distributed sources to the distribution network has been adopted with regard to the state and expected development of the distribution network, and after calculation of voltage drops, load flow, short circuit current and total harmonic voltage distortion. Defining the conditions for connection to the distribution network ensures reliability of the electric power system and user facility, and avoids at the same time unacceptable detrimental effects between them. Technical requirements for connection of

generating units to the distribution network are delivered by the distribution system operator. The Grid System Rules define the basic features at the connection point to the distribution network and general requirements for the connection of system users to the distribution system, as well as special conditions to be met by all generating units connected to the distribution system under normal operating conditions. The distribution system operator defines the basic technical information relevant to the design of manufacturing plants:

- Available capacity
- Data for insulation coordination
- Concept of protection (fault clearance time in the user's facility with the primary and backup protection)
- Maximum and minimum short circuit power
- Terms of parallel operating with electric power systems
- The share of higher harmonics and flickers towards the principles for determining the effect on the system
- Breaking capacity for the corresponding nominal voltage of the transmission network
- Way of earthing,
- Maximum and minimum continuous operating voltage, the duration and level of short-term overdraught,
- Typical load profiles,
- Nature and extent of reactive power exchange, and installed reactive power reserve into the user's facility, for the production and delivery of energy, power plant must generate a sufficient quantity of reactive power. Production of reactive power should be in the range of  $\cos \varphi = 0.85$  inductively to  $\cos \varphi = 1$ , except for solar power plants, where such a claim does not arise, and wind farms with asynchronous generators for which it is expressed in additional terms of Grid System Rules,
- Stake in the plan of the defense system (under frequency load shedding, under voltage shedding, manual and automatic control)
- Share in securing ancillary services,
- Behavior in large-scale disturbances (the ability to pass through a state of failure)
- The method of measurement and calculation
- Integration into the remote control system
- Integration into the telecommunication system

## **6.1 Criteria for connecting electricity generating plants to the distribution network ČEZ supplier.**



Way to connect electricity generating plants to the distribution network determines the network operator. When connecting to evaluate the effects of backward production plant to the distribution system of low or high voltage. They will cover the following feedback effects:

- Change Voltages when operating an electricity generating plant
- Change Stress during switching
- long term flicker
- Current harmonics
- Influence to device ripple control (HDO)
- Influence to short-circuit conditions

For photovoltaic plants are judged mainly voltage changes in the operation of the electricity generating plant, issued by harmonic currents and the effect on ripple control devices.

Voltage changes in the operation of the electricity generating plant.

PPC variations in voltage caused by connecting or disconnecting the electricity generating plant must not be at the medium voltage level (22 kV) exceed. Voltage change in the distribution of medium voltage by connecting electricity generating plant at the connection point (PCC) must not exceed 2%.

Variation in voltage distribution system low voltage by connecting electricity generating plant at the connection point (PCC) must not exceed 3%. Voltage changes when switching electricity generating plant 3%.

PPC variations in voltage caused by connecting or disconnecting the electricity generating plant must not be connected to low voltage (0.4 kV) exceed 2%.

These limits apply only to the case where switching is more frequent as once every 1.5 min., Which is at most plants using RES respected.

Most mass-produced dispersion of resources should have in their technical dossier factor information flicker. The amount of this quality parameter depends on the uniformity of the equipment operation. Generally, machines with great energy of rotating masses have little flicker factor and therefore not a source of flicker, for example: turbo generators and hydro generators. Problematic are the production of electricity from renewable sources, where it reaches a factor of flicker to 40. The highest values achieved without wind power converters and a small number sheets. Photovoltaic plants are generally deemed to be devices with very low duty flicker.

From the perspective of long-term rates flicker at each connection point to observe the following limits:

Term flicker effect can be determined by short-circuit power networks and rated apparent power of the connected source.

When flicker factor is declared by the equipment manufacturer.

## **7 Case study for the selected part of the medium voltage distribution system.**

Outline of the line.

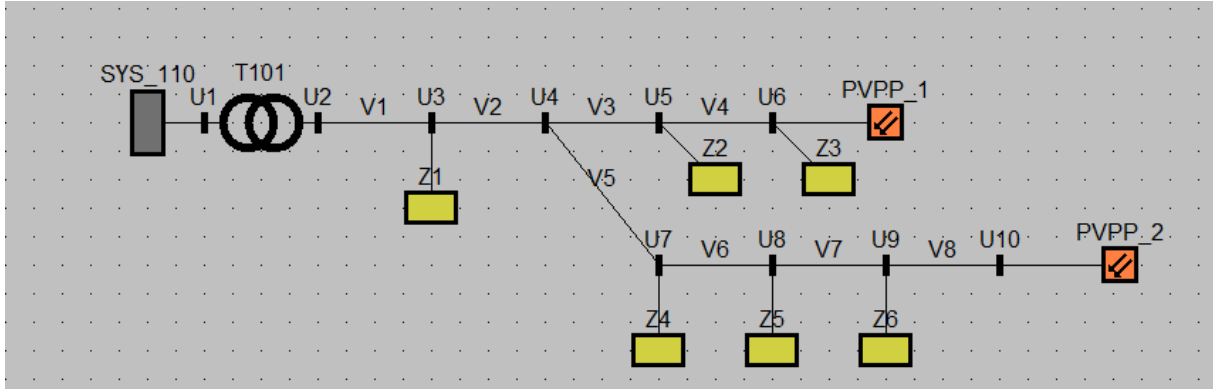


Figure 7.1 – Network topology

### Transformer T101

Manufacturer	Type	$U_{n1}$ (kV)	$U_{n2}$ (kV)	S (MVA)	$P_k$ (kW)
Škoda	8 ERH 31 M-O	110	23	25	140

