Czech Technical University in Prague

Faculty of Electrical Engineering

Bachelor Thesis

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Czech Technical University in Prague

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Department of Electrical Power Engineering

Future integration of photovoltaic power plants to the grid: a case study Azerbaijan

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BACHELOR'S THESIS ASSIGNMENT

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Guidelines:

1. Introduction:
- Electrical energy is one of the most important daily needs: The importance of renewable energies has grown significantly and shown a stable reliance on its sources in the 21st century.
- The huge Pv Solar resource represents the potential to use solar to power a vast area of the earth with renewable energy.
- Many PV solar plant concepts have been proposed, but much work still needs to be done on Intelligent Distribution Systems with Dispersed Electricity Generation.
- The High-speed development of photovoltaic solar plants in Azerbaijan
- Prospective growth of renewable sources and their consumption based on productivity.
2. Renewable energy overview
• Main sources of renewables
• Wind Energy
• Solar Energy
• Biomass Energy
• Hydropower
3. Evolution of photovoltaic power plants and methods of connection to the grid
4. Photovoltaic power plant and solar in Azerbaijan, also suggest a method of integration.
6. Results & Conclusion

Bibliography / sources:

• Ghaeth Fandi; Zdenek Muller; Vladimir Krepl. Design of an Emergency Energy System for a City Assisted by Renewable Energy, Case Study: Latakia, Syria. 2018, 11, 3138 [from mdpi.com]
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III. Assignment receipt

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I hereby declare that this thesis is the result of my own work and that I have clearly stated all information sources used in the thesis according to “Methodological Instruction of Ethical Principle in the Preparation of University Thesis”.

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Abstract

In today's conditions where energy supply is increasing day by day, it is unavoidable to turn to sustainable renewable energy sources in order to meet energy needs. Our country has a high potential in terms of solar energy, which is one of the renewable energy resources due to its climate characteristics and geographical location. For this reason, in terms of the energy sector of our country, there is a need for a renewable energy planning based on natural resources, which is integrated with the environment.

This bachelor thesis dedicated to the research on development of photovoltaic power plants in Azerbaijan. First part is about the overall approach to the renewable energy sources(study case as solar energy) and the second part is about the development of photovoltaic power plants in Azerbaijan. The importance of project based on the close future to gain enough energy without utalization of unrenewable energy sources.

Abstrakt

V dnešních podmínkách, kdy se dodávky energie každým dnem zvyšují, je nevyhnutelné obrátit se na udržitelné obnovitelné zdroje energie, abychom uspokojili energetické potřeby. Naše země má vysoký potenciál, pokud jde o solární energii, která je díky svým klimatickým charakteristikám a zeměpisné poloze jedním z obnovitelných zdrojů energie. Z tohoto důvodu je z hlediska energetického sektoru naší země zapotřebí plánování obnovitelné energie založené na přírodních zdrojích, které je integrováno do životního prostředí.

Tato bakalářská práce se věnuje výzkumu vývoje fotovoltaických elektráren v Ázerbájdžánu. První část pojednává o celkovém přístupu k obnovitelným zdrojům energie (studijní případ jako solární energie) a druhá část se týká rozvoje fotovoltaických elektráren v Ázerbájdžánu. Význam projektu založeného na blízké budoucnosti pro získání dostatku energie bez využití neobnovitelných zdrojů energie.

Keywords

solar system, solar panels, renewable energy, photovoltaic, alternative energy, photovoltaic systems, solar farm, solar powered generator, windmill, hydropower, biomass energy, hydroelectric energy, photovoltaic cells.

Klíčová slova

solární systém, solární panely, obnovitelná energie, fotovoltaika, alternativní energie, fotovoltaické systémy, solární farma, solární generátor, větrný mlýn, vodní energie, energie z biomasy, vodní energie, fotovoltaické články.

List of Abbreviations

CSP - Concentrated solar power.

PV- Photovoltaic

E - The generated energy for each year.

HAWT - Horizontal axis wind turbines

VAWT - Vertical axis wind turbines

HPP - Hydroelectric power plants

CdTe - Cadmium telluride

CIS - Copper Indium Diselenide

FPV - floating photovoltaics

IRENA - International Renewable Energy Agency

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1. Introduction

Energy has a significant role in our life. In present-day, the work in all areas is automated, and the emergence of new technologies day by day puts us in a state of dependence on energy in all sectors such as business, education, health, industry, communication, transport, food and etc. There are different types of energy sources such as light energy, electrical energy, heat energy, mechanical energy, gravitational energy, sound energy, chemical energy, nuclear or atomic energy. [1]

Nowadays, people mostly use energy from non-renewable energy sources such as a burning of oil, coal, natural gas which can cause breathing problems because of releasing Sulphur dioxide. This type of energy source is depletable and it needs an enormous amount of time to be naturally refilled. In addition to that, they release carbon dioxide to the atmosphere, that is one of the main reasons of global warming and have large-scale damage to the environment. However, renewable energy does not damage human health and the environment, due to generating electricity far from the cities. According to replenishing the source quickly, renewable energy technologies are intensifying day by day as against fossil fuel. [2]

When comparing green technologies, photovoltaic technology which alternates sunlight to electrical energy using semiconductors, has had a huge gain in the last years. Photovoltaic solar energy has an enormous yielding potential because of a huge amount of solar resources that can be reserved at the same amount of the whole reserves of oil, coal and natural gas, just in 18 days of sunshine on Earth. According to statistics of photovoltaic power in the European Union was 2.17MW in 2005, just in 14 years it raised to 130.67MW. These values are still not sufficient for covering European Union 100% with solar energy, that is why this technology needs to be integrated for higher values. There are several countries such as Iceland, Norway, Kenya, Sweden and so on, can provide an important amount of energy from renewable resources, that's why integration of renewable energy technologies has to be upgraded for ignoring environmental pollution, decreasing operational costs etc. Solar-grid integration is the most significant part of it. The further magnification of this industry broadly depends on diminishing the bulk of total installed system costs and operational costs, regulated photovoltaic systems into grid developments enhancing the building energy balance and it has enormous opportunity for cost reduction. [3, 4]

Many countries such as Italy, China, Turkey, India, Czech Republic and so on are ensured with traditional energy sources such as oil and gas by Azerbaijan, because of having huge amounts of energy sources. In addition to the gradual depletion of traditional energy sources forced to use alternative energy sources in Azerbaijan, as well as around the world. The development of solar energy is more promising because of the natural climatic conditions of Azerbaijan and there are 300 days that are sunny in a year. [5, 66]

2. Renewable energy

2.1. Wind energy

Wind power; It is a natural inexhaustible, perfect and everlasting force and its source is the sun. The breeze, which takes its source from the temperature distinction that happens because of the various points of the sun falling on the earth, is shaped by the relocation of hot and cold air. The cold air layer descends towards the ground and wind is formed as a result of this displacement. A small part of the solar energy that reaches the world is changed over into wind energy. As the air moves rapidly and covers the whole climate, it transforms into kinetic energy by quickly changing its area. The focuses that produce power from the breeze energy shaped in this manner are called wind power plants. With wind power plants, the kinetic energy of the air turns the propellers and converts the motion energy into electrical energy with a generator. Wind turbines are machines that change the dynamic energy of the moving air first into mechanical energy and afterward into electrical energy. [7]

The way that breeze energy is spotless and sustainable builds the significance of this energy type. Pretty much every nation can give wind energy. Nonetheless, effectiveness can differ contingent upon the speed and congruity of the breeze. The utilization of wind energy gives extraordinary preferences, as different areas on the outside of the world are reasonable for wind. On account of wind energy, it has been seen that power age can meet utilization extremely and wind energy has picked up significance from year to year.

Onshore and Offshore wind turbines

Turbines to be introduced for wind energy can be introduced ashore just as in oceans. Onshore wind farms have huge installations of wind turbines on land, however offshore installations of wind farms are located in bodies of water.

a.Offshore wind turbines b.Onshore wind turbines

Figure 1: Wind turbines(a,b) [9, 10]

Because of the totally extraordinary nature of their areas, onshore and offshore wind energy have practically inverse pros and cons. The points of advantages and disadvantages of onshore and offshore wind energy can be discussed from four viewpoints: Cost, location limitation, environmental impact, and capacity factor. Compared to offshore wind farms, cost of onshore wind farms are relatively low-priced, on the other hand, in view of their difficult to arrive at areas, Offshore wind farms can be costly to assemble and keep up, they are defenseless to harm from extremely high-speed winds during storms which is costly to fix. It is illegal to fabricate wind turbines because of their sight and noise emission in specific zones where normal protection is the need or residential conditions must be thought of. On the contrary, offshore wind turbines do not often face limitations for installation. Onshore wind turbines are present hazards to flying creatures like birds and bats, the influence of offshore wind farms on marine life are not fully understood yet. Onshore wind turbines are more likely to have lower limit factors on account of their environmental factors such as natural landscapes: forests and hills or man-made structures like buildings or towers. These factors can slow down the incoming wind, despite this, offshore wind turbines do not test such issues. Typically out at sea, it has much higher potential of wind speed which allows for more energy to be generated, nothing can block or impact the wind speed over open water, that’s why this wind is more sustainable and stronger. [6, 8]

HAWT and VAWT

Regarding the base shaft direction of wind turbines, they can be differentiated into two types. Horizontal axis wind turbines (HAWT) operate with their rotation axes parallel to the direction of the wind and their blades perpendicular to the direction of the wind blowing. With the blades being perpendicular to the wind blowing direction, the turbine rotor can hold the maximum energy and the rotation of the blades can generate more energy compared to VAWT. Be that as it may, the establishment of this sort of turbine needs a severe support for the tower to help the heaviness of the blades, gearbox and generator just as using a sizable crane to lift the parts to the highest point of the tower. [14]

a.Horizontal axis wind turbine b.Vertical axis wind turbine

Figure 2: Construction of wind turbines (a, b) [12, 13]

In vertical axis wind turbines (VAWT), rotational motion occurs due to the difference in pulling force between the concave and convex surfaces of the blades. The rotation axes of these turbines are vertical.

It is the oldest type of wind turbine used due to its simplicity of operation. Vertical axis wind turbines have lower efficiency than horizontal axis wind turbines.

Different blade numbers

Regarding the quantity of blades, wind turbines can be grouped into single blade, double blades, triple blades and multiple blade types. The quantity of blades is dictated by numerous components including streamlined productivity, unpredictability, cost, commotion and style. For the most part, enormous scope wind turbines embrace double or triple blades. Wind turbine with fewer blades requires higher revolution speed to utilize the wind power, accordingly, making more noises. Then, an excessive number of blades will influence one another and lessen the working efficiency. At present, three blade wind turbines predominated the market, halfway in light of the fact that they look steadier and aesthetic. [11]

Upwind Turbines and Downwind Turbines

In upwind machines that have been utilized generally for quite a long time, the rotor face is facing the wind. Its most significant advantage is that it has little exposure to the wind shading effect behind the tower, that is, the wind arrives at the tower by leaning. Even if the tower is round and flat, the power produced by the turbine diminishes with each passing of the wing through the tower. Therefore, the wings must be made rigid due to the wind pull and the wings must be placed at some distance from the tower. Also, frontal wind machines require a "Yaw" mechanism to turn the rotor against the wind.

