

Czech Technical University in Prague
Faculty of Electrical Engineering

Department of Electrical Power Engineering

BACHELOR PROJECT ASSIGNMENT

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Specialisation: Applied Electrical Engineering

Title of Bachelor Project: **Integration of the renewable energy sources to distribution network**

Guidelines:

1. General information on renewable energy sources, types of power plants utilizing renewable energy sources
2. RES connection rules and standards
3. A case study for selected type of RES

Bibliography/Sources:

- [1] Energy Word Outlook 2016
- [2] Electricity transmission and distribution
- [3] Distribution network code
- [4] eVlivity application manual

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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, 05.06.2017 Signature

Acknowledgement

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Abstract

Diploma work regarding renewable sources of energy, benefits, disadvantages, special characteristics. This thesis is about the general information on distributed energy sources, types of power plants, taking into the focus photovoltaic power plants (constraints, laws, standards and requirements), and the rules for connecting dispersed energy sources to the distribution system. Also, diploma consists of the case study, which shows voltage difference in greed (before and after connection the photovoltaic power plant). Also, this diploma tells why it is important to think about and use the renewable sources of energy nowadays, as our recourses of oil and gas are disappearing.

Key words

Renewable sources, solar energy, Wind energy, Hydro energy, Distribution system, generation, power plants, solar cells, renewables.

Abstrakt

Diplomová práce týkající se obnovitelných zdrojů energie, výhod, nevýhod, zvláštních charakteristik. Tato práce se zabývá obecnými

informacemi o distribuovaných zdrojích energie, typech elektráren, o fokusních fotovoltaických elektrárnách (omezení, zákonů, normách a požadavcích), o pravidlech pro připojení rozptýlených zdrojů energie do distribuční soustavy. Také diplom se skládá z případové studie, která ukazuje rozdíl napětí v chamtivosti (před a po připojení fotovoltaické elektrárny). Také tento diplom říká, proč je důležité v dnešní době přemýšlet o obnovitelných zdrojích energie a využívat je, protože naše zdroje ropy a zemního plynu se rozpadají.

Klíčová slova

Distribuční system, generace, elektrárny, solární články, obnovitelné zdroje energie, Solární energie, větrná energie, vodní energie.

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General Review

In recent years become very popular concept of "renewable energy sources (RES)." Assess the feasibility of their wide application range from enthusiastic to moderately pessimistic. The energy crisis of 1973-1974 in the capitalist countries has shown that it is difficult to constantly increase the installed power production based solely on traditional energy sources (oil, coal, gas). Power-society - the basis of its scientific and technological progress, the base of the productive forces. It is necessary not only to change their consumption patterns, but also more widely deploy innovative, alternative energy sources. Unlike fossil fuels, alternative energy forms are not limited to geologically accumulated reserves. This means that their use and consumption does not lead to the inevitable exhaustion of stocks. A structure of the energy economies to date has developed in such a way that four out of five produced kilowatt obtained, in principle, the same method which was used by primitive man to warm, i.e. the combustion of fuel, or by using stored therein chemical energy transforming it's into electricity in thermal power plants. However, methods of combustion have become much more complex and sophisticated. Increased to the environmental requirements demanded a new approach to energy. What are these non-conventional and renewable sources of energy? These usually include solar, wind and geothermal energy, tides and waves, biomass (plants, various types of organic waste), low potential energy of the environment. The main factor in the assessment of the feasibility of using renewable sources of energy - the cost of the energy produced in comparison with the cost of energy produced by traditional sources. Of particular importance are non-traditional sources of energy to meet local consumers. Considered in the new energy conversion schemes can combine

single "eco energy" terms, which refers to any methods of producing clean energy without causing environmental pollution.

Pluses and minuses of Green Energy

The main reason why Green Energy has positive side – because, this Energy is pure, it is not pollute the Nature. Renewable sources are spread widely. Also, usage of RES doesn't consist of fuel based operations, so we can think that this Energy is "free"

Negative quality – this is very small power that human can get from Green Energy. It results in building large power plants with very expensive equipment, which make Renewable sources not so popular in comparison with oil based power plants.

More troubles we get from "changing" character of Renewable recourses such as solar radiation, wind, flow of small rivers. For example, if time variability of geothermal resources is constant, solar radiation has the different pattern – although we can predict how much sunlight we shall have, it however has a large element of luck, which depends on weather conditions.

Renewable recourses of Energy are free, but it doesn't matter, because equipment for usage such energy is very expensive. So we have a little paradox here – free energy can be used only by rich countries. Small countries, which have a lot of problems with fuel based recourses, are now searching for opportunity to use Green Energy as it will help them in building energy potential of their homeland. But, high prices of devices are the main question in this problem. Rich countries use renewable recourses only because they are nervous when speaking about polluting the Nature.

Wind Energy

Wind energy - energy industry specializing in the use of wind energy - the kinetic energy of air in the atmosphere.

Man uses wind energy since very ancient times. It is sailboats, which surf the oceans for thousands of years, and windmills were used only a tiny fraction of the 2.7 trillion kWh of energy, which have winds on Earth. It is believed that it is

technically possible development of 40 billion kW, but even that is more than 10 times higher than the hydropower potential of the planet.

Why is it so abundantly available and environmentally friendly source of energy so little used? Nowadays engines using wind, cover only one-thousandth of the world's energy needs.

Wind energy potential of Earth in 1989 was estimated at 300 billion [kWh] per year. But only 1, 5% is suitable for technical purpose. The main obstacle for it - are mindedness and the volatility of wind power. Inconstancy of wind energy facilities requires batteries, which significantly increases the cost of electricity. Due to scattering in the construction of the output equal power, solar and wind power plants require up to five times larger area (however, these lands can be simultaneously used for agricultural purposes). But in the world, there are areas where winds blow with enough perseverance and strength. Examples of such areas may be the coast of the North, Baltic, Arctic seas.

Recent studies are directed primarily to receive electrical power from wind energy. The wish to master the production of wind energy machines has led to the birth of a plurality of such units. Some of them are tens of meters high, and is believed to be over time that they could form a real electric network. Small wind power units are designed to supply electricity to homes.

Wind power stations are constructed DC and AC. Wind wheel drives the dynamo - electric current generator, which simultaneously charges the parallel-connected batteries.

Today, wind power units reliably supply the oil shock; they successfully work in remote areas, in the distant islands, in the Arctic, thousands of farms, where there is no nearby large settlements and public power.

Modern methods of generating electricity from wind energy - the principle of operation of a wind turbine: under the pressure of the wind wind - wheel rotates with the blades, passing the torque through a transmission shaft of the generator system, generating electricity, water pump. The larger diameter of the propeller, the greater the air flow, and it captures more energy.

The fundamental simplicity gives here an exceptional scope for design creativity, but for the untrained eye the construction of wind turbine seems simple.

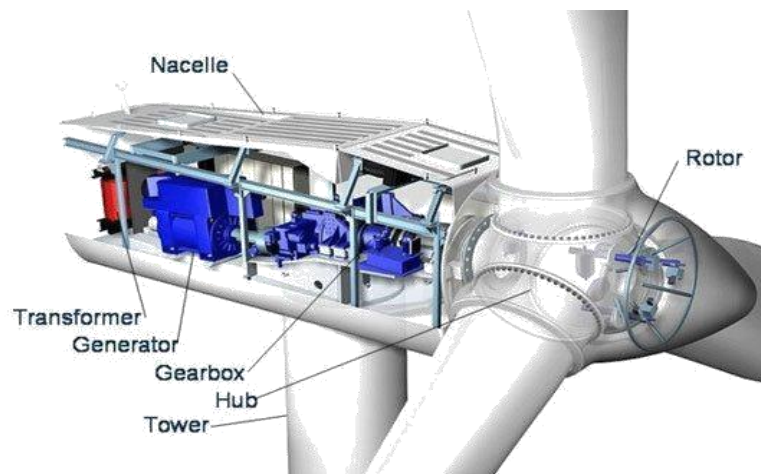


Figure 1 – Wind Turbine.

