TÜRKİYE ULUSAL AJANSI
TURKISH NATIONAL AGENCY

ISMSES

Innovative and Smart Maintenance in Solar Energy Systems

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Innovative and Smart Maintenance

In Solar Energy Systems

2020-1-TR01-KA202-093257

2021-2022

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"Innovative and Smart Maintenance in Solar Energy Systems"

Project Partners

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First Publish: 2022

PROJECT SUMMARY

The aim of our project is to develop solar energy systems maintenance and repair modules for the electrical-electronic and energy systems departments of vocational and technical education institutions, to predict and prevent solar energy systems (SES) failures with artificial intelligence methods.

The most important energy source in the world is the sun. The radiation energy of the sun is the main energy source that affects the physical formations in the earth and atmosphere system. The flow of matter and energy in the world is possible thanks to solar energy. With the latest energy production and consumption methods, our energy resources, which cannot be substituted, are consumed, as a result, irreversible damages are given from nature and environmental pollution is created. Renewable energy sources, including solar energy, contain important opportunities and are the only energy sources waiting to be developed. Solar energy, with its potential and ease of use, has the opportunity to become more widespread than other renewable energy sources.

According to the International Energy Agency (IEA), the sunlight falling on the earth in 90 minutes is enough to meet the annual energy need of the world. The IEA predicts that 11% of global electricity production will be provided by solar energy in 2050 and reports that renewable energy sources will be the fastest growing energy sources with an annual growth rate of 7.6% until 2030. Many countries in the world increase their investments in SES and train qualified personnel for the sustainability of this energy. Along with the growth potential, the need for maintenance and repair of these systems and the need for technical personnel are also increasing. The need to train technical personnel for SES, which has become widespread with the changing and developing technologies, has also increased. While the maintenance and repairs of these systems are important, predictive maintenance is vital for these systems. Thus, by predicting possible system errors, the system can stay healthy for a long time and can be prevented before they occur. Uninterrupted operation of the SES and continuous energy production are very important for both businesses and users. Today, predictive maintenance applications have become possible thanks to developing artificial intelligence algorithms and machine learning applications.

The simultaneous transfer of technological innovations to education and training environments directly affects the education levels and development levels of countries. Since the 2000s, there have been important developments in the field of artificial intelligence and it has started to make a name for itself with many disciplines. Within the scope of the project, in order to train qualified trainers on predictive breakdown

maintenance of SES, to integrate SES and artificial intelligence discipline, to produce solutions for existing applications and to achieve the purpose of the project;

- Research on Solar Energy Systems will be conducted and a publication will be prepared on potential, failure, maintenance and repair.
- A SES repair and maintenance module will be prepared to be used in vocational and technical education.
- Software infrastructure will be prepared for failure estimation and preventive maintenance.

Our project is directly related to the environmental and climate targets and innovative practices priorities in the digital age in the 2020 Erasmus+ Program guide. Although SES is among the renewable energy sources today, it is also known as environmentally friendly energy. The creation of predictive maintenance procedures using artificial intelligence tools in the vocational and technical training of SES, which is one of the most important energy sources of the future, is presented as a good example of innovative applications in the digital age.

CONTENTS

1. INTRODUCTION

Today, energy is one of the most important basic needs of the world. In addition to technology products whose use and production are constantly increasing, the need for continuous energy is inevitable for electrical and mechanical devices that have become indispensable in daily life. Lighting, informatics, communication, transportation, production etc. energy is needed in all areas. Meeting the ever-increasing need has created a continuity problem. Therefore, it has become necessary to find renewable energy sources instead of energy solutions obtained from limited resources such as fossil fuels. The limitations and efficiency of these resources change depending on the continuous evaluation of situations such as survey studies, cost studies, etc. in the areas where they can be used.

In recent years, not only the need for energy but also the environmental problems caused by energy use and the solutions produced for these problems have occupied the global agenda. In this direction, the effects of the global warming problem, which has become one of the main problems and affects life significantly, are becoming more serious with each passing day. For this reason, it has become a research and development issue to obtain energy that is environmentally friendly, renewable with natural methods, and at the lowest cost in terms of continuity.