The rotors of downwind machines are placed behind the tower. Their important advantage is that they do not need the "Yaw" mechanism to return to the wind. If the nacelle and rotor are designed appropriately, the nacelle passively monitors the wind. A more important advantage is the flexible feature of the wings. This is an important advantage in terms of both weight and power dynamics of the machine. Thus, the advantages of these machines; It is the reduction of the tower load as a result of making it lighter than machines with frontal wind. However, the power fluctuation that occurs as the wing passes through the tower will do more damage to the turbine than machines with frontal wind. [15]

2.2. Solar energy

As it is known, the solar system consisting of the Sun and its surrounding planets is a basic energy source for the world. In particular, it is an undeniable fact that the sun is an indispensable source for living creatures on earth. The vast majority of the different energy sources used today have emerged or have come into being as a result of events caused by the sun. Earth with solar energy can be illuminated; Water cycles can be achieved with rainfall and most importantly, living life can be maintained by photosynthesis. Industrially, energy can be produced from this star, which is of vital importance to our world.

The Sun is a star with a diameter of 1,400,000 km (about 110 times the earth's diameter), a mass of $2x10^{30}$ kg (about 330,000 times the earth's mass), and it turns around its own pivot. It is known that in the center of the sun, a fusion reaction occurs mainly by the fusion of hydrogen nuclei and the temperature reaches approximately 15-16 million ° C. In this context, it is stated that approximately 90% of the sun consists of hydrogen [16].

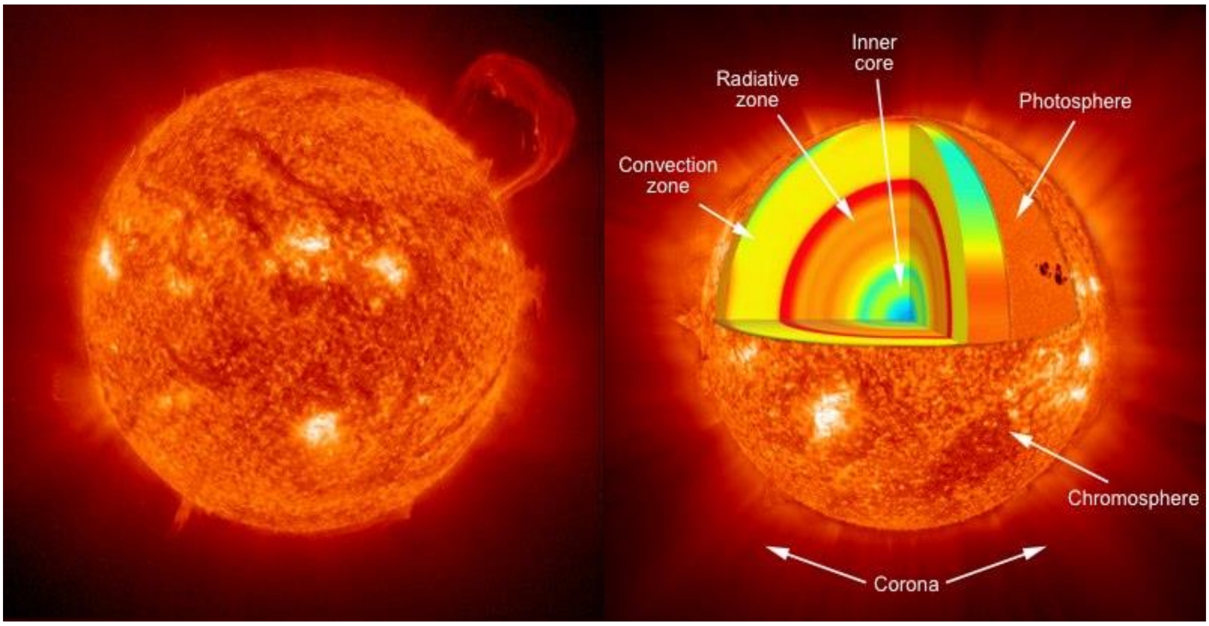

Figure 3. The Sun with its layer structure depicted[17]

In the core of the sun, helium nuclei are formed by fusing hydrogen nuclei, and this response brings in a great deal of energy. Since the total radiation of the sun is 3.8x1026 J / second, approximately 600 million tons of protons, in other words hydrogen, are consumed in the sun in one second. Although this number may seem frightening at first glance, considering that the mass of the Sun and nearly 90% of this mass are formed by protons, it turns out that there is still a period of approximately 5 billion years for the hydrogen fuel in the Sun to be consumed. In this respect, it is stated that the sun is an inexhaustible source of energy for humanity [18].

Electricity is produced from solar energy by two methods: Concentrated Solar Power (CSP) and Photovoltaic technology.

Concentrated Solar Power

Concentrated solar thermal power plants (CST) are used as a source of renewable heat energy or electrical energy. CST systems focus the sun rays falling over a wide zone through mirrors and sun tracking systems connected to these mirrors into a single small area. The concentrated daylight is then used to generate the heat required for conventional power plants. In addition, the generated heat energy can be used for other purposes.

There are four optical types which are used by Concentrating technologies: parabolic trough, solar power tower, concentrating linear Fresnel reflectors and dish Stirling. Different types of concentrators generate various pick temperatures and thermodynamic efficiency. However, the way these methods use solar energy and their solar tracking mechanisms are different from each other. Thanks to advances in technology, these Concentrated solar energy methods are becoming cost effective day by day. [19]

Solar photovoltaic technology

Photovoltaics (regularly abbreviated as PV) gets its name from the way toward changing over light (photons) to electricity (voltage) by solar cells, which is known as the photovoltaic effect. The photovoltaic effect can be summed up as sunlight striking a semiconductor and making electrons be energized because of energy in the sunlight(photons). The thrilled electrons become liberated from their atomic structure and, in moving away, they abandon 'holes' of relative positive charge that can likewise move throughout the material. By setting two various semiconductors together in slim layers the free electrons and 'holes' can be isolated at their interface, making a distinction in charge, or voltage, across two materials. A single photovoltaic device is called a cell that generates only a modest voltage and current which is around 1 or 2 watts of power. When photovoltaic cells are electrically connected in series or in parallel, they can obtain a useful amount of current, voltage or power levels. [19, 20]

2.3. Biomass energy

Biomass is the name for a range of organic matter such as forestry products, energy crops like miscanthus, agricultural byproducts like straw and animal manure. While organic substances, which are sources of energy, are synthesized by photosynthesis, the oxygen necessary for living things to breathe is also released into the atmosphere. Carbon dioxide, which is produced as a result of the burning of organic substances produced, has been taken from the atmosphere during the formation of these substances, so energy from biomass. We can generate electricity from biomass in a way that is close to carbon neutral over the materials life cycle. It will not be sustainable if we use biomass faster than we grow it, otherwise we end up with more CO_2 in the atmosphere. [23, 27]

Figure 4: Overall system of biomass energy(Australia)[24]

It is possible to divide biomass energy into two classes as classical and modern. While logging, simply burning wood and animal waste is in the classical biomass energy group, fuels such as biodiesel and ethanol obtained from energy crops, energy forests and wood industry wastes are included in the group of modern biomass energy resources. [23]

Biomass Conversion Technologies

In general, biomass-to-energy conversion technologies have to deal with a feedstock which can be highly variable in mass and energy density, size, moisture content, and intermittent supply. Therefore, modern industrial technologies are often hybrid fossil-fuel/biomass technologies which use the fossil fuel for drying, preheating and maintaining fuel supply when the biomass supply is interrupted. Biomass can be changed over into a few valuable types of energy utilizing conversion technologies. [25, 26]

1. Direct combustion processes
    - Co-firing
2. Biochemical processes
    - Anaerobic Fermentation
    - Methane Production in Landfills
    - Biodiesel
    - Ethanol Fermentation (to ethanol)
3. Thermochemical Processes
    - Pyrolysis
    - Gasification
    - Carbonization
    - Catalytic Liquefaction

2.4. Hydropower energy

One of the principal uses of hydro energy was for mechanical processing, for example, pounding grains however today present-day hydro plants produce power utilizing turbines and generators. Hydroelectric energy is a type of energy that harnesses the intensity of water in motion (such as water streaming over a waterfall) to produce power. This renewable energy transforms the potential energy of water into kinetic energy.

The source of hydraulic energy, one of the oldest energy sources used, is water. There are some procedures while generating energy from water. Most hydroelectric stations use either water redirected around the regular drop of a waterway, for example, a waterfall or a dam is worked over the stream to raise the water level and ensure enough water flow to generate a driving force. It flows through the plant intake into a pipe called a penstock which carries it down to a turbine waterwheel at the lower water level. The water pressure increases as it flows down penstock. Turbine which is connected to the generator is driven by pressure and flow. Inside the generator is the rotor that is spun by the turbine. Large electromagnets are attached to the rotor located within coils of copper wire called a stator as the generator rotor spins the magnets a flow of electrons is created in the coil of the stator. This produces electricity that can be stepped up in voltage through the station transformers and sent across transmission lines. [28, 31]

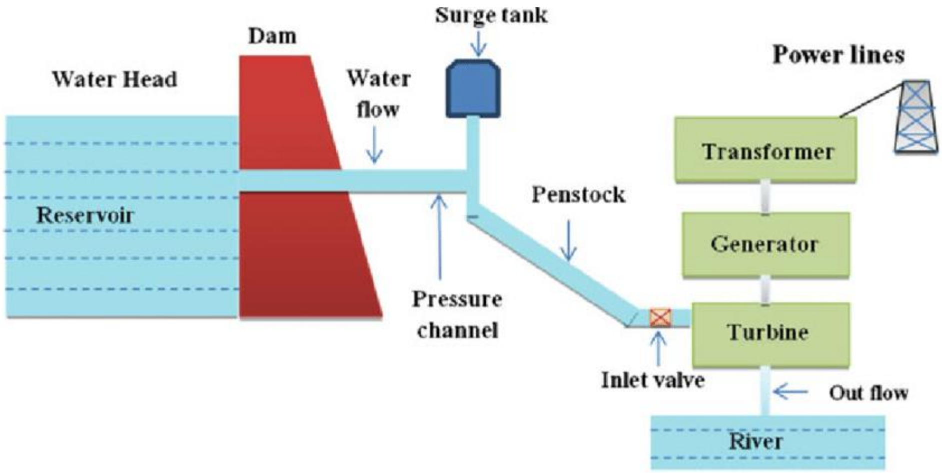

Figure 5: Schematic diagram of HPP

Hydroelectric power plants are the most important renewable energy resources and have the largest share in energy production. Potential energy of water carried high by rain and snow is converted into electrical energy by means of turbines and generators. Hydroelectricity is one of the energy resources groups that is qualified as renewable because rainfall is repeated every year. [29]

There are three main types of hydroelectricity:

- Impoundment
- Diversion (Run-of-river)
- Pumped storage

Impoundment facility utilizes a dam to keep and control the flow of water in the pool or reservoir which is coming from the river. When water is released from a dam, the presence of a height difference between the reservoir surface and the turbine outlet ensures energy for power generation.