Where:

Rotor – rotating part of a wind turbine.

Nacelle - A Nacelle /nə'sæl/ is a cover housing that houses all of the generating components in a wind turbine, including the generator, gearbox, drive train, and brake assembly.

Gearbox - 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 1,000-1,800 rpm; this is the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

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 – responsible for controllability, maintainability, environmental compatibility. Controls blades and keeps the rotor from turning in winds that are too high or too low to produce electricity. **Tower** - Supports the structure of the turbine. Because wind speed increases with height, tall tower lets wind turbine capture more energy. **Generator** – usually, an asynchronous machine, which is connected to electricity grid. The rotational speed is slower than equivalent rotation speed of an electrical network. That is why **Gearbox** is put between rotor hub and the generator. This also reduces generator cost and weight. **Transformer** - Substations provide the vital link between wind turbines and the electrical grid.

The formula for calculating power of wind turbine:

where

P = Power output in **[kW]**

C_p = Maximum power coefficient, ranging from 0.25 to 0.45, dimension less (theoretical maximum = 0.59)

ρ = Air density, **[kg/m³]**

A = Rotor swept area, ft² or $\pi D^2/4$ (D is the rotor diameter in **m** , π = 3.1416) **[m²]**

V = Wind speed, **[m/s]**

k = 0.000133 A constant to yield power **[--]**.

Vane wind turbines



Figure 2 – Vane Wind Turbine

Conventional windmills arrangement - with a horizontal axis of rotation - a good solution for units of small size and capacity. When the blade swings up, this arrangement proved ineffective, as on the different heights wind blows in different directions. In this case, it not only fails to optimally orient the assembly in the wind, but also risks breaking the blades.

For vane wind turbines, the greatest efficiency is achieved at which the action of the air flow perpendicular to the plane of rotation of the wing blades, and it requires automatic rotation device. The wing-stabilizer used. Turning wind turbines have the advantage that they can be operated at any wind direction without changing its position.

The utilization factor of wind energy in vane wind turbine is much higher than the carousel. At the same time, the rotary wind turbines have much more torque. It is maximal for rotary vane assemblies at relative zero wind speed.

Propagation of vane wind turbines explains the magnitude of their rotation speed. They can be directly connected to electric current generator without any step-up gear. Vane wind turbine rotational speed is inversely proportional to the number of wings, however the amount of aggregates with more than three blades are not used.

Carousel wind turbines



Figure 3 - Carousel Wind Turbine

The difference in aerodynamics gives carousel settings advantage in comparison to conventional wind turbines. By increasing the speed of the wind, they rapidly increasing traction, then the rotational speed is stabilized. Boring slow moving of wind turbines allows the use of a simple electrical circuit, such as an asynchronous generator, with no risk to suffer an accident with a random gust of wind. An even more important advantage of rotary design was its ability without additional tweaks to ensure "where the wind blows", which is very important for surface prowling streams. Wind turbines of this type being built in the United States, Japan, Britain, Germany and Canada.

The rotor blade wind turbine is the most easy to use. Its design provides maximum torque when starting the windmill and an automatic self-maximum rotational speed during working. With increasing of load rotation, speed is reduced and torque is increased up to a complete stop.

Pluses and Minuses.

Wind turbines are removing portion of the kinetic energy of a moving air mass that reduces the velocity of their movement. With mass use of wind turbines (eg in Europe), this slowdown could theoretically have a noticeable impact on the local (and even global) climatic conditions of the terrain. In particular, the decrease in the average wind speed is able to make the climate of the region a little more continental due to the fact that slow-moving air masses have time to become very hot summers and cool winters. Also, removal of energy from the wind can contribute to changing humidity conditions of the surrounding area. However, scientists have so far only deploy research in this area, studies that analyze these aspects do not give a quantitative assessment of the impact of large-scale wind energy on the climate, however, suggest that it may not be as negligible as previously thought.

A large amount of harmful substances released in modern cities, including those from industrial plants and automobiles. Natural ventilation of cities comes from wind. In this case, the above-described decrease in wind speed, because of the massive use of wind turbines, can reduce breathability of cities. Especially unpleasant consequences it can cause in large metropolitan areas: smog, increase in the concentration of harmful substances in the air and, as a consequence, increased morbidity. In this connection, the installation of wind turbines near large cities is undesirable.

Wind power plants produce two kinds of noise: mechanical noise - noise from the operation of mechanical and electrical components (for modern wind turbines is virtually absent, but it is significant in wind turbines of older models) and aerodynamic noise - noise from the interaction of the wind flow from the installation blades (enhanced by passing the blade near Wind Turbine tower). In the vicinity of the wind turbine at the axis of the propeller noise is sufficiently large; wind turbines may raise it to 100 [dbs.]. Laws passed in the United Kingdom, Germany, the Netherlands and Denmark, to limit the noise level of operating of a wind power plant of up to 45 [dB] in the daytime and 35 [dB] at night. The minimum distance of the installation - 300 [m].

Low frequency vibration transmitted through the soil to cause bounce of glass in homes at a distance of 60 [m] from the megawatt-class wind power. Typically, homes are located at a distance of not less than 300 [m] from the wind turbine. At this distance, the contribution of wind power in the infrasonic vibrations can no longer be isolated from background vibrations. Interference of metal construction

of wind turbines, especially elements in the blades, can cause significant interference in the reception of a signal. The larger wind turbine, the more noise it may produce. In some cases, to solve the problem we have to install additional repeaters.

Hydro – power

Man has always lived near rivers and could not pay attention to the energy potential that rivers had. History of using hydro power goes deep into the centuries, when man learnt how to use water energy in grain milling or in producing iron bars.

Step by step water mills got improved more and more, but people started to use full water potential in the end of 19th and beginning of 20th centuries, in 1930s, when man learnt to gain electricity.

Hydropower plant represents a complex with a different buildings and equipment, which are used to transform water's energy into electricity. Hydro technical structures help to concentrate water flow, while the rest of operations are done by special devices.

Hydropower plants are built on the rivers, which make them dams and water storages. The big issue for effectiveness of a plant is an area. We have to consider two factors: stable and strong flow of water throughout a whole year and as much as possible the slope of the river. Hydropower plants are divided into two groups – **Dam** (needed water level gained by building a dam) and **Derivations** (it is done by water drainage from the river bed to a place with a high level difference).

The principle of work of such plants is based on a usage of Kinetic Energy of falling water. For transformation this energy turbines and generators are used. Firstly, those devise producing mechanical power, after that – they producing electro energy. Turbines and generators can be placed in Dams or nearby them.