The main problem in nuclear energy, which is used instead of fossil fuels in the production of electrical energy in many developed countries, is the unavoidable uneasiness caused by the damage to the environment in the event of a leak, both in waste and in the production of nuclear fuels used in production. For this reason, while many countries choose to shut down their nuclear power plants, they use electricity generation techniques from alternative energy sources such as wind energy, solar energy, hydro energy, biological fuel energy, tidal power of seawater and wave energy, geothermal energy to meet the increasing energy demand has gone into development. With the use of these energy types, carbon emissions that harm the environment are reduced. However, their use requires various conditions and technologies.

In addition, although these resources are described as Clean Energy, they harm nature in different ways. To summarize briefly; While wind turbines pose a danger to birds, the low/high-frequency sounds emitted by the moving mechanical parts do not disturb humans, but disturb animals and cause them to migrate from their environment. Dam lakes, which are created by damming rivers and accumulating water in large areas, destroy vegetation and change the balance of the environment by causing climate changes. Turbines installed in the sea to generate electricity pose a danger to sea creatures as well as cause marine pollution. Likewise, the facilities established on geothermal resources also cause pollution of groundwater. The situation is not very different in solar energy systems. Such systems, which are installed on large agricultural lands to obtain high power, cause a decrease in agricultural lands and may cause heat changes on the soil surface in the future as they reflect the sun's rays to a great extent. In addition, high levels of greenhouse gases are emitted during the construction of photovoltaic (PV) devices.

In short, all kinds of changes made by human beings in nature, technological devices used to produce and transfer energy damage nature in some way. What we have to do is to reduce energy consumption by being as economical as possible and producing the energy we need from different sources with the least damage to nature. In this way, while ensuring continuity, less damage will be done to nature.

When we think about PV systems, instead of installing such systems on large productive fields, installing them on roofs, parking lots, and irrigation ponds, which we describe as idle, will make these systems more environmentally friendly. In order to achieve this, it will be sufficient to introduce a series of regulations and measures in urban planning. For example, restrictions/regulations should be introduced such as placing buildings so that they do not shade each other, developing new roof designs to create large surfaces on the roofs and these surfaces should face south. As a result, it stands out as Solar Energy Systems, thanks to its applicability to building roofs and inefficient vacant lands, and its ever-increasing efficiency, and its source is the Sun, which is an indispensable resource in life.

The most important issue that Solar Energy Systems are currently working on is the efficiency of the systems. In 1839, with the discovery of the PV effect by Alexandre Edmond Becquerel, it was discovered that electric current could be generated from sunlight. Russell Ohl managed to produce the first solar panel cell with the technology of the day in 1941, and the first commercial solar panel was made by Bell Laboratories in 1954. While the electricity generation efficiency of the panels produced in the 2000s was in the range of 12-15%, today the average efficiency value is 20%. In addition, it is seen that an efficiency of 36% is achieved in experimental solar panel applications using high technology. However, productivity also declines over time. In an average of 10 years, the panels have a 2% loss of efficiency and an average life of 50 years.

Increasing the efficiency and life of the panels will be possible with smart and innovative maintenance methods. In this direction, it will be useful to use artificial intelligence in order to reveal new algorithms and to analyse the collected data in order to maintain the panels more efficiently. This resource has been created to provide information and guidance in this direction.

2. RENEWABLE ENERGY SOURCES

When we focus on the definition of renewable energy sources, we see that the expressions that constantly renew themselves, that occur from natural processes in life and that do not harm natural life in this direction come to the fore. All resources that provide these properties can be defined as renewable. The Paris-based International Energy Agency's assessment of today's renewable energy as of 2021 is as follows:

"Renewable energy sources have grown rapidly in recent years thanks to policy support and high-cost reductions, especially for solar photovoltaics and wind energy. The electricity sector remains the brightest spot for renewable energy sources in recent years, with the strong growth of solar photovoltaics and wind as well, relying on the already significant contribution of hydroelectricity. However, electricity still accounts for only one-fifth of global energy consumption. The role of renewables in the transport and heating sectors remains critical to the energy transition. ʼʼ [1]

Renewable energy sources are listed under 7 main headings by evaluating the method of production or, in other words, the source.