The next type of hydroelectric energy plant is a diversion facility which is also called run-of-river. While comparing with impoundment plants, diversion plants have less. It uses a series of canals to channel flowing river water toward the generator-powering turbines.

The last one is pumped storage plants that act like a battery, it accumulates the energy from different sources such as solar, wind and nuclear energy and reserves this energy according to demand of electricity for future. When the demand for electricity is low, a pumped storage facility stores energy by pumping water from the lower reservoir to an upper one, however if demand is high, water that is located in the upper reservoir is released back to the lower pool and it makes the turbine turn to produce more energy. [33]

There are various sizes of hydro plants that produce electricity:

- Large hydropower
- Small hydropower
- Micro hydropower

Large hydropower plants have more than 30 MV capacity which is enough to provide electricity to many consumers. The other types of hydropower operate for their own energy needs or to offer capacity to use. Small hydropower has capacity from 100 kilowatts to 10 MV and micro hydro power plants have up to 100 kilowatts. The Three Gorges Dam in China is the largest hydroelectric dam in the world that is able to generate 22500 megawatts of power. [33]

Figure 6: The Three Gorges Dam in China [30]

Hydroelectric creates electricity without carbon dioxide emissions, electricity without acid rain, mercury and other pollutants. It is completely renewable unlike wind and solar power. It's reliable that water in certain areas always flows but the water flow can be changed to meet times of need. They are environmentally friendly systems since they do not create any waste during and after electricity generation. It is the most reliable source of renewable energy, which is established by far. There is some period when the sun goes down or wind stops blowing, however water always has regular and steady flow 24/7. Hydraulic plants are activated very quickly for maximum energy need and can be deactivated very quickly in emergencies. Since it uses natural resources as raw material in the investment made, it is not externally dependent, that is why production costs remain the same depending on the state of external resources. Hydropower is adjustable, it can generate more energy when it needs and it can decrease the amount of energy output when it is not required. The other renewable energy sources are not able to be adjustable.

It has such pros as well as cons, the most important disadvantage is the greenhouse effect. Although the greenhouse effect does not emit gas or waste, they affect the climates of their regions as a result of the formation of large lakes and water basins. Due to the fact that the methane gas carried by the plant and animal wastes at the bottom of the rivers and lakes is rapidly rotated from the turbines and released, such power plants have a greenhouse effect in their production. The installation costs of hydraulic power plants are high, construction durations are long and it may be adversely affected by rain. [34]

3. Evalution of photovoltaic power plant and methods of connection to the grid

Photovoltaic power plants are based on the principle that solar radiation is converted into electricity. It is a system consisting of several different components, which will be described in the following subchapters. The basis of the whole operation is considered to be a photovoltaic cell, which is built into each photovoltaic panel and in which solar energy is converted. The electrical efficiency of this conversion depends on its PV cell materials. Silicon cells with a maximum efficiency of 20% are most often used. The production of electricity depends mainly on the intensity of solar radiation. When ideal conditions occur, the intensity of solar radiation reaches approximately 1 kW/m^2 [36].

Photovoltaic power plants are located in buildings are often either integrated into them or mounted on to their roofs. In such a case, it is mainly the use for own purposes or within the energy system, where the majority of the produced electricity is supplied to the distribution system. [37].

In general, a photovoltaic power plant (PVPP), often referred to as a solar or solar power plant, is considered to be a device that operates on the principle of a photovoltaic effect that takes place in photovoltaic cells connected in the form of a photovoltaic panel. This makes it possible, as already mentioned above, to convert solar radiation into direct current, which is converted into alternating current in the converter. It can be used directly or stored in the battery. [38]

Based on the above, it is quite clear that photovoltaic power plants are very simple gadgets. In addition, However, it does not have to achieve too much power, especially if it is the purpose of your own electricity needs. That is sufficient with a couple of photovoltaic panels. This chapter will discuss this issue, the methods of connection and connection to the distribution network.

3.1 Development of photovoltaics and its place in renewable energy sources

History has preserved the fact that the Sun is considered the giver of earthly life. It is a source of energy in the form of sunlight. It is formed inside the Sun by combining hydrogen nuclei at a temperature of 15 million ° C. This method of producing solar radiation has been functional for more than 5 billion years. According to the above, the sun is therefore understood as a thermonuclear reactor, with the ability to convert 600 million tons of hydrogen to helium in a single second. Thanks to this process, an energy of 3.8×10^{26} Joules is produced. [39]

Therefore, annually, the amount of solar energy that hits the earth's surface is approximately 8000 times the world's primary energy consumption in 2009. Therefore, it would be enough to use only 0.01% of all energy produced by solar radiation to cover global electricity consumption. [40] With a view to predicting the depletion of fossil fuels in the first half of the 21st century (by 2050), alternative, i.e. renewable, sources have been sought. From this aspect, solar energy appears as one of their forms due to the energy of the productive sun. Here you can already refer to the photovoltaic system. [41]

The concept of photovoltaics originated by connecting two words, namely photo and volta. The first word mentioned is considered to be a derivative of the Greek phós, which could be translated as light. The word volta is based on the surname of the Italian physicist Alessandro Volta. He is considered to be the inventor of the electric cell. According to him, the unit of electrical voltage was also named. The term photovoltaics can therefore be understood as the process of converting sunlight into electricity. [42]

The very history of photovoltaics is linked to a milestone in 1839, when a young French physicist, Becquerel, discovered in his experiments with metal electrodes immersed in electrolyte that a small amount of electricity began to flow through them when illuminated. However, Becquerel did not have an adequate explanation for this effect, however, this experiment is considered a major breakthrough in the field of solar energy. This led to the discovery of the photovoltaic effect, which led to further research and experiments in the following years. The production of the first photocell, a selenium semiconductor, did not take place until 1883. The American Charles Fritz is considered to be the inventor. However, this finding is associated with low efficiency, about 1%. Albert Einstein also contributed to a certain extent to the development of photovoltaics, and in 1905 he explained the regularities of this photovoltaic effect. In 1921, he received the Nobel Prize for it. The photovoltaic cell in its current form, that is, the one made of silicon, was invented by the American Russel Shoemaker Ohl. Together with the Pole Jan Czochralski, he discovered a method by which it is possible to prepare monocrystalline silicon. In 1946, it was patented in the USA. Silicon has since been considered an essential material used in the formation of photovoltaic cells, also due to the fact that this element is abundant in the earth's crust. [43]

In 1954, the first silicon photovoltaic cell was made by G. L. Pearson, Daryl Chapin and Calvin Fuller at an American research base dealing with the possibility of using sunlight. In this case, the efficiency was already around 6%, which proved to be sufficient for solar technology to be implemented in practice. From the 1950s, solar technology began to be used as a source of electricity in space satellites. However, photovoltaics did not reach practical use until 20 years later, in connection with the fall in the price of this technology. Coincidentally, after 1973 (the oil crisis), it was necessary to look for ways to reduce dependence on oil. Therefore, the implementation of alternative technologies for energy production, including solar energy, was also started. A factor enabling higher use of photovoltaics in practice was also the massive expansion of semiconductors, which were made of silicon. [43]

3.2 Basic components of a photovoltaic power plant

Photovoltaic systems provide direct conversion of solar radiation into electricity in so-called photovoltaic cells, which work on the physical principle of electric current flow between two interconnected semiconductors with different electrical properties, which are affected by solar radiation. The system of cells creates a module or panel which, due to its electrical properties, is a source of direct current. [37]

This current is used by some simple electrical devices. However, most common electrical appliances need AC power, which is supplied by the public distribution network. Where alternating current is required, a voltage converter must be included in the system, which produces alternating current from direct current. [36]

The solar cell converting light into electricity has no moving parts, which increases its reliability and significantly reduces maintenance and operation. Solar cells can generate electricity in any day's weather (their output reaches 80% of maximum power in partly cloudy skies and 30% of power in fully cloudy skies during the day). [38]

The performance of the panels is expressed by the value of the so-called nominal power (Wp). 1 Wp is the power of the device at the intensity of solar radiation of 1000 W/m2 incident on the cell at a nominal temperature of 25 ° C. These conditions are achieved in good weather at a time when the Sun is at the highest point in the sky [44]. A standard 10 x 10 cm photovoltaic cell with 10% efficiency can produce 1 watt of electricity on a clear and sunny day in Central Europe. Such cells are mounted in panels in which they are interconnected and protected on both sides by a pane of tempered glass and a plastic EVA film. The larger the area of the panel and the intensity of the radiation, the greater the current flowing through them.

Panels with dimensions of 100 x 40 cm have a nominal peak power of 40 to 50 Wp. However, for most of the day, the intensity of solar radiation is less than 1000 W/m^2, and in addition, the photovoltaic panel also heats up above the nominal temperature. This reduces the performance of the panel [44]. For typical Central European conditions, an average daily profit of 6 Wh (2000 Wh per year) can be expected from each Wp. For comparison: a 50 watt light bulb consumes 5 Wh in 6 minutes (50 W x 0.1 h = 5 Wh).

Selection of a suitable location and sizing principles

The effective performance of a photovoltaic system is based on local conditions. Therefore, it is considered important to evaluate what it will be used for, what consumption it should have (i.e. electricity production), what appliances will be connected, whether the system will be connected to the network, etc. The number of hours of sunshine is considered an important parameter in this regard and the intensity of sunlight. They vary based on how polluted the atmosphere is, different conditions in the city, different in the village and in the mountains. A number of shielding barriers also need to be considered. One of the main factors influencing the performance of a photovoltaic system is the orientation of the roof. The orientation is most ideal to the south and slightly to the southwest, but even a roof oriented to the east or west is still suitable, although the performance of the panel will have some loss. For individual orientations there are losses: east 19%, southeast 5%, south 0%, southwest 5%, west 18%. Another factor is the slope of the roof. [36] In the Central European region, the most ideal inclination is 32 ° to 35 °. For flat roofs, it is possible to raise the panel most often to a slope of 20 °, but it is usually installed horizontally, without lifting the panels, but this method is less intended for locations where it snows more during the winter, as the photovoltaic power plant will remain without yield. For the given slopes there are losses: 0 ° 14%, 15 ° 4%, 35 ° 0%, 45 ° 1%.