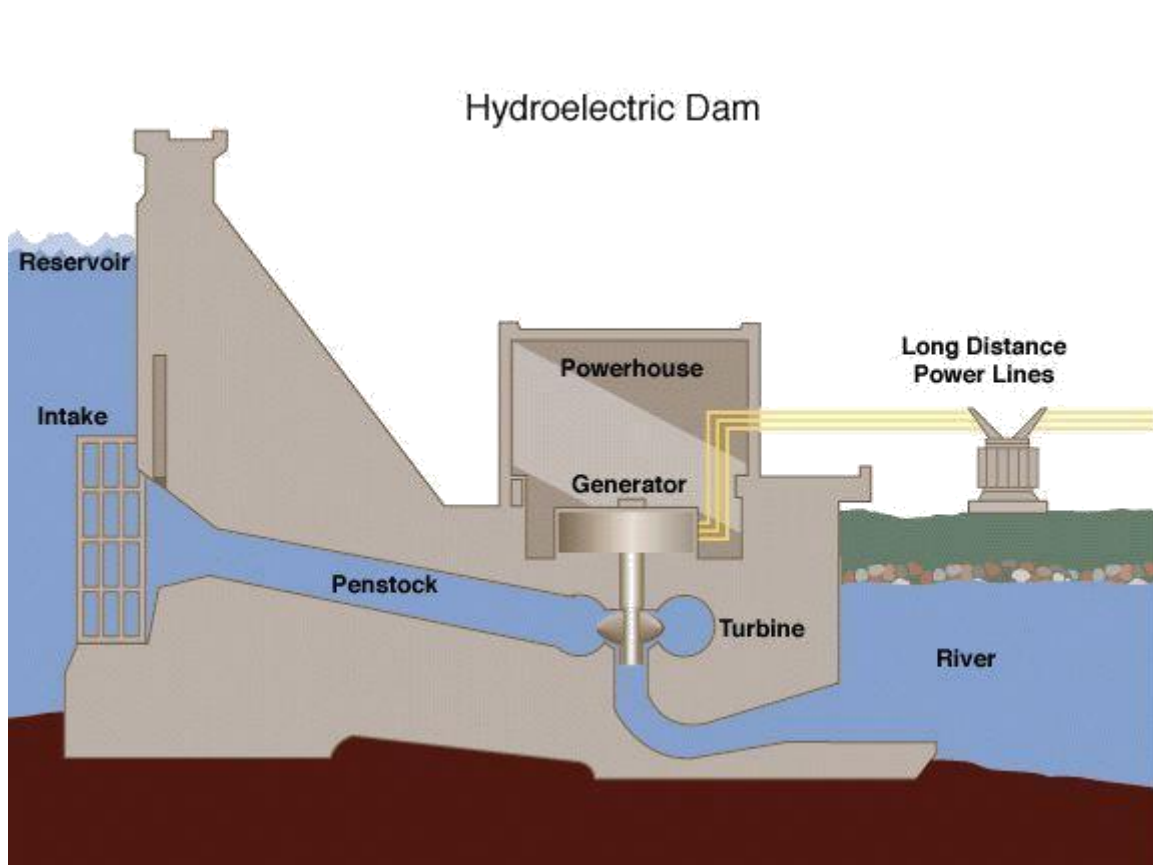


Figure 4 – Hydro Power Plant.

Where:

Reservoir – is the place behind the dam where water is stored. The reservoir is located higher than others dam structures. The height of reservoir decides how much potential energy will water have – higher the reservoir higher the energy. Also, this position of water lets it flow effortlessly.

Intake gates - These are the gates built on the inside of the dam. The water goes through these gates due to gravity. When water flows through the gates, it has potential and kinetic energy.

Penstock – a long pipe that carries water from a reservoir to the power generation unit. The total amount of hydro power plant depends on height of reservoir and amount of water which flows through the penstock.

Water Turbine – water falls on the blades of turbine, and kinetic and potential energy of water are converted into rotational energy of turbine. The rotation of blades of turbine also causes shaft to rotate. The shaft is enclosed inside the generator.

Generator – rotating shaft in generator results in producing the alternating current in the coils of generator. It is producing magnetic field due to rotation,

and this magnetic field is converted into electricity by electromagnetic field induction.

Total power of hydro power plant can be explained by formula

Where

P is power in **[W]**

η - Is the dimensionless efficiency of the turbine

ρ - Is the density of water **[kg/m³]**

Q - Is the flow **[m³/s]**

g - Is the acceleration due to gravity **[m/s²]**

h - Is the height difference between inlet and outlet **[m]**

Indicators for power measure of Hydropower plant are two variables: water consumption, which is measured in cubic meters, and hydrostatic pressure. The hydrostatic pressure is the height difference between starting and final points of falling water. Project of a power plant can be based on one of these variables, or on both.

Modern technologies of hydropower allow get very high efficiency.

Sometimes, it's two times higher than efficiency of heat power plants. But this efficiency obtained because of equipment features of such plants. It's very reliable and simple to use.

Also, all of the used equipment has a big advantage. Devices can be used for years, because there is no heat in producing electricity. So there is no need to constantly change and repair any of equipment.

The minimum term of service of Hydropower plant is around fifty years. In some post – soviet countries are still functional hydropower plants which were built in 1920s or in 1930s. Hydroelectric power plants are managed through a central hub, and therefore, in most cases a small staff working there.

Pluses

The basic advantages of hydropower plants are obvious. Of course the main one is renewability: the water storage is almost inexhaustible. Also, hydro technologies are far ahead of the others sources of renewables, and they can supply energy to a big cities and even regions.

Beside of that, usage of this type on Energy is very simple, which is confirmed by the history of hydropower. For example, generators of hydropower plants can be turned on or off, depending on energy consumption. The price of such a station is relatively small, and exploitation of such a station doesn't result in polluting the nature.

Minuses

Hydropower facilities have a significant impact on the environment. This impact is local one. But, for example, building huge water storages, with idea to turn some rivers bed from Siberia to a Central Asia, can cause environmental problems in a whole region. When projecting a hydropower plant, we must consider terms of building and usage.

The first period is relatively short – a few years. In the time of this period in the region of building natural landscape is damaged. Because of roads construction, construction of industrial facilities, the noise level increases dramatically. The water, which is used for different type of works, returning to the river with a mechanical impurities: sand, dust, etc.

Due to reduction of the flow velocity and reduce water migration in depth significantly changed physical-chemical characteristics of the water relative to household river conditions to create a reservoir. The quality during a reservoir affects populated flooded area, the species and age composition forest undergrowth and litter, the presence tributaries mode and the depth of the reservoir drawdown and m. P. Water quality degrade wastewater of industrial, mining and livestock farms Communal and household wastewater and removal of fertilizer to agricultural land. For southern regions unpleasant consequence of saturation of water in the reservoirs and organic nutrient (mainly nitrogen and phosphorus ions) is a rapid development in warm water blue-green algae. When creating reservoirs should be scrutinized combined influence of all the factors taking into account the prospects for the construction of hydroelectric and take measures to maintain water quality. Water quality - characteristic of the composition and properties of water, determining its suitability for specific types

of water. Adjacent land use in agriculture is necessary, applying advanced methods of farming practices that limit the removal of fertilizers in the reservoir.

Solar Energy

There can't be a life on our Planet without Energy. Conservation Energy Law tells us that Energy can't appear from nowhere and can't suddenly disappear. People learnt to get energy from natural resources like coal, gas and even Uranium, and transform it into convenient for us forms – heat and light. There are a lot of examples of energy storage and its usage around us, but the most important energy for humanity – is the Solar Energy.

Solar energy – is the type of Green energy. It is one of ecologically safe natural resources, which doesn't pollute the nature. The borders of usage of solar energy are almost limitless, and scientists from all around the world work on the systems, which shall help to extend opportunities to use the Solar Energy.