2.1 Solar Energy

Solar energy is a resource that can be easily accessed almost everywhere in the world and especially in our country. On the other hand, it is very difficult to reach fossil fuel energy sources and extract and process them. In addition, the use of these resources causes great harm to the environment. However, making fossil fuels usable results in high costs. But people do not need to make efforts to access solar energy. [2]

Formations such as wind, sea waves, and rivers are caused by solar energy. In other words, in addition to directly benefiting from solar energy, other energy sources created by the sun in nature are also used.

Solar energy is very powerful energy produced by the fusion reaction that converts hydrogen gas in the sun's core into helium. Technologies such as solar collectors, solar power plants and solar cells (photovoltaic cells) have been developed to benefit from this energy that comes to our world through the sun's rays. Thanks to these technologies, solar energy can be used directly as heat energy or indirectly by converting to electrical energy. [3]

2.2 Wind Energy

Wind energy is due to solar radiation heating the ground surfaces at different rates. The different warming of the seas and the air causes the formation of a pressure difference and this pressure difference causes the movement of the air. This movement of air from high pressure to low pressure is known as wind. Wind energy is used to produce mechanical energy or electrical energy[3].

With the advancement of technology, large wind turbines have been developed and high power electricity generation has been achieved. The kinetic energy of the wind is transformed into motion energy by rotating the blades on the high towers.

This motion energy generated in the blades of the wind turbine rotates the generator to which the blades are connected. This generates electrical energy.

Since wind turbines work with the principle of rotating their blades and engine room according to the direction of the wind, they can always capture the wind better and produce higher power. Since the rotation of the blades in very strong winds can damage the turbine, the wind turbine can brake when necessary. In order for wind power plants to operate efficiently, feasibility studies are carried out in the planned region before installation, as should be done before every renewable energy plant is established.

Wind turbines can be installed as high power plants connected to the power line, or they can be used as turbines with low power and simpler systems. Low-power wind turbines do not need a control system. They are positioned towards the direction of the wind with the help of their tails[2].

2.3 Geothermal Energy

Geothermal energy is the natural heat of the earth and is defined as the thermal energy contained in hot fluids (water vapour, gas) and hot dry rocks under pressure accumulated deep in the earth's crust. This energy is used for electrical energy generation or for heating purposes. [3]

Since Turkey is a rich country in terms of geothermal resources due to its tectonic and volcanic features, a large part of geothermal energy is used for heating residences and spa tourism, as well as power plants producing electricity from geothermal energy, are increasing day by day. [2]

2.4 Hydraulic Energy

One of the widely used renewable energy sources is hydro energy. The most common use of this energy is to build dams on rivers and accumulate water in the reservoir, to generate electrical energy in the turbine by utilizing the potential energy of the accumulated water. Hydroelectric power plants (HPP) are utilized for this purpose. [3]

The potential of hydro energy produced by utilizing water power depends on the rainfall regime. Hydroelectric power plants, whose main purpose is to generate electricity; when they are built with storage (accumulation-dams), they can also fulfil the purpose of preventing floods, agricultural irrigation, water products development, tourism development, and facilitating transportation. Hydro energy is a continuous and renewable energy source besides the continuation of the water cycle, which is necessary for the survival of living things. [2]

2.5 Biomass Energy

Biomass is the total mass of living or living organisms in a given period of time. Biomass energy is a type of energy obtained by various methods from unusable wastes such as plant, animal and urban wastes [2].