The size of the roof is also an important parameter. An area for a photovoltaic power plant with an output of 10 kWp - 61 m^2 is required on a sloping roof. On the flat roof, the modules need to be raised to increase the output, so we must omit the space behind them for shade, and thus the required area for a photovoltaic power plant with an output of 10 kWp to 120 m^2 will increase. [44]

Based on the given variables, it is possible to determine how much electricity the photovoltaic panel produces in one year. The production of a photovoltaic system is the ability to produce a certain amount of electricity over a period of time. It is given in watt hours (Wh) or more practical in kilowatt hours (kWh) or megawatt hours (MWh). In practice, 1 kWp of installed PV power per calendar year in Central European latitudes will produce electricity of 1,200 kWh (1.2 MWh). Of course, there are geographical differences. Photovoltaics produce electricity differently during the months of the year (of course, at night, PV plants do not produce electricity). [42]

3.2.1 Basic principle and types of photovoltaic cells

The conversion of solar energy into electrical energy consists in a physical effect that occurs when solar energy hits the surface of a photovoltaic active material (see Fig. 7). The photovoltaic active material is formed from a semiconducting layer of a PN junction, in which the energy of photons can release electrons from their bonds upon the impact of solar radiation. Photons are absorbed by this effect. When released from the lattice, the electrons become freely moving and a hole is formed at the original location of the electron. The inner field of the PN junction causes the negatively charged electron to be attracted to the conductive contact closer to the N layer and the positively charged hole to the conductive contact closer to the P layer, causing a potential difference or voltage. When the circuit is closed, current begins to flow through the circuit. However, some electrons recombine or do not participate in the flow of electric current [37].

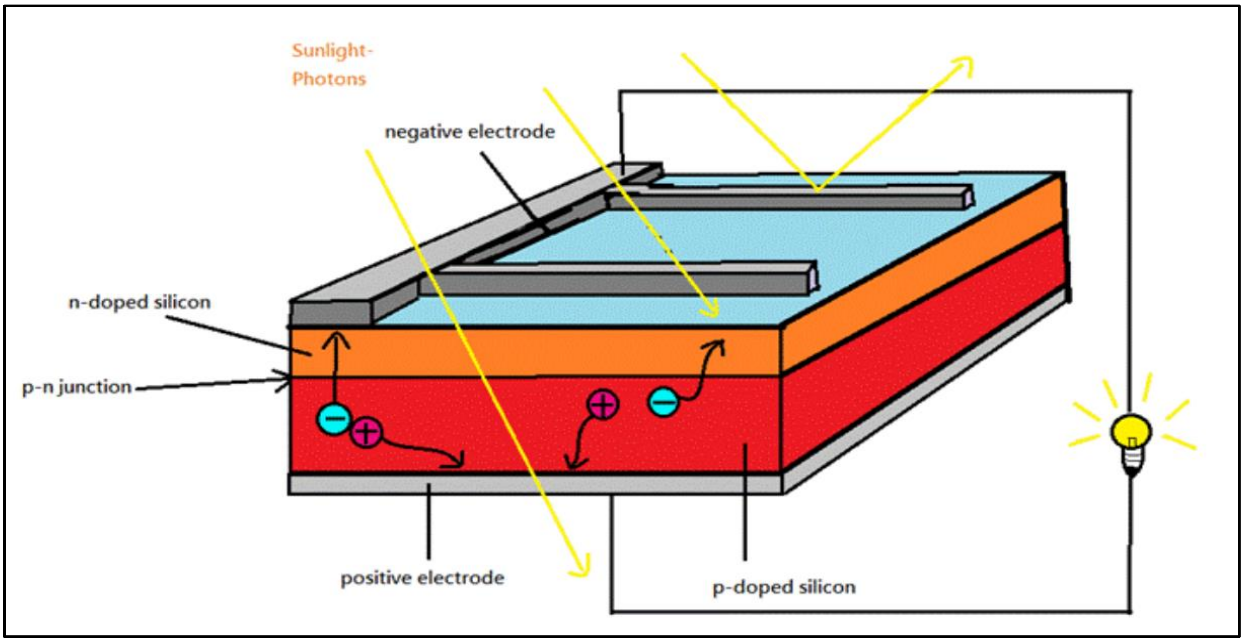

Figure 7: Graphic representation of the PV cell principle [45]

The basic photovoltaic cell consists of differently doped silicon layers P and N. The side on which the solar radiation falls is negatively doped with, for example, phosphorus (N) and the layer below it is positively doped with, for example, boron (P). In order to be able to conduct current from the layers of the photovoltaic cell, electrodes must be conductively attached to the layers. While a full-area electrode is used on the back of the cell, a grid-shaped electrode is most often used on the front to cover as small an area of the cell as possible, thus allowing the best possible penetration of photons into the PN passage. To increase efficiency, an anti-reflective coating is applied to the front and a heat sink can be placed on the back. Each PV cell operates at a certain spectrum of solar radiation (see Fig. 8). [46]

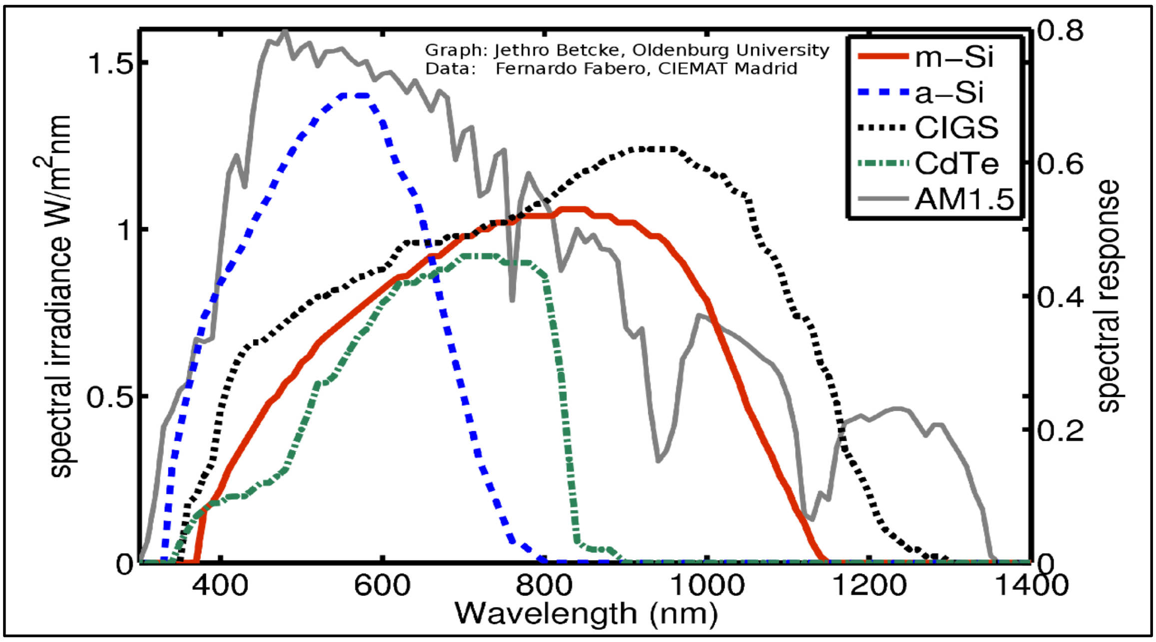

Figure 8: Sensitivity of PV cells [47]

PV cells have undergone great development since their discovery and can therefore be divided into four generations for better clarity: [38], [48]

- The first generation solar cells are made of monocrystalline silicon plates. This type is characterized by high efficiency and long-term stability. These are the most common types of articles for large installations. Their only disadvantage is the high consumption of very pure silicon, and therefore expensive production.
- The second generation is characterized by an effort to reduce production costs by using a thinner layer of silicon. Therefore, polycrystalline, microcrystalline or amorphous silicon began to be applied. Their disadvantage is their lower efficiency and durability.
- The third generation of cells began to use materials other than silicon. These are mainly electrochemical and polymer cells that have enabled the production of photovoltaic foils, which allow the cell to bend without losing its properties. It is possible to glue them during the reconstruction of the metal roof, on which they ensure water impermeability and the production of electricity. Furthermore, mainly for the army, clothes or backpacks are being made. In practice, they can be encountered rather rarely due to their low efficiency and durability.
- The fourth generation is made of composite materials, which consist of several layers of different materials. Each layer can use a different part of the spectrum of solar radiation and the part that it cannot use is passed to the next layer, which is to ensure greater usability of the spectrum of light radiation, and thus greater efficiency.

Depending on the material used and the production process during production, their production complexity, energy return, but also properties as well as sensitivity to a certain spectrum of light radiation, etc. depend on the following types of PV cells, which are described below.

Monocrystalline silicon cell

It is the oldest type, very pure silicon is used for on thin wafers of silicon. The slices are made by cutting from a rod-shaped casting to a thickness of more than 0.1 mm with a thin band saw. The resulting slices are then polished to level the surface structure and remove impurities. [49]

Newer methods make it possible to produce slices directly from the melt, thus minimizing losses. The resulting slices are of various shapes and sizes, mostly square, but because a lot of waste is generated during production, round and hexagonal ones are also used. The slice has a dark blue to black color after production. The efficiency of monocrystalline PV panels in practice reaches 15-17%. [38]

Polycrystalline cell

This type can be produced by casting in a mold of a suitable shape, so that less waste is generated during the production of square boards. Production raw material and production is cheaper, but the slices have a higher internal resistance, which causes their lower efficiency of 13-16%. The slice has a blue color and an interesting structure that resembles polished stone, so they began to be used as facade cladding. [50]

Amorphous cell

Production requires much less material, so panels are much cheaper in series production. It is possible to produce flexible panels, in the form of foils, which can also be used as part of clothing. However, they have many disadvantages, the main disadvantage being the sharp drop in power after commissioning, which stops at about 80-85% of the original power. The efficiency of the panels is only around 7%, but using multilayer technology it is possible to achieve an efficiency of around 13%. [38], [46]

Copper Indium Diselenide - CIS cell

These cells achieve the best efficiencies of up to around 11-16% within thin-film technologies so far. These panels do not undergo the aging process like amorphous panels, but are sensitive to higher temperatures and humidity. For this reason, a waterproof cover must be used to prevent the cell from coming into contact with moisture. These panels have great potential for reduction with increasing production volume. [51]

Cadmium telluride – CdTe cell

CdTe cells can be manufactured at low production costs. It is a thin-film technology with an efficiency of about 11%. The panels can be used at mains voltages up to 1,000 V, so it is advantageous to apply them to large projects. The biggest advantage is the low price of the panels and the short energy return under five months. [51]

3.2.2 Electrical properties of photovoltaic cells

Three magnitudes are mainly important for the use of an electric power source: electric voltage, electric current and internal resistance of the source. In the case of photovoltaic cells, the no-load voltage is mainly determined by the material of the PN cell passage used. The PV cell acts as a constant current source, the intensity of which is limited by the number of photons incident on the PN passage layer per unit time. A volt-ampere characteristic is used to characterize the source, i.e. the current-voltage dependence. However, the current of the photovoltaic cell is affected by several parameters, such as lighting, temperature, internal resistance. For this reason, there is an effort to operate the panels in conditions where they achieve the highest possible performance. As the temperature increases, the performance of the panels decreases, most panels achieve the highest performance at 25 ° C, so the effort is to get as close as possible to this temperature. In practice, cooling is used for larger installed capacities, but for small installations the use of cooling would be unprofitable. To maximize energy gain, modern MPPT inverters have been developed that can load a photovoltaic panel to maximize its performance. The power of the panels is given at a solar radiation intensity of 1,000 W/m^2. [38], [44]