One square meter of Sun radiates 62 900kWh. It is, approximately, equal to a power of one million electric bulbs. Numbers are impressive – Sun gives to Earth 80 thousand billion of kWh, which is higher than energy, we get from all power plants on our planet together. Nowadays, scientists try to use this energy with its full potential, because energy, which comes from Sun, is one of the safest sources of Energy. People need to know, that Sun and its Energy – is the future of all mankind.

Coal and gas, with such speed of their usage nowadays, shall wear out in the next 100 years. Humanity will have energy for the next 200 or 300 years, but the reason why everybody's looking ahead – it is a question "What will happen then?" Our children and their children shall not have this type of resources in future, and usage of oil and gas shall harm enormously our planet.

Of course, the same potential has Nuclear Energy. It can give a huge amount of energy, but the Chernobyl Catastrophe in the April 1986 showed to the whole world what kind of effects can this Energy bring. The people from all around our Planet were agreed, that humanity can use the Energy of Atom, but we need to be very careful.

And, from this, we can say – the cleanest and the safest source of energy – is the Sun!

Solar energy can be transformed into useful energy by using active and passive energy systems.

The passive usage of Solar Power

Passive systems use the sun's energy.

The most primitive way of passive use of solar energy is dark-colored water tank. Dark color, accumulating solar energy, transforms it into heat – the water is heated.

However, there are more advanced methods of passive use of solar energy. Developed construction technologies in the design of buildings taking into account climatic conditions, selection of building materials, maximum use of solar energy for heating or cooling, lighting buildings. With this design very design of the building is a collector that accumulates solar energy.

So, in 100g BC Pliny the Younger built a small house in the North of Italy. In one of the rooms windows were made of mica. It turned out that this room is warmer than others and heating of it required less firewood. In this case, the mica was as an insulator.

Modern building designs take into account the geographical location of buildings. So, plenty of windows are south-facing, include the Northern regions that received more sunlight and heat, and limit the number of windows on the East and West sides to limit the flow of sunlight in the summer. In such buildings the orientation of windows and their location – a single design system.

Active usage of Solar Power

This type of usage is realized by solar collectors and solar panels. Solar collectors transform solar energy into heat, than can be used to warm houses and to heat water.

Solar collector is a device for collecting solar radiation. Solar radiation – is the energy in electromagnetic form from the infrared (long) to the ultraviolet (short) wavelengths.

There are basically 3 types of solar collectors.

Flat Collector.

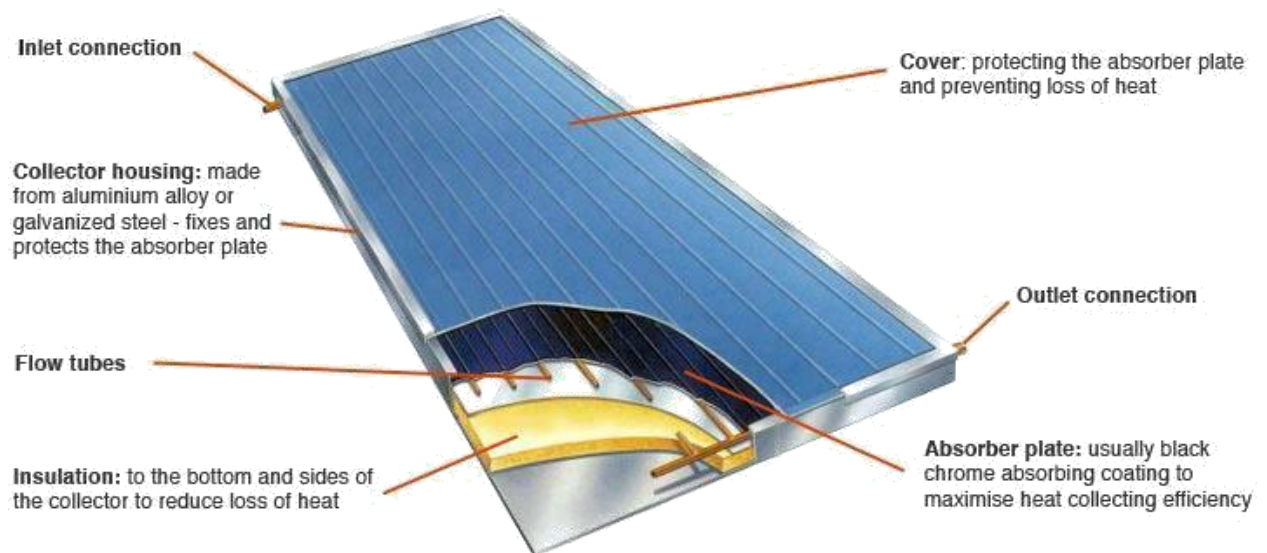


Figure 5 – Solar Collector.

This is the most common type of solar collectors. It is used in household systems of water supply and space heating

A flat collector consists of element absorptive a sunny radiation (absorber), transparent coverage and thermo insulating layer. An absorber is related to the heat-conducting system. It is covered by a black paint or special selective coverage (usually black nickel or oxide of titan coating) for the increase of efficiency. A transparent element is usually executed from hard-tempered glass with the lowered maintenance of metals, or special corrugated polycarbonate. The back-end of panel is covered by heat-insulation material (for example, polyimide). Tubes, through which coolant-moderator spreads on, are made from the sewn together polyethylene or copper. A panel is air tightness, due to openings in it closed by silicon encapsulate.

In situations of lacking of heat (stagnation) flat collectors are able to warm water to 190-210 C.

The more incident solar energy is falling to the heat carrier flowing in the tubes, the greater its effectiveness. To increase it, we can apply a special optical coating that is not emitting heat in the infrared spectrum, the efficiency of which could reach about 95%. The standard solution to improve the efficiency of the collector was the use of an absorber made of sheet copper due to its high thermal conductivity, since the use of copper against aluminum gives a gain of 4 % (although the conductivity of aluminum is twice less, which means a significant excess of "reserve capacity" for heat transfer), slightly in comparison with the

price). Also, high efficiency is achieved by increasing the contact area of the tube and copper sheet: molded sheet and the soldered connection is a maximum, the connection by ultrasonic welding - less. Also, are used aluminum screen.

Pluses and minuses.

Benefits:

- 1) The ability to be cleaned from snow and frost
- 2) High performance on Summer time
- 3) Excellent ratio price/performance for southern latitudes and warm climates
- 4) The ability to install at any angle
- 5) Lower initial cost

Minuses:

- 1) High heat losses
- 2) Low efficiency in the cold season
- 3) The complexity of installation

The Vacuum Collector.

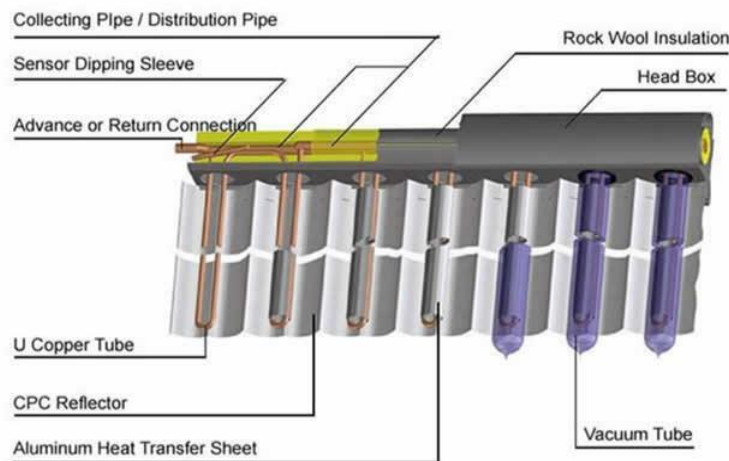


Figure 6 – Vacuum Solar Collector.