Biomass energy is an energy source obtained from plant and animal origin substances containing carbohydrate compounds. Today, fuels such as bioethanol, biodiesel and biogas are obtained by using biomass energy sources. Bioethanol and biodiesel are a type of fuel produced using various plant or animal oils. Biogas, on the other hand, is mainly methane and carbon dioxide gas, which is formed as a result of the fermentation of organic materials (plant and animal wastes, urban and industrial wastes) in an oxygen-free environment.[3]

2.6 Wave Energy

The renewable and clean energy source produced by the rotation of turbines placed in suitable places by sea waves is called wave energy.

On the coasts where the tidal amplitude is high, a dam is built at the river mouth or at the sea entrance. A tunnel is opened into this dam and when the waters rise, inward flow occurs through this tunnel, and when the waters decrease, reverse (outward) flow occurs. Electric energy is produced by the turbines placed in the tunnel, rotating with the flow rate of the water and rotating the generator they are connected to. [2]

2.7 Hydrogen Energy

Hydrogen is a simple, colorless, odorless, tasteless and abundant light gas that runs on fuel cells. Hydrogen is an energy source that can be transported easily and safely and has a low loss when transported. Hydrogen can be easily converted into heat, electricity and mechanical energy. Hydrogen also called the energy source of the future, is easily converted into different types of energy, although it is more expensive than other fuels. The method of use is to obtain hydrogen by separating water into hydrogen and oxygen by electrolysis method, and its storage is possible by converting the obtained hydrogen into liquid or gas. Hydrogen can be used in two ways: The first is the fuel cell system, where hydrogen is used as fuel and chemical energy is converted into electrical energy. In this system, the only products of hydrogen combustion are water and water vapour. The second is the use of hydrogen in direct combustion engine technology. In this newly developed system, hydrogen is supplied to the system directly or with the help of any source that releases hydrogen. [2]

3. SOLAR ENERGY

The Sun, the source of life on Earth, has a diameter of about 1.4 million kilometers and is about 149.6 million km away from the Earth. It provides the energy of the sun by converting 4 hydrogen atoms into 1 helium atom, this transformation is called Fusion. 4 H atoms have a mass of 4,032 atomic units, while 1 He atom has a mass of 4,003 atomic units. When 4 H atoms turn into 1 He atom in the sun, 0.029 atomic unit mass increases and this amount of mass is converted into energy with Einstein's energy expression ($E = m.c^2$). In the sun, 564 million tonnes of H atoms are transformed into 560 million tonnes of He atoms in 1 second. As a result, 3.86 x 1026 J energy is released for 4 million tonnes of mass [4,5,6,7,8]. Since the total energy reserve of the Sun is 1.785 x 10^{47} J, it will continue to radiate for millions of years. Solar energy, which is considered an alternative to primary energy sources such as oil, coal and atomic energy, is very promising. The rays coming from the sun are not of the same wavelength and intensity. As can be seen in Figure 1, the wavelength of the rays coming into the Earth's atmosphere varies between approximately 200nm and 2500nm, while the intensity distribution is similar to the Rayleigh distribution function. According to this distribution, the radiation in the visible region has the highest intensity, while the harmful ultraviolet rays are less intense and the infrared rays, which provide heating, have less intensity but more wavelengths. These rays come to earth in about 8 minutes. 45% of the rays are in the visible region, 46% in the infrared and 9% in the ultraviolet region [5,8].