In the winter months, at a lower temperature of the panels, higher efficiency is achieved, in the summer the panels usually reach a temperature of around 50 ° C, it is reported that the nominal power of the panel decreases by 0.4-0.5% due to a 1 ° C increase in PN pass temperature. Nevertheless, 80% more energy can be obtained from panels in summer than in winter. [46]

The performance of a PV is also affected by its shading. Since the cells on the panels are connected in series, when one of them is shaded, the maximum current of the panel is equal to the smallest current of the cell in the branch. At the same time, this cell becomes an appliance and begins to heat up, this point is also called a hot spot. In the worst possible case, this cell will burn out and the whole panel will be broken. To solve this problem, a bypass diode is used, which conducts current outside the shaded cell, usually one diode is used to bridge 18-20 cells. This connection increases the performance of the panel in case of partial shading and protects the panel from destruction. [46]

3.2.3 Improving the performance of photovoltaic panels

Developing the efficiency of photovoltaic panels is advantageous due to the high price of the panels. It is possible to increase the efficiency by increasing the intensity of the radiation that hits the PV cell and is consumed by it. The materials of photovoltaic cells have a relatively high refractive index of light, and therefore part of the incident light is reflected. Especially if it falls at a small angle. For this reason, the efficiency of PV panels can be boosted by using an anti-reflective layer on the surface of the PV panel. For example, by creating a pyramidal structure on the surface by etching, we facilitate the entry of photons from the structure and prevent the output of photons reflected from the back of the panel. [51]

Another possibility to increase the efficiency of PV panels is the use of transparent contact layers made of conductive material, usually tin oxide. This reduces the shading of the surface of the PN passage through the electrode grid. By using double-sided panels, it is also possible to increase the performance of the panels. Recommended especially for panels mounted on white or silver substrates with a high proportion of reflected light or with mirror concentrators. Manufacturers report an increase in energy production of up to 30 %. [49]

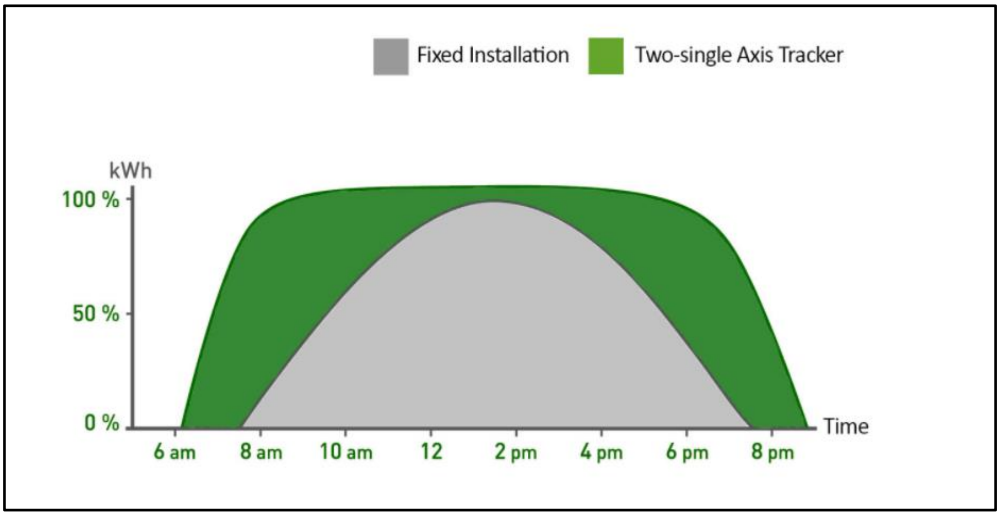

Figure 9: Comparison of the performance of a module mounted on a fixed structure and a monitoring device [52]

The simplest constructions do not allow changing the inclination of the panels in any axis. A significant increase in daily electricity production can be achieved by using a structure for mounting PV panels with the possibility of rotating the panels (see Fig. 9).

Small systems use constructions that allow the angle of the panels to change with respect to the height of the Sun above the horizon. On these structures, the angle to the sun is manually adjusted several times a year according to different periods so that the rays fall perpendicular to the panel. Small systems also use a more complex design, which allows you to monitor the daily movement of the Sun across the sky by automatic rotation in one axis. adjusting the inclination of the panels to the height of the Sun above the horizon is still manual. In large systems, automatic panel tilt adjustment is used, as well as daily monitoring of the Sun. These systems are usually controlled by a computer, which adjusts the rotation of the panels in both axes so as to guarantee the highest efficiency of the PV panels [48].

Increasing the lighting intensity of the panels is also possible by using concentrators. The concentrators collect solar radiation from a large area and concentrate it in one point, i.e. on the PV panel, thus increasing the electric current it supplies. The use of concentrators is advantageous because they are cheaper than PV panels and their use allows the use of more efficient panels at a higher cost [49].

In practice, many types of concentrators are used, which can be divided into groups [53]:

- Mirror: with plane mirrors, with parabolic mirrors, compound parabolic concentrator CPC
- Lenses
- Other (Dielectric, fluorescent).

However, the use of concentrators also has many disadvantages, so we do not encounter them so often. One of the cons is the small use of diffuse radiation or the need tracking behind the Sun. Optical losses that occur when using mirrors, lenses, or uneven illumination of the module reduce efficiency. With a high concentration of solar energy, the PV module overheats, which not only brings less efficiency, but could even destroy the entire PV module. For this reason, it is necessary to use active cooling. [53]

3.2.4 Environmental friendliness of photovoltaic panels

As electricity consumption increases, so does CO_2 production, leading to air pollution and environmental degradation. Approximately 90% of electricity is generated without incidental carbon dioxide emissions. Increasing electricity production in nuclear power plants, which do not produce carbon dioxide, however nuclear waste from power plants has to be stored for a long time and there is also a risk of a nuclear power plant accident, which is less risky, but could have devastating consequences. For this reason, there is an effort to find ways to generate electricity that does not generate carbon dioxide and by-products [41].

According to the information obtained, the share of electricity produced in hydropower plants and also in photovoltaic plants is also increasing, however, it always depends on local conditions, depending on the length of sunlight during the day. In contrast to the conditions of Central Europe, the share of photovoltaic power plants in the world is much larger. This is due to the fact that, as mentioned above, carbon dioxide is not produced during the production of electricity from a PV power plant. However, it must not be forgotten that energy is consumed in every material processing and production of a product, otherwise this is not the case in the production of photovoltaic panels, not to mention that harmful materials are also used in the production of PV panels. [37]

The energy consumption required to produce an electrical panel depends on the production technology used and the type of panel. However, the total energy consumption for the production of PV plants should not exceed 9000 kWh per kWp of rated output [26]. When using thin-film technologies, this value is halved. The solar energy payback period in Europe is 1.8 to 3.6 years and the panel is expected to produce 8 to 25 times more energy during its lifetime than was used to produce it. [44]

However, harmful substances such as fluorine are also used in the production of PV panels. These substances have up to 23000 times more harmful effects on the climate than carbon dioxide. During production, manufacturers try to reduce leaks by using closed production cycles, but this technology is relatively expensive and not all manufacturers can afford it. For example, to equilibrate the climate balance of PV cells manufactured in Germany, the cells must produce electricity for another six months. Most of these substances are found in CIS and CdTe articles. During their normal operation, they constitute almost no risk to the environment. The problem could occur in the event of a fire, when toxic gases could begin to form. All panels are considered electronic waste, but CdTe panels are even considered special waste. [51, 54]

At the end of expiry date of its service life, all PV panels made of silicon can be recycled. Recycling takes place by separating the components of the panels by combustion at 500 ° C. The panels are broken down into basic components such as silicon, metal and glass. It is possible to re-produce the panels from the obtained components, but they have a slightly lower efficiency. However, their production can save 80% of the energy needed to produce a PV panel, and therefore their energy return is reduced to about one year. [55]

The impact of a photovoltaic power plant on the environment is minimal, but during their operation, electricity converters produce electrosmog, which they can also transmit to the electricity grid. However, modern connections prevent the transmission of electrosmog to the network. Electrosmog is low frequency or high frequency electromagnetic interference. The value of this electrosmog depends on the inverter technology. In the case of a converter with a transformer, the value of the electric field one meter from the device reaches around 0.8 V / m. [54]

In the case of a transformerless inverter, this value is up to about 17 V / m at a distance of 1 meter from the inverter. Inverters can also generate unwanted noise. A two- to three-kilowatt inverter with a transformer can emit noise of up to 35 dB and a fifty-kilowatt converter can make noise of 60 dB. For low-power transformerless converters, some manufacturers even report noise of 0 dB. For this reason, it is recommended to install the equipment outside the living space, for example in a garage or cellar. [55]

3.3 Classification of photovoltaic systems according to the methods of connection to the grid

In order to meet the diverse requirements of the market, there are three basic connections for photovoltaic systems. There are "off grid" systems, so-called stand-alone systems, for the possibility of electrification of homesteads remote from distribution networks. To reduce household costs, "on grid" systems have been designed that enable the supply of surplus to the public electricity grid. And for the best possible coverage of your own consumption, there are hybrid systems. The main advantages of this system are its use in places where connection to the distribution network would be expensive and another advantage is the independence of the system from power failure [38].

3.3.1 Grid connection systems

Systems with connection to the distribution network (see Fig. 10) are the most widespread. They are dimensioned to cover 30% of their own consumption per year. Their oversizing would increase input costs and their operation would not be economically viable. Compared to off grid systems, they are cheaper. Permission from the distributor is required for their operation. Excess unused energy is supplied to the grid or can be used to heat hot water or to run air conditioning. In the event of a power failure, the device switches off for safety reasons [54].