We can increase heat carrier temperature up to 250-300 °C in the limiting mode of heat transfer. This can be achieved by reducing heat losses which can be realized by using of multi-layered glass coating, sealing or creating vacuum in the reservoirs.

In fact, solar heat pipe is a device, similar to a household thermos. Only the outer part of pipe is transparent and the inner part of pipe is covered by a selective coating, which traps the solar energy. Between the outer and inner glass tube is a vacuum. That is a vacuum layer gives you the opportunity to save about 95% of captured thermal energy.

In addition, in the vacuum solar collectors are used heat pipes acting as a conductor of heat. Under irradiation of solar light fluid in the bottom of the tube, when heated, turns into steam. Vapors rise to the top of the tube (the condenser), where the condensing heat goes to collector. The use of this scheme can give greater efficiency (compared to flat collectors) when working in low temperatures and low light.

Modern household solar collectors can heat water up to boiling point even at negative ambient temperature.

Pluses minuses.

Benefits:

- 1) Low heat losses
- 2) Working in the cold season, down to -30°C
- 3) The ability to generate high temperatures
- 4) A long period of work during the day
- 5) Ease of installation
- 6) Excellent ratio price/performance for temperate and cold climate

Minuses:

- 1) The inability to self-cleaning from snow
- 2) Relatively high initial cost of the project
- 3) The working angle of at least 20°

Solar air collectors

Solar air collectors are devices that work on solar energy and heating the air. Solar air collectors it is actually the most often simple flat-plate collectors and are mainly used for space heating, drying of agricultural products. The air passes through the absorber by natural convection or under the influence of the fan. Because air conducts heat worse than the liquid, it transmits to the absorber less heat than a liquid heat carrier.

In some solar air heaters we can attach the fans to the absorbing plate, which increase air turbulence and improve heat transfer. The disadvantage of this design is that it consumes energy on the fans, thus increasing the cost of operation of the system. In cold climates the air is directed into the gap between the plate absorber and the insulated back wall of the collector: thus, they avoid heat loss through the glazing. However, if the air is not heated more than 17 °C above ambient air temperature, the heat carrier can circulate on both sides of the plate-absorber without big losses of efficiency.

The main advantages of air collectors are their simplicity and reliability. Such collectors have a simple device. With proper care such collector will last 10-20 years, and controlling them is very easy. The heat exchanger is not required as the air does not freeze.

A potential way of reducing the cost of collectors is their integration into walls or roofs of buildings, and the creation of reservoirs, which can be assembled from prefabricated components.

Collectors are designed for space heating with sufficient solar illumination and in the absence of (or along with) the other energy sources (such as gas, electricity, liquid and solid fuels). Collectors may not be the main heating system, as it does not provide the constant characteristics during the day and when the seasons change. However, the system can be integrated into any existing heating system and ventilation.

Solar Panels

In the far 1839 Alexander Edmond Becquerel discovered the photovoltaic effect, the operating principle of Solar Cell.

After 44 years, Charles Fritts managed to construct the very first solar cell for Solar Energy usage. It was made from selenium with a thin layer of gold on it. Charles discovered that such combination of elements allows, although in a very small portion (1%), to transform Sun Energy into electricity.

The year of birth of Solar Energy is 1883. Although, not everybody thinks it's true. Among the scientists it is common to consider, that Albert Einstein was a Father of Solar Energy Dawn.

In 1921 Einstein was honored with a Noble Prize. Everyone think, that this award one of the greatest scientists in XX century was given for Theory of Relativity, but

it is not true. The famous physic got the award for the explanation of Photoelectric effect.

Nowadays, solar cells are not so surprising for us; everybody now heard at least something about Solar Energy, Solar Panels and how to get energy from Sun. But, first of all. What the Solar Cell is?

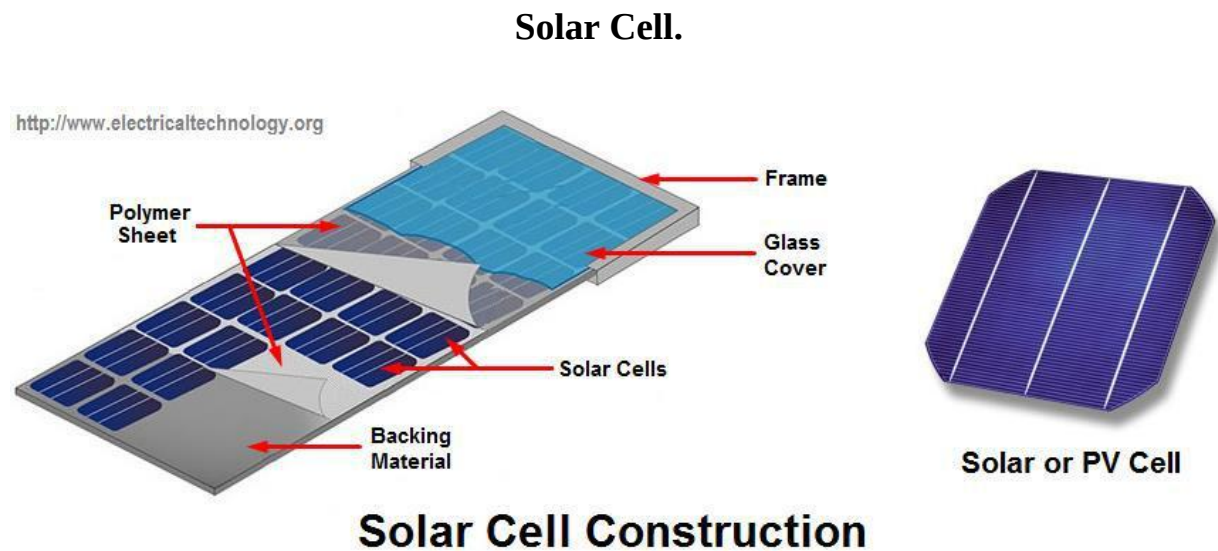


Figure 7 – Solar Cell construction.

Solar cell – Photocell — an electronic device that converts energy of photons into electrical energy. They are divided into vacuum and semiconductor solar cells. The device is based on photoelectric emission or the internal photoelectric effect.

The most effective, from an energy point of view, devices for converting solar energy into electricity are semiconductor photovoltaic cells (solar cells), because it is a direct, one-stage transition of energy. Efficiency of solar cells in industrial purposes is average 16 %, with best samples up to 25 %. In the laboratory already achieved efficiency 43,5 %, 44,4 %, 44,7 %.