Table 1

### Overhead lines

Name of a line	Start of a line	End of a line	Distance (km)
V1	U2	U3	6
V2	U3	U4	8
V3	U4	U5	5
V4	U5	U6	6
V5	U4	U7	5
V6	U7	U8	5
V7	U8	U9	3
V8	U9	U10	4

Table 2

### Overhead lines parameters

Name of line	Type	R ( $\Omega/\text{km}$ )	X ( $\Omega/\text{km}$ )	B $\mu\text{S}/\text{km}$	I <sub>max</sub> (A)
V1 – V4, and V5 – V8	120AlFe6	0,225	0,363	1,469	357

Table 3

### Loads

Name of a node	Load [kVA]	Power factor [-]
Z1	600	0,92
Z2	400	0,92
Z3	400	0,92
Z4	600	0,93
Z5	500	0,95
Z6	500	0,95
PVPP_1	1000	1
PVPP_2	1400	1

Table 4

### Calculation Results

Calculation of new photovoltaic power plant impact on distribution network (voltage difference) is carry out with application eVlivy.

#### Voltage difference before and after connection of PVPP1 .

	dU before[%]	dU after[%]	Voltage difference
U1	-4,490	-4,497	-0,007
U2	-8,774	-8,805	-0,049
U3	-8,040	-8,332	-0,300
U4	-7,379	-8,020	-0,648

<b>U5</b>	<b>-7,111</b>	<b>-7,969</b>	<b>-0,866</b>
<b>U6</b>	<b>-6,950</b>	<b>-8,067</b>	<b>-1,127</b>
<b>U7</b>	<b>-7,232</b>	<b>-7,873</b>	<b>-0,649</b>
<b>U8</b>	<b>-7,282</b>	<b>-7,923</b>	<b>-0,649</b>
<b>U9</b>	<b>-7,369</b>	<b>-8,009</b>	<b>-0,649</b>
<b>U10</b>	<b>-7,610</b>	<b>-8,249</b>	<b>-0,648</b>

*Table 5*

Result of calculation for PVPP1

Difference of voltage before and after connection PVPP1 with capacity 2100 kW to distribution line 22 kV is 1.127 % and it does not exceed the limit, which is 2% by Czech standards.

**Voltage difference before and after connection of the PVPP2**

	<b>dU before [%]</b>	<b>dU after[%]</b>	<b>Voltage difference</b>
<b>U1</b>	<b>-4,487</b>	<b>-4,497</b>	<b>-0,011</b>
<b>U2</b>	<b>-8,759</b>	<b>-8,805</b>	<b>-0,070</b>
<b>U3</b>	<b>-7,918</b>	<b>-8,332</b>	<b>-0,424</b>
<b>U4</b>	<b>-7,117</b>	<b>-8,020</b>	<b>-0,914</b>
<b>U5</b>	<b>-7,065</b>	<b>-7,969</b>	<b>-0,914</b>
<b>U6</b>	<b>-7,164</b>	<b>-8,067</b>	<b>-0,913</b>
<b>U7</b>	<b>-6,666</b>	<b>-7,873</b>	<b>-1,219</b>
<b>U8</b>	<b>-6,414</b>	<b>-7,923</b>	<b>-1,522</b>
<b>U9</b>	<b>-6,319</b>	<b>-8,009</b>	<b>-1,704</b>
<b>U10</b>	<b>-6,319</b>	<b>-8,249</b>	<b>-1,946</b>

*Table 6*

Result of calculation for PVPP2

Difference of voltage before and after connection PVPP2 with capacity 2100kW to distribution line 22 kV is 1.946 % and it does not exceed the limit, which is 2% by Czech standards

**7.1 Conclusion of the case study:**

In this case study I did calculations of voltage changes within the distribution network of 22 kV. Voltage changes were within the Czech standards. In case of PVPP1 connection to the distribution network there is 1.127% (U6) voltage difference from the nominal voltage before connection, and in case of PVPP2 system there is a 1.946% (U10) voltage difference from the nominal. Due to the fact that in Czech Republic there are norms of 2% voltage difference, it is possible to conclude – that both of PVPP1 and PVPP2 can be connected to distribution network.

## **8 Conclusion:**

Alternative energy is the energy obtained from renewable, inexhaustible sources of energy - wind, sun, biomass, geothermal heat of the earth. To obtain alternative energy, there are used special installations: wind generators, solar batteries, solar collectors, biogas reactors and others. The main reason for the weak growth of usage of renewable sources lies in the fact that as the cost of energy carriers rises; the price of manufacturing alternative devices also becomes higher. Among the advantages of alternative energy sources is the widespread prevalence of most species, environmental friendliness and renewability, as well as low operating costs. Among the negative - the instability in time and low energy flux density, which forces manufacturers to use large areas of power plants. To become a real substitute for traditional energy resources, these types of energy sources must meet a number of criteria. For example: ensuring a stable and controlled energy production. Nuclear test or the process of burning fossil fuels can be stopped and restarted when needed, but we cannot predict when the sun looks or hides, when the wind blows, and when it abates. In order to ensure a constant level of voltage in such power grids, it is necessary to use various accumulation units, which significantly reduces the efficiency of these power plants.

If we take into account the rapid growth of energy consumption throughout the world, it is recognized that energy produced from renewable sources is not yet able to fulfill the needs humanity. Therefore, we can conclude that it is necessary to increase investments in those areas that are engaged in the creation of new energy installations, and that the whole world community should engage in this, since this is the problem of the whole planet.

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