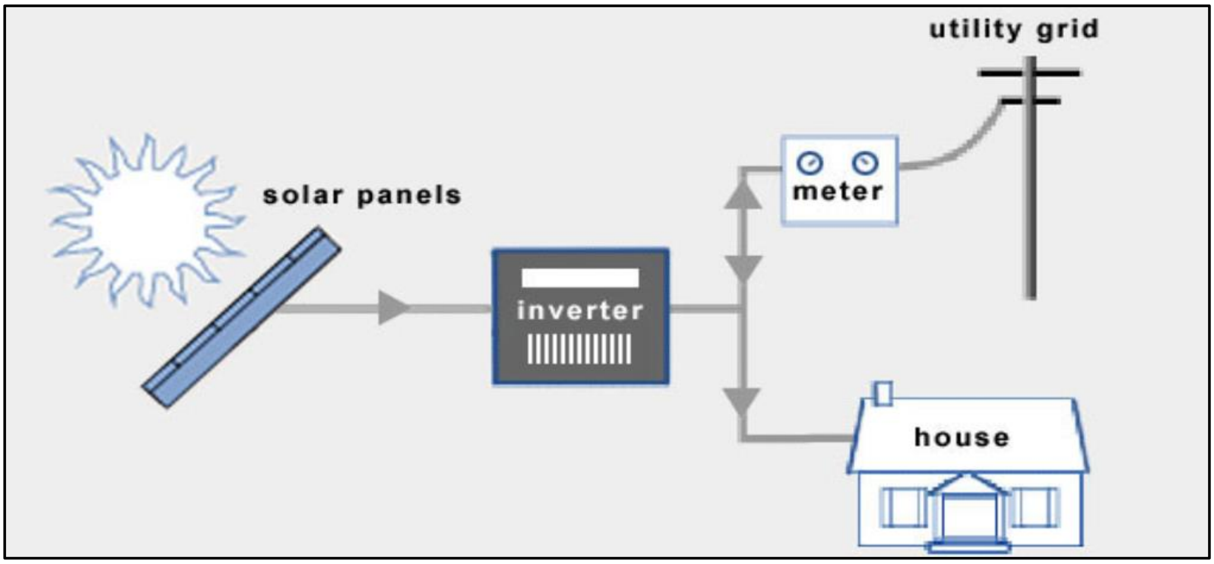

Figure 10: On grid connection of the PV plant to the distribution network [56]

These systems are most widely used in areas with a dense electrical distribution network. They work as separate power plants, where they supply excess (unused) electricity to the grid via an output electricity meter. In the case of insufficient solar radiation intensity, on the other hand, they take electricity from the distribution network through a second electricity meter. The system works completely automatically. [54]

The set contains a set of modules, a voltage converter, a device for measuring and mains protection, two electricity meters (one measures the energy consumed and the other the energy supplied to the distribution network). They are highly efficient because the electricity produced is consumed where it is needed or is supplied to the grid if there is a surplus. Systems with an output of 1 to 5 kW mounted on family houses are most often used, and in the implementation of a solar power plant, the output is around 1 to 5 MW. [55]

One of the basic elements of the set is an inverter, which converts the direct current supplied from the PV panels to alternating current (230 V / 50 Hz), or to 22 kV / 50 Hz for PV power plants. The condition is its appropriate cooperation with the distribution network. Another task of the inverter is that it provides a protective and safety function. These include fully automatic disconnection of the inverter in the event of a power failure or total power failure, short-circuit protection and protection against atmospheric discharges. [54]

To connect grid on systems to the grid, certain conditions must be followed. The first is to agree with the competent authority and the distribution network on the possibility of connection. Subsequently, it is necessary to prepare a complete project documentation and give it to the distribution system owner for approval. Finally, it is necessary to install the system, fulfill the reporting obligations, obtain a contract for connection to the electricity distribution network and carry out an inspection of electrical equipment. [37]

3.3.2 Stand-alone systems (grid off) systems

These systems (see Fig. 11) do not allow connection to the network, for this reason they must be oversized to cover the maximum consumption from the network even in more adverse conditions. This fact makes these systems quite expensive. Batteries are used to store energy, which have a limited lifespan and are relatively expensive. For these facts, they are used only for applications where it is necessary. To reduce costs, it is combined with other energy sources or backup generators to cover maximum consumption. [37]

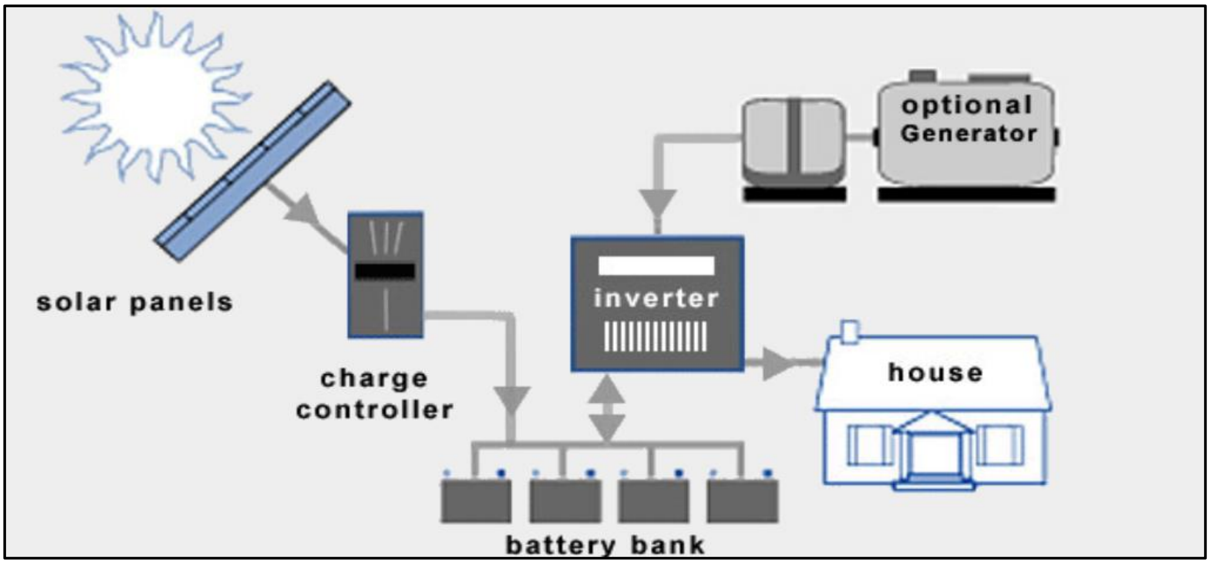

Figure 11: Grid off connection of the PV plant to the distribution network [56]

In the case of a grid off system connection to the distribution network, two subspecies are distinguished, namely as autonomous systems and as systems with direct power supply.

Grid off autonomous systems

They are built wherever it is not inappropriate to set up an electrical connection and it operate independently. The installation is suitable if the connection point to the distribution network is between 500 m and 1,000 m away. The system output is in the range from 10 to 10 kWp. The device mainly contains an accumulator, into which electrical energy is accumulated during enough radiation intensity and from which electric energy is drawn in case of low radiation intensity and at night. For trouble-free operation, the system is equipped with regulation of battery charging and discharging. Households can be connected to either direct current (12 V or 14 V) or alternating current, using inverters. These systems are mainly used for remote cottages, meteorological stations or telecommunications equipment. [57]

Grid off systems with direct power supply

This system is only used where it is not necessary for it to work continuously, because the connection only works in sufficient intensity of sunlight. The operation of these systems is therefore irregular. It is just a matter of connecting the PV module and the appliance. They are used for charging accumulators, powering solar circulation pumps, low irrigation pumps or powering electric fans for ventilation.[62]

3.3.3 Hybrid systems

Hybrid systems (Fig. 12) combine the advantages of the two previous systems. They can work in a grid connected or grid off connection system as needed, but they are more expensive than grid on systems also due to the storage of energy in batteries. If the distribution network works, it is an identical system which is connected to the distribution network (as a level of the grid on system), while the surplus does not end in the distribution network, but are stored in the accumulator or are used to heat water or run air conditioning. Thanks to energy storage, the coverage of own consumption will increase to 60%, the amount of coverage might not be economically advantageous. These systems can supply electricity even when distribution networks fail, in which case the system operates itself as a grid off system. When distribution networks fail, the system must automatically ensure the disconnection of the system from the distribution network in order to protect workers who eliminate the distribution network failure. [37], [56]

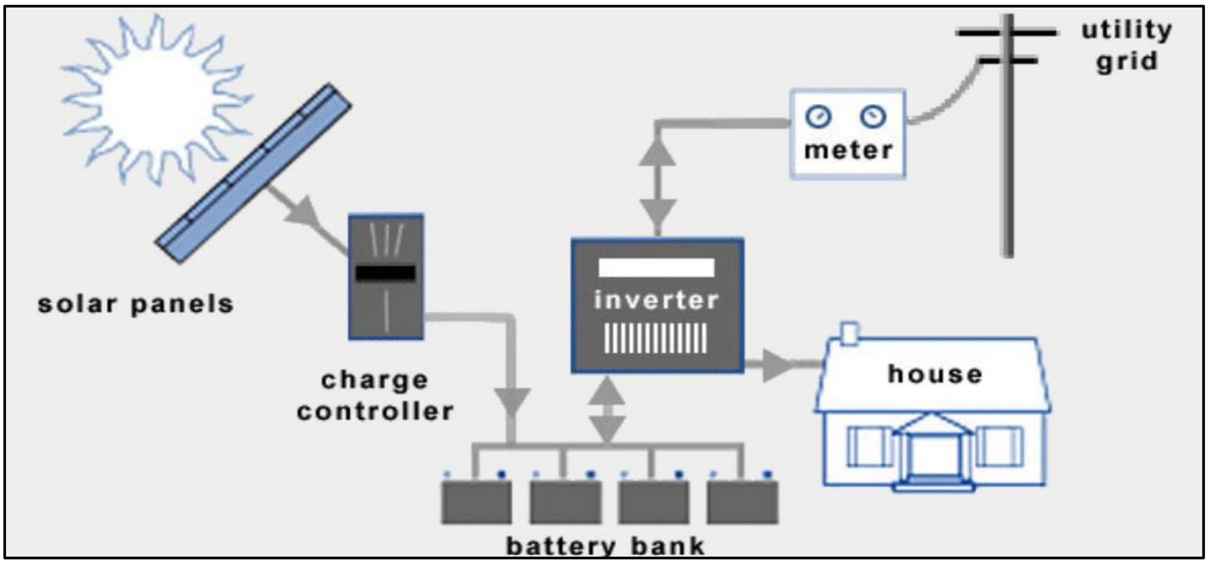

Figure 12: Hybrid system for connecting the PV plant to the distribution network[56]

It is used in places where long-term operation or occasional high-power consumption of energy equipment is expected. In the winter, the amount of electricity produced is smaller than in the summer months. If a PV system were designed for the requirements of winter operation, it would be oversized in the summer months and thus unnecessarily overpriced. In these cases, it is more appropriate to supplement the PV system with another additional energy source. Usually a wind generator, a cogeneration unit or a small hydroelectric power plant is used. Hybrid systems usually contain batteries and must be equipped with more complex regulation and control elements. [58]

3.4 Passive and active use of solar energy

The use of solar energy can be divided into two basic types, namely passive use, characterized by an effort to use the most suitable architecture, where the shape and space of the building are designed so that the incident radiation leads to the greatest possible effect. The second type is the active use of solar energy, in which solar collectors are already used for the preparation of domestic hot water, respectively. space heating and electricity generation by solar (photovoltaic) cells. [37]

Passive solar architecture is used in buildings using existing technologies and materials to heat or cool and illuminate building spaces. Such an architecture involves the integration of traditional building elements, such as high-quality insulation or energy-efficient windows, and the location of the building, respectively the layout of the interior of buildings in order to achieve the maximum energy effect. [57]

The layout of individual rooms and their orientation is a very important element in terms of heat gains and losses of the building. Solar architecture can contribute up to 20% to the energy savings required for heating in buildings. The main principle is to orient all large windows to the south. The building designed in this way consumes up to 25% less energy for heating compared to a house that is oriented to other parts of the world. Living and children's rooms should be in the southern part of the house, and other parts such as the kitchen, bathroom, storage space, hallway in the northern parts of the house or apartment. Large south-facing windows must be combined with shading elements. [59]