Physical Principle

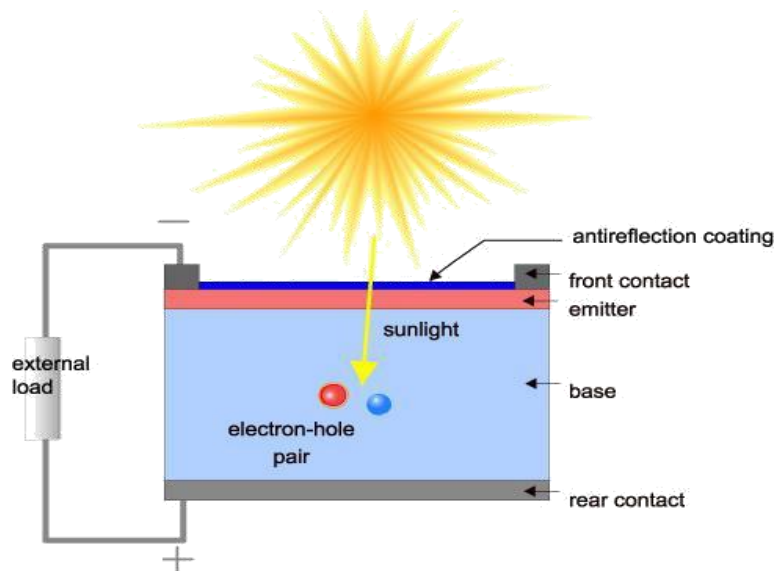


Figure 8 – Solar Cell physical principle.

How do solar panels work with such a structure? In the following way - the inner layer of the element is the p-semiconductor, external, much thinner - n-semiconductor. On the boundary layers is the so-called "zone of the p-n junction" is formed due to the formation of bulk positive charges in the n-layer and negative in the p-layer.

In the transition zone there is a certain energy barrier caused by the potential difference of the charges. It prevents penetration of the main carriers, but freely lets non - main carriers, also in opposite directions. Under the action of the sunlight part of the photons are absorbed by the surface of the element and generates an additional "hole-electron" pair. That is, electrons and holes are moved from one semiconductor to another, giving them additional negative or positive charge. The initial potential difference between the n - and p-layer is reduced, and in the external circuit generates a current.

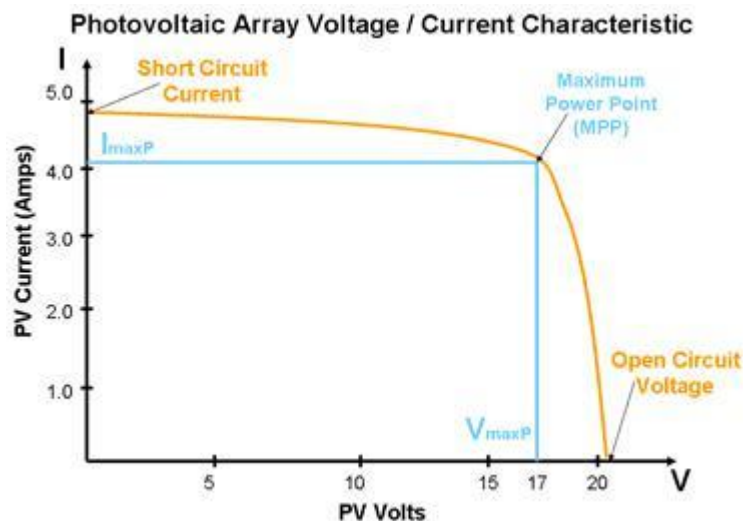


Figure 9 – Volt – Ampere characteristics.

Energy conversion in solar cells based on the photovoltaic effect, which occurs in inhomogeneous semiconductor structures when solar radiation falls on them. The heterogeneity of the structure of solar cells can be obtained by doping the same semiconductor with various impurities (to create p-n junctions) or by combining different semiconductors with varying band gap — the energy separation of the electron from the atom (the creation of heterojunctions), or by changing the chemical composition of the semiconductor, leading to the appearance of a gradient of width of forbidden zone (creation of a graded gap structures). It is also possible to have various combinations of these methods. The conversion efficiency depends on the electrical characteristics of inhomogeneous semiconductor structures, and optical properties of solar cells, among which the most important is the role of photoconductivity. It is caused by phenomena of internal photoelectric effect in semiconductors at irradiation by sunlight.

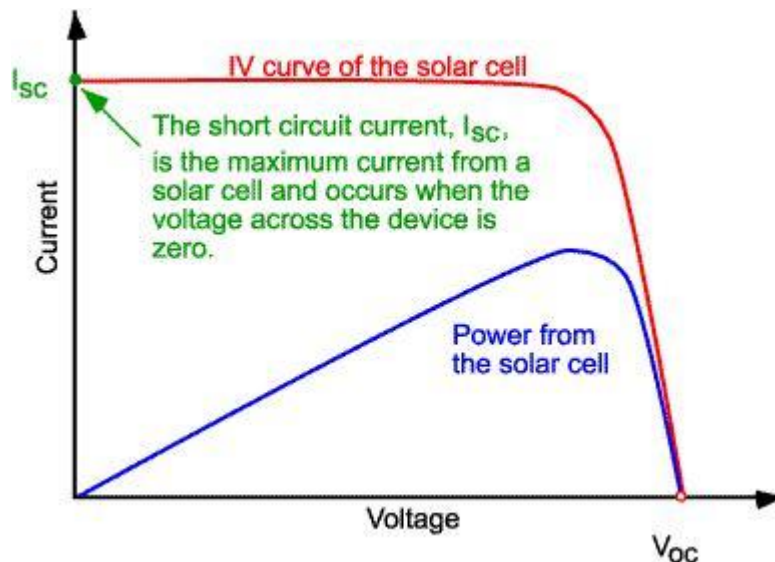


Figure 10 – Volt – Ampere characteristics 2.

Types of Solar Cells. Mono and Pole – Silicon



Figure 11 – Mono silicon Solar Cell.

The battery, which is based on silicon, today is the most popular. This is due to the widespread use of silicon in the earth's ground, its relative cheapness and high performance in comparison with other types of solar panels. Silicon panels are made from mono - and polycrystalline Si and amorphous silicon.

Monocrystalline solar panels represent silicon cells connected together. For their manufacture is used the most pure silicon obtained by Czochralski method. After curing, the finished single crystal is cut into thin plates with a thickness of 250-300 microns, which penetrate the mesh of metal electrodes. The technology which used is relatively expensive, and therefore monocrystalline batteries are more expensive than polycrystalline or amorphous. But we choose this type of solar panels for its high efficiency (17-22%).

To obtain a polycrystalline silicon melt is exposed to slow cooling. This technology requires less energy; therefore, the cost of silicon, obtained with its help is less. The only disadvantage of polycrystalline solar panels - they have a low efficiency (12-18%) than their mono "competitor". The reason is that inside the polycrystalline regions are formed with grain boundaries which reduce the efficiency of the elements.

Amorphous Silicon Cells

If we shall take into a count of the materials used, the amorphous silicon battery refers to silicon itself, but if we look the technology of production –it reminds thin film. When production of amorphous panels of crystalline silicon is not used, but a Silane or silicon - hydrogen thin layers are applied to the substrate material. The efficiency of such batteries is only 5-6%, they have very low efficiency, but despite these shortcomings, they have a number of advantages:

- 1) The rate of optical absorption is 20 times higher than that of poly - and single crystals.

- 2) The thickness of the elements (less than 1 micron)
- 3) In comparison with poly - and single crystals have better performance in cloudy weather.
- 4) High flexibility.

In addition to the above types of silicon solar cells, exist their hybrids. So for the more stable elements, are used a two-phase material, consisting of amorphous silicon with inclusions of Nano - or microcrystals. The properties of the resulting material are similar to polycrystalline silicon.

Based on CdTe

Studies of cadmium telluride, as light-absorbing material for solar cells, began in the 70-ies. At that time it was regarded as one of the best options to use in space, but nowadays batteries based on CdTe are among the most promising in the earth's solar energy. Since cadmium is a cumulative poison, the discussions arise and have only one question: toxic or not? But studies show that the level of cadmium released to the atmosphere is negligible, and fear of harm is not necessary. Efficiency is about 11%. We can agree, the figure is small, but the cost of a watt of power such batteries is 20-30% lower than silicon.