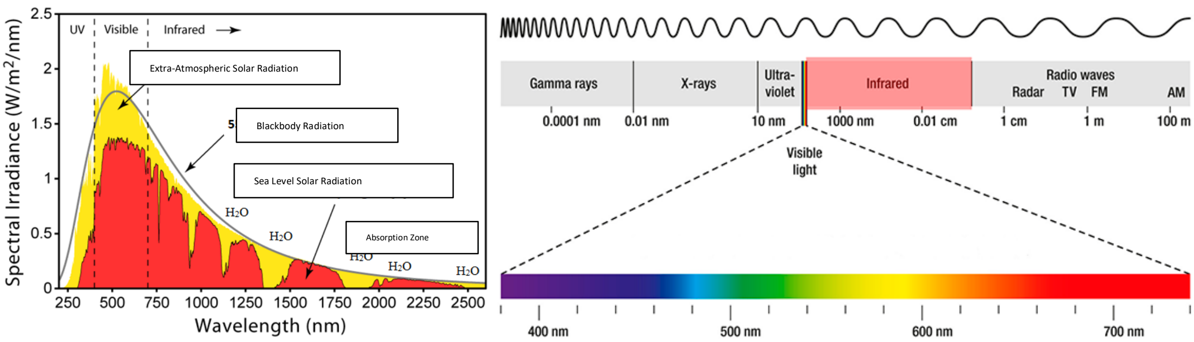


Figure 1. a) Intensity distribution of the rays emitted from the Sun according to wavelength, b) Naming the rays coming to the earth's surface according to the wavelength

When the sun rays reach the earth as a wide wave H2O spectrum enters the Earth's atmosphere, depending on the interactions in the atmosphere; It consists of Direct (Direct/Ray radiation), Diffuse (Diffuse/Diffuse/Scattered/scattered) and Reflected (Radiant) radiations (Figure 2) [5,6,7,8,9].

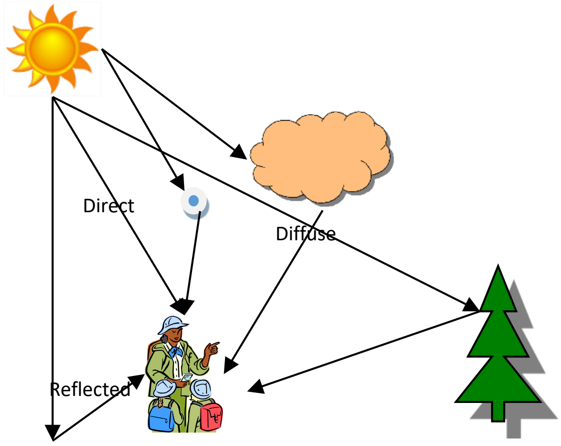


Figure 2. Direct, Diffuse and Reflected rays come to the Earth's surface.

Direct radiation; The rays of the sun that enter the atmosphere and reach the person on the earth without contacting anything directly are called. Diffuse radiation is the part of the sun rays entering the atmosphere that reaches people on the Earth's surface by scattering from clouds and ions in the atmosphere. The reflected radiation is the radiation that reaches people by reflecting the direct radiation from the Earth's surface.

The sum of all these rays is called total radiation/radiation or global radiation/radiation. If there were no reflected and diffuse rays, there would be regions of complete darkness and light on Earth, and objects in the dark regions would certainly not be visible.

Not all of the radiation from the Sun reaches the Earth's surface; about 30 per cent of these rays are directly reflected back by the Earth's atmosphere. Radiations passing through the atmosphere are reflected or absorbed according to the cloud density of the air.

10% - 20% of the radiation coming to the earth on a cloudless day is diffuse and reflected radiation. In cloudy weather, 70-80% of the rays are reflected out of the atmosphere, while only 20-30% come to earth. In completely open air, 80% of the rays reach the earth (Figure 3).

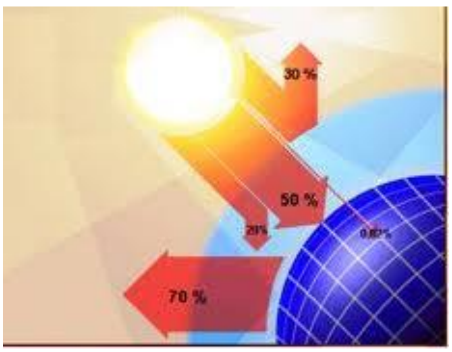


Figure 3. Transmission and reflection rates of solar radiation from the atmosphere

In general, when considering an average day, it can be said that approximately 50 per cent of the sun's rays pass through the atmosphere and reach the earth's surface.

With this energy, the temperature of the Earth rises and life on Earth (wind movements, ocean fluctuations, photosynthesis, etc.) becomes possible [8].