Another way of passive use of solar energy is just eco-architecture, it is a house with a residential attic and skylights. Living in the attic is very advantageous from an energy point of view, a house with a sloping roof and skylights has a higher gain from solar energy compared to a house with a flat roof and at the same time achieves lower energy losses, up to 19%. A positive reduction of the heated volume by about 20 to 25% while maintaining the same floor area can be taken as a positive slope. The mistaken claim that by adding each window we increase the heat loss of the building is refuted by the fact that a window of 78x140 cm installed at an angle of 45 ° with a southern orientation and low heat loss has a plus energy balance of up to +18 kW. Surveys also show that homeowners with residential attics do not start the heating season until several days later than homeowners without attics. [59, 60]

Active use of solar energy means the use of solar energy using certain technical systems, whether photovoltaic systems, concentrated solar power, and solar water heating, and such use of solar energy achieves much higher efficiency than passive use but is also more costly. [37]

In practice, water heating is considered to be the most suitable use of solar energy. This is evidenced by the fact that these systems are the most common throughout Europe. Getting heat from solar energy is no problem. The simplest system by which this can be achieved consists, for example, of a conventional container with a black matt surface. The basic problems of these systems are considered to be heat loss, storage for later use and the way in which heat can be dissipated and transported. However, it is not a condition that every solar thermal system has all the parts (i.e. collector, storage tank, transport system, control elements, backup source), and these parts are not always separate. There are also simpler systems, such as a dark black container stored in an insulated box with a transparent lid, but in this case the system is less efficient and has a short accumulation time. [55]

4. Photovoltaic power plant and solar energy in Azerbaijan

In a globalizing world, a qualitatively new economic transformation is taking place. This is not a systemic transformation, but a transition from sustainable depletion to renewable resources, which provides a different approach to previously unused natural resources for the sake of economic progress, while maintaining ecological balance. The country's geographical location and climatic conditions play a decisive role in this regard. One of the greatest needs of society is energy, and the improvement of the ways of its acquisition and use is the main goal here. Each country tries to choose the most effective way to achieve this goal, depending on the characteristics of its existing potential. For example, Japan is trying to make the most of its scientific potential at a time when its natural resources are scarce. In this country, not only energy production, but also efficient use of energy is important.

Azerbaijan, which has significant energy resources such as oil and natural gas, invests more in energy production than exploitation to ensure its further development. Because, unlike Japan, it has abundant energy sources and in reality, its scientific potential lags far behind that of Japanese scientists. In fact, this type of sustainable development is typical not only for Azerbaijan, but also for Eastern European countries.

Although the role of alternative energy sources in Azerbaijan's sustainable development is highly valued, the choice here is quite complex, and it is clear that future priorities will depend on this choice. Thus, the potential of the selected renewable energy source, the amount of investment required, the payback period of the investment, the country's production capacity in this area, geographical assessment and risk assessment are important.

According to the world's leading scientific and technological centers, the expansion in the efficiency of complex semiconductor photocells to 30% will alleviate the expense of power by 1-1.5 times. At present, in about 70 countries of the world as 600 MW in the United States, 100 MW in France, 100 MW in Israel, 50 MW in Turkey etc. solar power plants are in activity and promising projects have been evolved to increase their production capacity in the near future.

The natural climatic conditions of Azerbaijan open wide opportunities to increase the production of electricity and heat using solar energy. Thus, the number of sunny hours a year is 2500-3000 hours in the United States and Central Asia, 500-2000 hours in Russia, and 2400-3200 hours in Azerbaijan. The development of solar energy can partially solve the energy problem in many regions of Azerbaijan.

Recently, photovoltaic technology has been widely used in a number of leading countries around the world. Azerbaijan's involvement in this program can play an important role in the application of such energy systems in the region. It should be noted that the efficiency of solar power plants depends on the natural climatic conditions and geographical location of the country. Thus, the amount of solar energy per 1 m^2 of land per year is 1500-2000 kWh in the United States, 800-1600 kWh in Russia, 1200-1400 kWh in France, 1800-2000 kWh in China and 1500-2000 kWh in Azerbaijan. As can be seen, the amount of sunlight falling on the territory of Azerbaijan is higher than in other countries, which can be considered as one of the criteria for the efficiency of attracting investment in the use of solar energy. According to statistical and experimental data the use of solar energy in favorable areas of Azerbaijan is very cost-effective.

As a result of the obtained calculations, the distribution of solar energy in the territory of Azerbaijan was studied depending on the atmospheric conditions. Based on these results, two areas were selected - Nakhchivan MR and Kur-Absheron. It was determined that the annual special electric power output of the photovoltaic plant in Nakhchivan MR is 246 kWh / m^2, in Kur-Absheron 230 kWh / m^2, and the number of solar hours is 2900 hours (Nakhchivan) and 2500 hours per year (Kur- Absheron). The annual amount of energy per square meter of the area is 2200-2600 kWh (Nakhchivan) and 1900-2200 kWh (Kur-Absheron). [63]

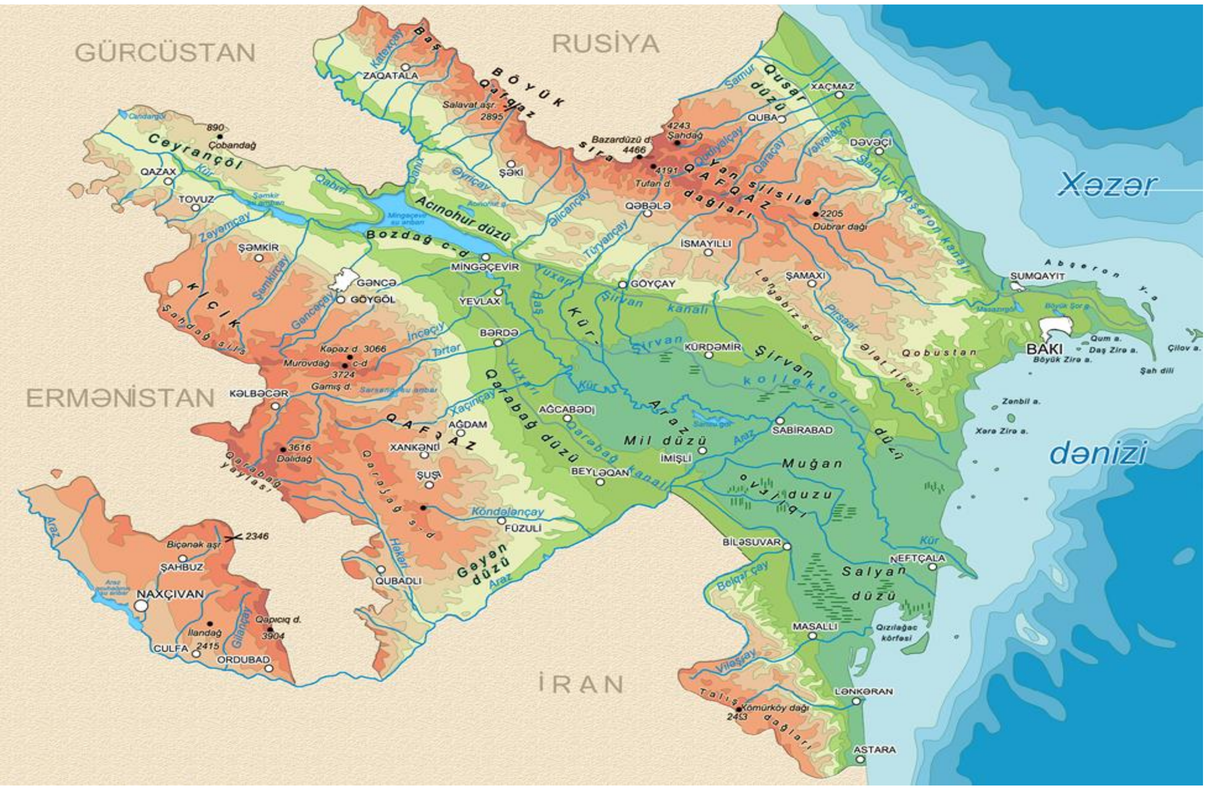

Figure 13:Climate map of Azerbaijan [73]

As can be seen from the above information, solar energy production also has great prospects for Azerbaijan. If we take into account that the Sumgayit Technology Park already produces photovoltaic cells for the production of solar energy, it produces 100,000 solar panels a year and it is clear that there will be a great real benefit only if there is some strengthened state support in this area.

4.1 Pilot Projects

The main two new pilot projects are planned to be implemented in Azerbaijan in the near future. The first project is a 100 kW PV Pilot Project to be built in Boyukshor lake for potential EPC Bidders. This project aims to demonstrate the feasibility and benefits of FPV through a pilot project, which will serve as a platform for hands-on technical capacity building. FPV performance in different configurations and water characteristics, and the potential for scale-up and replication will be assessed. A pilot FPV system consisting of solar PV panels, floating platform, mooring system, inverter/power conditioner station (land-based or above the water), cables, grid connection infrastructure, and auxiliary facilities. A complete meteorological station to be installed adjacent to the FPV and ground mounted PV systems to enable performance comparison and to facilitate hands-on technical training. A remote monitoring and data gathering system. The water is saline and was used as a dumping site for sewage and oil effluents. A 2012-2015 lake remediation program cleaned 300 out of the 1,100 hectares and built a promenade and park on its bank fronting the Baku Olympic stadium.

Figure 14. Location of the FPV plant in Boyukshor lake.

According to geological data, the average depth of the water in the lake is 3.40-3.95 meters; the maximum depth is 4.20 meters. The shoreline depth ranges from 0.50 to 1.70 meters. The lake is in oval shape and its length from the northwestern to southeastern bank is about 10 km whilst the maximum width is 1.5-2.0 km. The lake feeds from the underground waters and is completely contained from any rivers. The lake surface is 1,300 hectares and the volume is 45 million cm^3. The water on the lake has high salinity and pH.

The site selected reference coordinate is: 40.428685°N, 49.907195° W. A 95 kW floating solar plant of around 1800 m2 will be anchored at around 37 meters from the southern portion of the Boyukshor lake.

A substation is available near the project site, reference coordinate (0.427545°N, 49.908475°W) and which will serve as the connection point for both PV systems using an underground cable. The substation was inspected visually and an available switch for 3 phases of 400 A (160 kVA) has been reserved.