On the basis of the selenite of copper-India

As the name implies, semiconductors are used - copper, indium and selenium, sometimes some elements of indium get replaced by gallium. This practice is due to the fact that a large part of producing of indium is required today for the production of flat screens. That is why to save recourses indium got substitute by gallium, which has similar properties. Thin film solar battery on the basis of the selenite of copper-indium has an efficiency of 15-20%. It should be borne in mind that without the use of gallium the efficiency of solar panels increases by about 14%.

But, as we told above, solar cells are the main part of Solar Panels.

Solar Panels.

Solar battery — a common term, used in everyday speech or scientific press. Usually the term "solar panel" refers to several joined photoelectric converters (solar cells) — semiconductor devices which directly convert solar energy into direct electric current.

Unlike solar collectors that produce heating for houses and water, the solar cell produces electricity directly. Although, for the production of electricity from solar energy solar collectors are used: the collected thermal energy can be used for generation of electricity. Large solar collectors using highly concentrated solar radiation as energy to make the thermal and other machines (steam, gas turbine, thermoelectric, etc.) work and such huge solar plants are called Gelio Power Plants (GEES).

Nowadays, Solar Panels are being used more often, as humanity start to realize that

Efficiency of different solar cells	
Mono	17-22%
Poly	12-18%
Amorphous	5-6%
On the basis of cadmium telluride	10-12%
On the basis of the selenite of copper-indium	15-20%
On the basis of polymers	5-6%

oil and gas are about to wear out.

Solar Panels can be different form and shape, but their main task is – to convert Sunlight into the electricity.

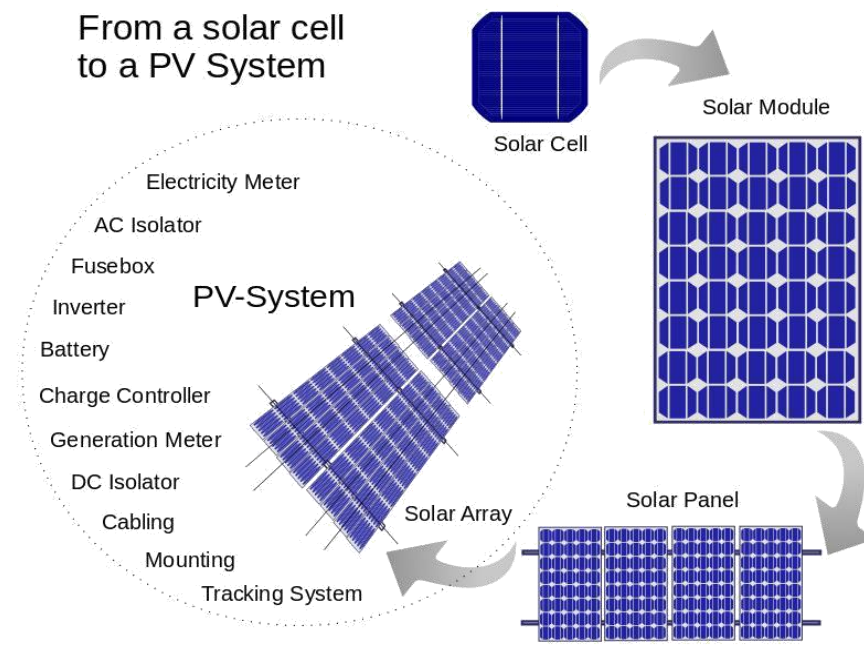


Figure 12 – PV – systems.

Photovoltaic modules (PV – modules) use sunlight (photons) to generate electricity because of photovoltaic effect. The most of modules use wafer – based crystalline silicon cells or thin – film cells. Top layer and the back layer we can consider as a structural (load carrying) members of a module. Also, protection of cells is the important question, because, it must be defended against mechanical damage. We have rigid modules, but it is possible to obtain semi-flexible ones. Cells are connected in series.

Cells can be connected in series to achieve needed output of voltage, or they can be connected in parallel to provide wanting amount of current. Wires in PV modules, through which current goes off the modules, made of silver, copper and other non – magnetic conductive transition metals.

Some PV modules have concentrators, where light is focused by lenses or mirror onto cells. This allows having high cost cells in a cost – effective way.

Types of Solar Power Plants.

Solar Power plant Tower – type

These kinds of power plants using the principle of generating steam by a solar radiation. Tower, which is 18 to 24 meters height, is in the center, surrounded by a heliostat. On the top of such a tower is a tank with water. Tank is painted into the black, so the light rays, that come from mirrors, that surround the tower (heliostat

mirrors), are heating the tank. There are also combinations of pumps that deliver water to the tank from the turbine generator.

The most difficult part in this scheme is heliostat mirrors and their set up. Mirrors must always face the sun, and they need to change their position depending on the position of the Sun. The efficiency of such a power plant is about 20%, which is relatively large.

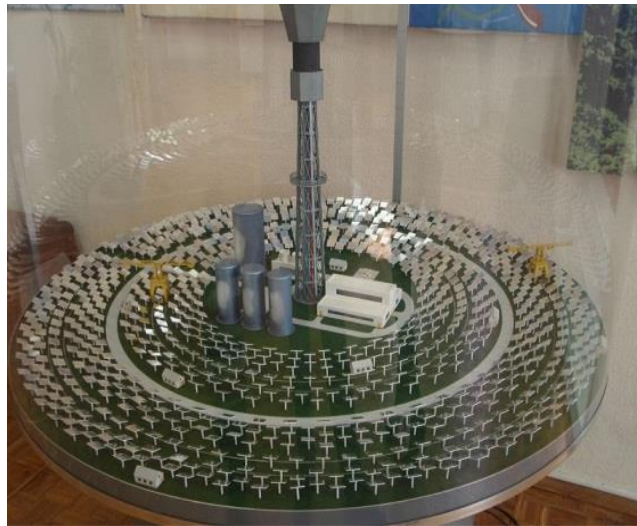


Figure 13 – Tower Solar Power Plant.

Dish Solar Power Plant

This type of SES based on the principle of producing electricity, similar to Tower Type Power Plant, but there are differences in the design of the station. The station consists of separate modules. The module consists of a pillar, on which are mounted receiver and reflector. The receiver is placed in the field of concentration of reflected sunlight. The reflector consists a mirror in the shape resembling a satellite dish (hence the name), radially arranged on the farm. The diameters of these mirrors reach 2 meters, and the number of mirrors is several tens (depending on module power). Such stations may consist of one module (stand-alone) and from several tens (work in parallel with the network).

Solar Power Plant using PV – system

Solar power plants of this type are currently very common, because in the general case, such plant consists of a large number of individual modules (solar panels) various capacities and output parameters. Solar plant of this type is widely used to supply power to both small and large objects (private cottages, resorts, motels, industrial buildings, etc.). We can install photocells almost everywhere, from the roof and facade of the building, ending with specially allocated territories. The

installed capacity also varies in a wide range, starting from supplying the separate pumps, ending with the supply of power to cities.



Figure 14 – Solar Power Plant using PV – system.