3.1 Solar Constant (Solar Radiation Outside the Atmosphere)

The unit of light energy coming from the sun to our world is generally given as W/m². Accordingly, the energy emitted from 1 m² of the sun in 1 second is calculated using the Stefan Boltzman equation [5,6,7,8,9,10].

It is calculated as;

$$\frac{E}{A} = \sigma T^4 = 5,67x10^{-8}\left(\frac{W}{m^2K^4}\right).(5777)^4(K^4) = 6,3x10^7\left(\frac{W}{m^2}\right) \quad (1)$$

The amount of energy perpendicular to the 1m2 area just outside the Earth (in the exosphere) was found to vary between 1353 and 1394 W/m2 in calculations made by different groups. The most widely accepted value is 1367 W/m². This number is called the solar constant and is given by the symbol Isc This value was found experimentally outside the atmosphere. At the same time, this value changes due to the change in the distance between the Earth and the Sun (1.47 x 10^{11} - 1.52 x 10^{11} m). The value of the constant Isc on different days is found by expression.

$$I_0 = I_{sc}\left[1 + 0,034\cos\left(\frac{360.N}{365,25}\right)\right] \quad (2)$$

Here N is the number of days from 1 January (February must be calculated as 28 days!).

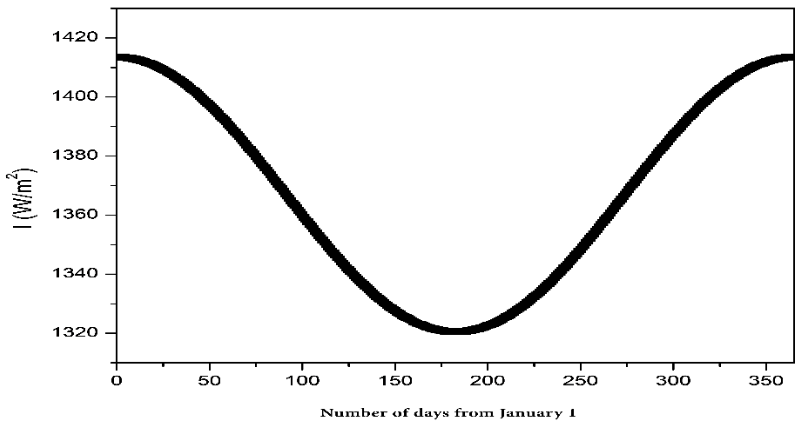


Figure 4. Change of solar constant in one year.

I_0 value reaches its maximum value in January and December.

3.2 Air Mass

Air mass is a measure of the intensity of solar radiation reaching the earth's surface.

It is important to know the air mass in the calculations and measurements of the mechanisms that use solar energy [5,6,8,11]. Air mass is the ratio of the path followed by solar radiation as it passes through the atmosphere to the path it would follow if the sun's rays were perpendicular to the surface and are denoted by A.M. (air mass).

According to this, the air mass can be obtained from the BAC triangle in Figure 5.