The project comprises the following components:

1. Floating PV plant
2. PV ground mounted reference PV plant
3. Weather ground measurement station
4. Data acquisition, storage and transmission.
5. Outdoor, environmentally friendly panels describing the project for capacity building

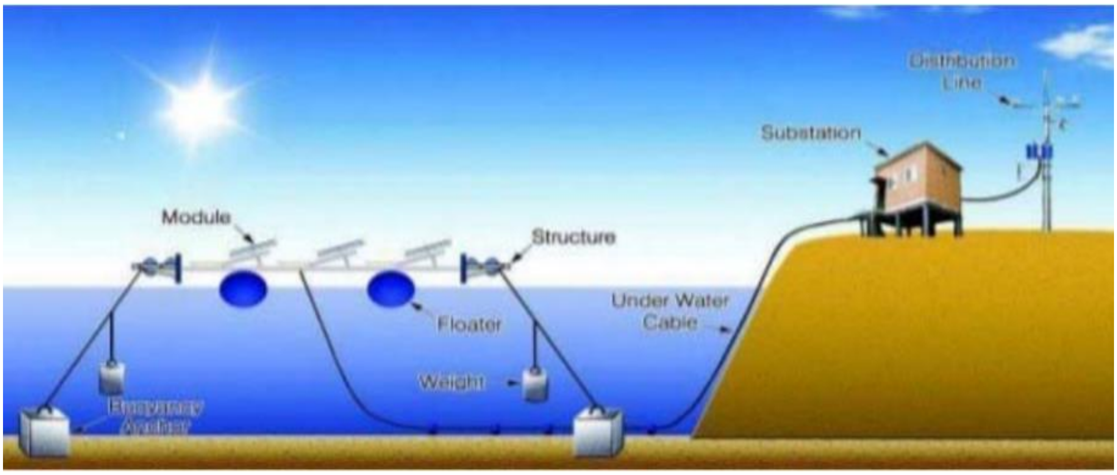

Figure 15. An indicative layout of the floating PV pilot plant

A 72-meter-long pontoon will also be installed connecting the FPV system to the shore. The pontoon and the floating solar plant will be assembled near an existing dock at the northern end of Boyukshor Lake from where it will be tugged to the installation site near the public park on the southern shore. There, it will be anchored to the lakebed and connected to the inverters. The inverter will be connected through an underground cable with around 150 m to the existing grid substation.

Further a 5 KW reference ground mounted PV plant of around 100 m^2 will be installed located near the shore of the lake and not far from the pontoon of the FPV system. This PV system will be connected to an inverter, housed jointly with one of the inverters from the floating PV system and then connected through the same AC cable connected to the substation located in the park.

A ground weather measurement station, located in the vicinity of the reference ground mounted PV system, will also be installed. It will be autonomously powered, without any power cables to the exterior. The image below shows the location of the pilot.

Figure 16. Location of the FPV and reference PV plants in the shore of Boyukshor lake

The Contractor will be responsible for designing, supplying, transporting, erection, testing, commissioning, operation and maintenance with a defect liability for a period of 2 years after commissioning and capacity. The Contractor shall make his own arrangements for transporting materials to the project sites by whichever method he chooses including arrangements for off-loading. A proposed storage and assembly area has been identified. Any limitation on loads due to local conditions, such as restrictions on bridges, availability of railway wagons, etc., shall be considered by the Contractor. The contractor will be responsible for obtaining the necessary permits for construction, commissioning and commercial operation of the PV plant.

Floating power plants are already used in a number of developed countries, such as Spain, Japan and China. The biggest one is China which is producing 40MW.

a)Murcia, Spain[67] b)Huainan, China[68]

Figure 17: Floating power plants

The Ministry of Energy of Azerbaijan Republic has signed executive agreements with "Masdar" company of the United Arab Emirates on the implementation of pilot projects on renewable energy. According to the agreements, pilot projects on construction of 200 MW solar power plants will be implemented with "Masdar".

4.2 Estimated generation of power for Nakhchivan MR

The highest radiation in Azerbaijan was recorded in the Nakhchivan region. Despite the operation of a solar power plant in Nakhchivan, more renewable energy can be obtained by using photovoltaic power plants on unused areas such as useless lands, building roof and etc. The estimated area of unused lands can be rated as 683000 m^2.

We used Photovoltaic Geographical Information System [71] to obtain specific data (Fig ,Fig) for Nakhchivan. The optimal slope of the solar panels which θ is 32 degree and average daily sum of global irradiation per square meter is G_0= 5.55 $kWh/m^2 \cdot day$ without power losses, however this value will change to G = 4.27 $kWh/m^2 \cdot day$.

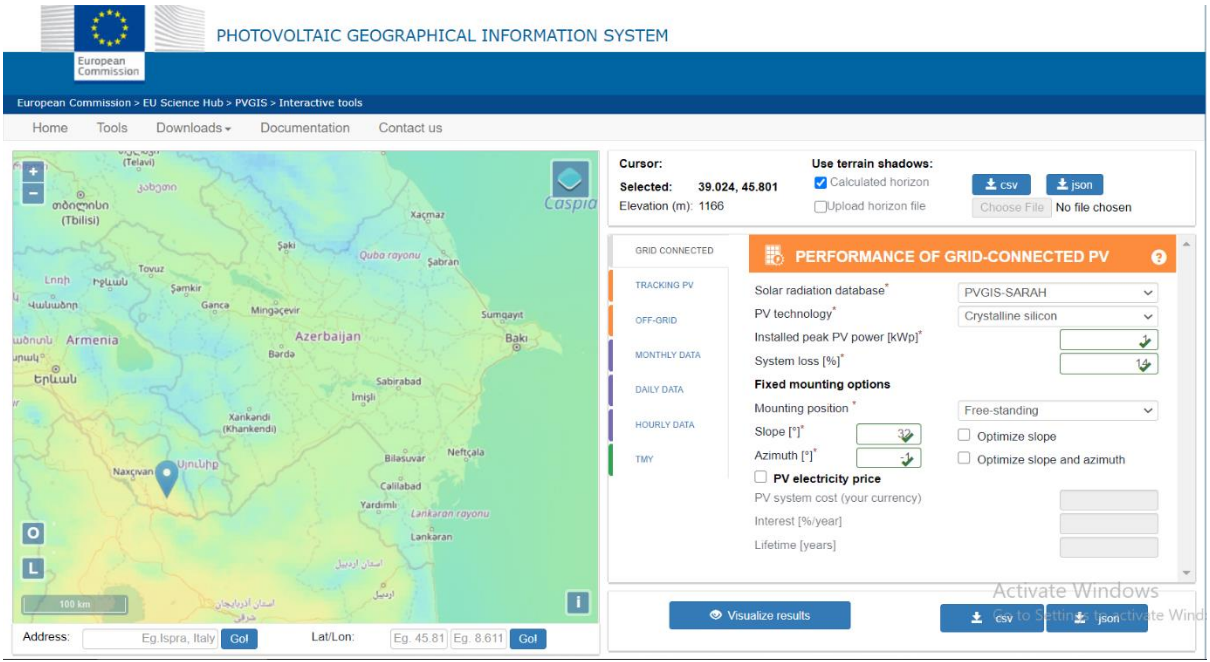

Figure 18: Photovoltaic Geographical Information System for Nakhchivan and optimal slope.

Nominal power of the PV system : 1.0kWp

Pv Technology: Crystalline silicon

Temperature and low irradiance [%]: -7.57%

Total loss [%]: -22.88%

Months	**Ed** [kWh]	**Em** [kWh]	**Hd** [kWh/m²]	**Hm** [kWh/m²]
January	2.61	81.01	3.11	96.43
February	3.23	90.56	3.93	110.07
March	3.94	122.24	4.96	153.83
April	4.48	134.35	5.84	175.18
May	4.92	152.39	6.47	202.56
June	5.39	161.67	7.39	221.76
July	5.49	170.15	7.51	232.71
August	5.56	172.29	7.50	232.43
September	5.25	157.36	6.97	209.01
October	4.06	125.75	5.24	162.33
November	3.63	108.96	4.44	133.24
December	2.67	82.86	3.21	99.64
Year	4.27	130	5.55	169
Total for year		1559.61		2029.18

Table 1: Solar radiation data and electricity production in Nakhchivan.

Ed: Average daily electricity production from the given system (kWh)

Em: Average monthly electricity production from the given system (kWh)

Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

We will try to define the area of a single panel needed for establishment. According to the area of a panel, we can calculate electricity production and the total number of PV panels for the considered area. The calculations should be made on 21 December when the sun will be most reduced in the sky where the shadow will be the longest. It is compulsory to utilize the sun's azimuth angle ψ to know the Sun's relative direction along the local horizon [72].

$$\alpha=17.07°, \psi= 140.26°$$

To calculate the distance between the solar rows it should be calculate the high of the solar panel from the Equation (1):

$$h = x \cdot \sin\theta \tag{1}$$

where: x = 1.98 m, which is length of the solar panel (m).

θ=32°: which is optimal slope angle (degree).

Therefore, h = 1.0492 m. After that it will be calculated the maximum shadow length D' Equation: (2)

$$D' = h/\tan\alpha \tag{2}$$

Therefore, D' = 3.42 m.

Then it could be calculating the distance between the solar rows D (Minimum array row spacing) from the Equation (3):

$$D = D' \cdot \cos(180 - \psi) \tag{3}$$

Therefore, D = 2.63 m. So, the area for each solar panel is sum of the area which the solar panel covers on the roof and the area of its shadow according to Equation (4):

$$S_1 = x \cdot \cos(\theta) \cdot y + D \cdot y \tag{4}$$

Where: y = 0.99 m: width of the solar panel (m).

Therefore, $S_1 = 4.264\ m^2$. So, the number of solar panels which could be installed is calculated from Equation (5):

$$N = S/S_1 = 683000/4.264 = 160170 \text{ solar panel} \tag{5}$$

The generated energy from the selected solar panel is calculated using the Equation (6):

$$Em = A \cdot \eta \cdot G \quad (6)$$

Where:

A: The solar panel area = 1.96 m^2

η: solar panel efficiency = 16.23%

G: Average daily sum of global irradiation (4.27 kWh/m^2 ·day). Therefore, Em = 1.358 kWh·day. So, the generated energy from all the solar panels for a year will be according to Equation (7):

$$E = 365 \cdot N \cdot Em \quad (7)$$

Therefore, E = 79.31 GWh.

4. Conclusion

As a final conclusion, we discussed the general approach to renewable energy and photovoltaic power plants. Among the renewable energy sources, solar energy took one of the biggest parts in electricity generation. Convert solar energy into electrical energy, there are some elements that affect the performance of photovoltaic systems. Among these factors, the ability of the panels to absorb the light from the sun is the biggest factor. The closer the light beams with the panels to the right angle, the greater the phenomenon of light absorption in the panels. Factors affecting the performance of a photovoltaic system are investigated and among them. The lower energy of the enhanced opening of sunlight, which has the greatest effect on performance, does not play a big role. Thanks to the designed mechanism within the project, one of the factors affecting the performance of the photovoltaic system was achieved with the aim of eliminating the v large measure. If this system is used in complete panels in a solar field, namely PVPP (Solar Power Plant), the energy to be produced will greatly increase and the capacity of fixed panels will be doubled in terms of performance.

For the last part of the thesis, I conversed and focused on the utilization and development of solar power plants for Azerbaijan in near future. Due to the climate map of Azerbaijan, the Nakhchivan region can be considered as one of the areas where solar radiation can be revealed as a pick. This obtained data from the figure 13 where the climate map of Azerbaijan is displayed. On this part of the project, the main focus is about the discussion for the general power generation of Nakhchivan MR Solar power plant. I have calculated the average power generation due to the inactive area for the Nakhchivan region of Azerbaijan. From the table above, it has been shown the yearly energy generation according to the unused areas. To conclude, we calculated overall power generated per year for inactive lands which is 79.31 GWh. This value is approximately 3.4 times bigger than the current production of solar power which is considered to be 23.04 GWh. [66] As a result, it is clear that unused areas can play an enormous role in doubling the production of electrical power.

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