SES, using Stirling engine

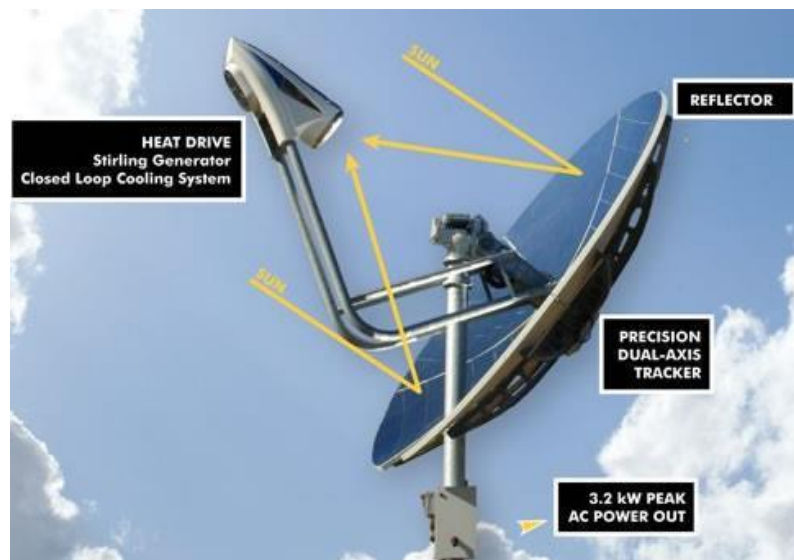


Figure 15 – Stirling Engine Solar Generator.

Represent SES with parabolic concentrators, which focus mounted Stirling engine. There are design Stirling engines that directly convert the oscillations of the piston into electrical energy without the use of a crank mechanism. This allows achieving high efficiency of energy conversion. The effectiveness can reach up to 31, 25 %. As the working fluid is hydrogen or helium.

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 to a distribution network in dependence to installed capacity:

- 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 overdraft,
- 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

Criteria for connecting electricity generating plants to the distribution network ČEZ Distribuce.

Criteria for connecting power plants to distribution network are included in Code for distribution network operators. 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
- Long term flicker, short 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:

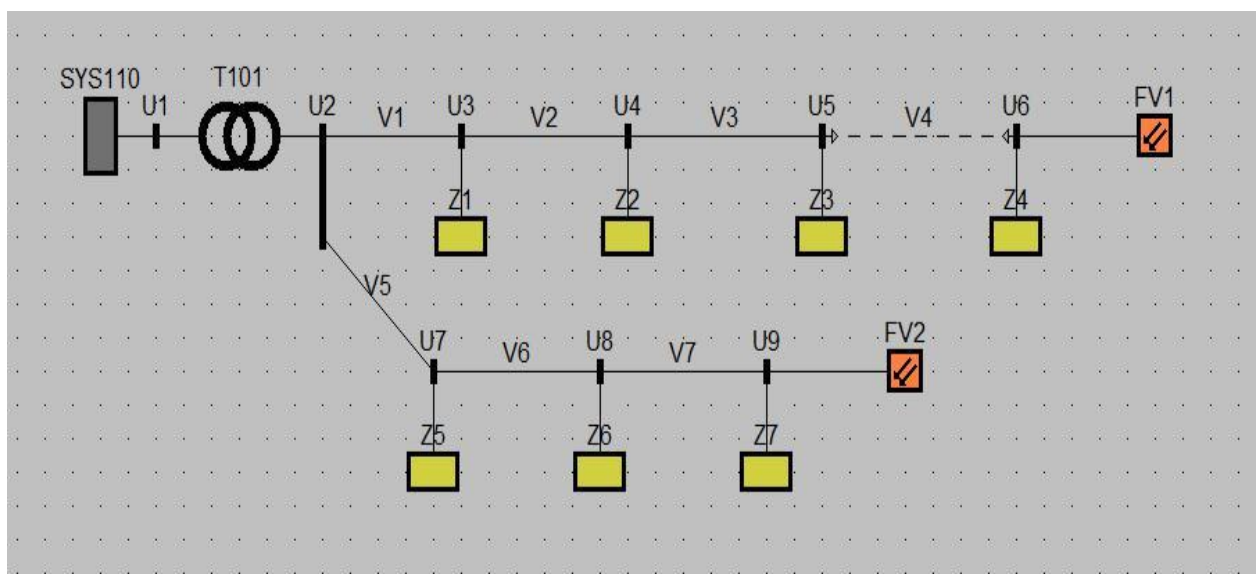
Term flicker effect can be determined by short-circuit power networks and rated apparent power of the connected source.

Flicker factor is declared by the equipment manufacturer.

Case Study

In this Case study I calculate impact of two Photovoltaic power plants to distribution network 22 kV. Photovoltaic power plant FV1 has installed capacity 1 000 kW and power plant FV2 has installed capacity 2 000 kW.

Photovoltaic power plants are connected into distribution overhead lines that distributed power in a small region in Central Bohemia. This region is supply from substation 110/22 kV.



Parameters of distribution network.

Overhead Lines.

Name of a line	Start of a line	End of a line	Distance (km)
V1	U2	U3	8
V2	U3	U4	5
V3	U4	U5	6
V4	U5	U6	2
V5	U2	U7	7
V6	U7	U8	5
V7	U8	U9	4

Parameters of Overhead Lines

Name of line	Type	R(Ω /km)	X(Ω /km)	B(μ S/km)	I _{max} (A)
V1 – V3 and V3 – V9	120AlFe6	0,225	0,363	1,469	357
V4	120AXEK CY	0,253	0,469	75	307

Load and generation in network nodes.

Name of a node	Installed power [kVA]	Power factor [-]
Z1	400	0.92
Z2	400	0.92
Z3	400	0.93
Z4	400	0.95
Z5	400	0.95
Z6	400	0.95
Z7	400	0.92
FV1	1000	1
FV2	2000	1

Transformer parameters.

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

Calculation Results

The input data are used in application E-vlivy that enables calculation of influence a new power plant into distribution network.

Voltage difference before and after connection of FV – 1.

U	dU before (%)	dU after (%)	Difference
U1	0,255	0,250	-0,005
U2	-3,833	-3,870	-0,046
U3	-3,010	-3,419	-0,410
U4	-2,636	-3,274	-0,640
U5	-2,345	-3,257	-0,913
U6	-2,290	-3,303	-1,015
U7	-3,881	-3,918	-0,046
U8	-4,055	-4,092	-0,046
U9	-4,302	-4,339	-0,047

Voltage Difference before and after connection of the FV – 2.

U	dU before (%)	dU after (%)	Difference
U1	0,251	0,250	-0,002
U2	-3,825	-3,870	-0,069
U3	-3,373	-3,419	-0,065

U4	-3,228	-3,274	-0,064
U5	-3,211	-3,257	-0,063
U6	-3,257	-3,303	-0,064
U7	-3,250	-3,918	-0,673
U8	-2,979	-4,092	-1,118
U9	-2,869	-4,339	-1,475

Conclusion of Case study.

If you compare voltage difference before and after connection of photovoltaic power plants we can certify that for connection of FV1 and FV2 limits by Czech standards are not exceeding. Both of PVPP can be connected to distribution network.

Maximal voltage difference for FV1 (node U6) is 1.015% (limit is 2%)

Maximal voltage difference for FV2 (node U9) is 1,475 % (limit is 2%).

From the case study – calculation/results – I can conclude that connection of a Solar Power Plant is the effective way to save energy. It is economical, although cost of such a plant is expensive, it can be built almost everywhere, where the Sun shines, which means, in future people shall pay less money for the energy. Nowadays usage of oil and gas will lead us to the renewable sources sooner or later. Case study shows that Solar Power Plants are the best choice.

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