$$\mathbf{A.M.} = \frac{\mathbf{CA}}{\mathbf{BA}} \quad \mathbf{(3)}$$

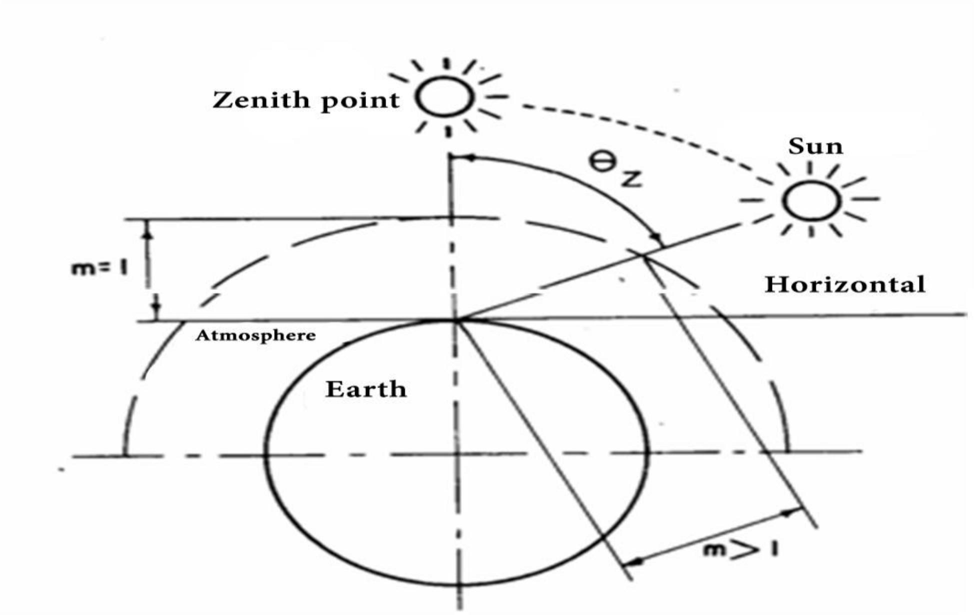


Figure 5. Change in Air Mass as the Sun's rays come to the Earth's surface at different angles

The angle that the incoming sun rays make with the normal to the Earth's surface is called the zenith angle. Since the line BA is parallel to the normal of the surface, the angle that this line makes with the line AC will be the zenith angle. In this case, the air mass is given in terms of the zenith angle.

$$\mathbf{A.M.} = \frac{\mathbf{1}}{\mathbf{cos\theta_z}} \quad \mathbf{(4)}$$

Like all electromagnetic radiation, solar radiation consists of particles called photons. Photons carry certain amounts of energy, depending on the spectral characteristics of the source. Due to the large distance of the Earth from the Sun, only the photons reach the Earth directly from the solar spectrum of the Earth. Above the atmosphere, the radiation intensity, or solar constant, varies between 1.353 and 1.367 kW/m2 and the spectral distribution here is referred to as Air Mass zero (A.M.0) (Figure 6).

The air mass number at the Earth's surface must always be greater than or equal to one. In the comparison of the performance of solar cells, the A.M.1.5 spectrum is used as a standard for the distribution of solar radiation falling on the ground surface (Figure 6). In the A.M.1.5 spectrum, the total power density is calculated as 1kW/m2.

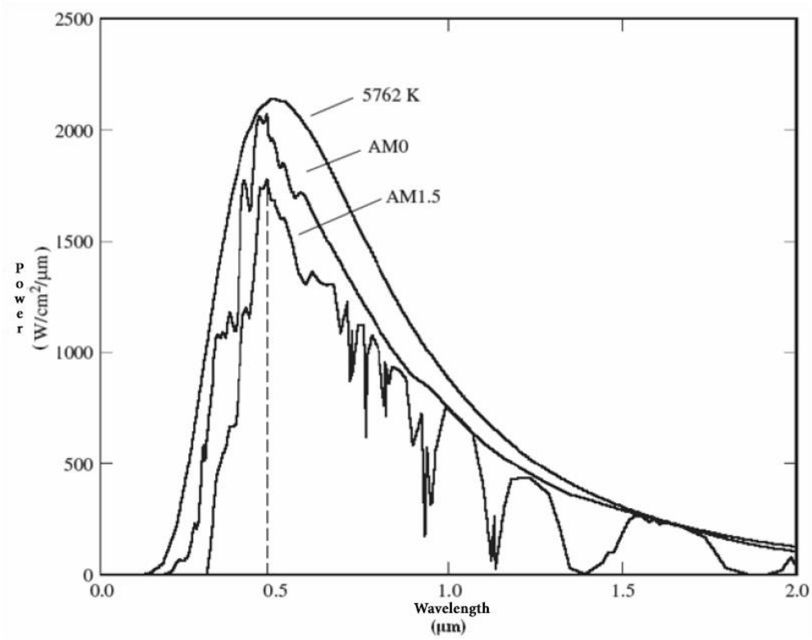


Figure 6. Comparison of the solar surface irradiance spectrum with AM0 and AM1.5 spectra

Air Mass measurements are normally taken at sea level. In space, air mass is zero. As seen in Figure 5, the air mass of point A is 1 when the Sun is at point B. If the Air Mass at a height Z from the surface is given as.

$$\mathbf{A.M._z = A.M._0 \frac{P_z}{P_0}} \qquad \mathbf{(5)}$$

Here, A.M.0 is the air mass at sea level, Pz is the air pressure at point z and P0 is the air pressure at sea level. If θz> 800, A.M. =∞. To eliminate this problem, the values found by Robinson in 1996 are used [6] (Table 1).

Table 1. Air Mass values at high angles

Açı (derece)	Hava Kütle (A.M.)
80	5,63 kg
85	10,69 kg
86	12,87 kg
87	16,04 kg
88	20,84 kg
89	28,35 kg
90	29,94 kg

3.3 Measuring Solar Radiation

Measuring solar radiation is important to minimize the design, implementation and repair costs of systems [5,8,12]. 20% error in solar radiation measurements. It causes a change of 4% to 20% in systems that convert solar energy into electrical energy. Therefore, these measurements are an important parameter and 2 branches of science working on this subject have been formed. These are:

1) Radiometry; It is the science that measures the amount of direct, radiated and total solar radiation falling on a surface with any angle of inclination.

2)Photometry; It is a sub-branch of radiometry that measures only the light in the visible band (400nm-700nm).

The unit of solar radiation in the SI unit system is W/m². It can also be converted to other unit systems as given below. 1 langley/hour = 1 calorie/(cm².hour) = 11,63 W/m²

We can collect the instruments measuring solar radiation in two classes (Figure 7);

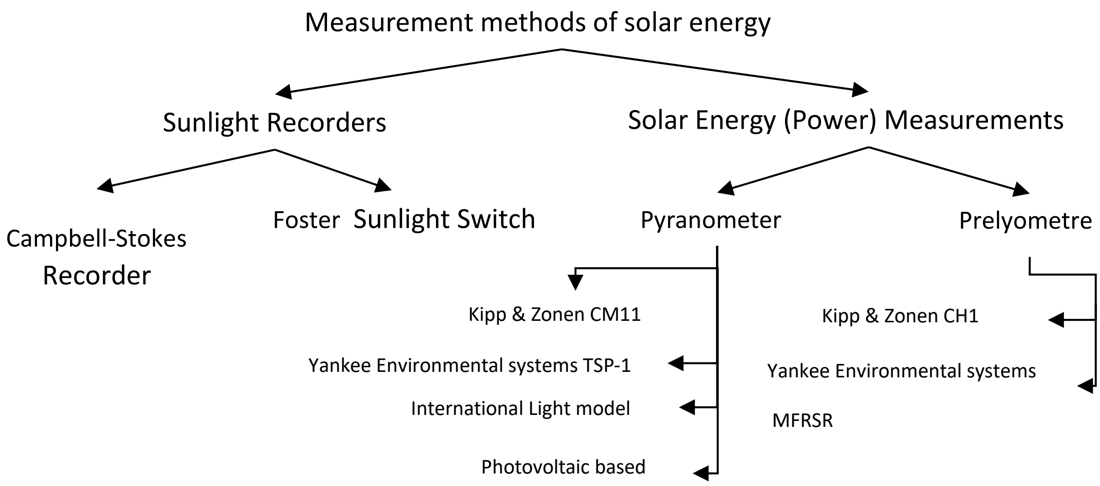


Figure 7. Classification of solar energy measurement methods

3.4 Measurement of Solar Energy

Such systems measure the power of incoming sunlight per unit area. While doing this, separate measurements are taken depending on whether the incoming rays are Direct/Beam radiation, Alternating/Reflected radiation, Scattering radiation and Total/Global radiation. There are two different systems. These; Pyranometer (pyranometer) and Preliometer (pyrheliometer) are [5].

Piranometre(pyranometer)

It is an instrument that measures the power of global and scattering radiation per unit area. It works with the principle of reading the temperature of a black body placed in a bell jar and the total voltage of more than one thermocouple placed under it (Figure 8).

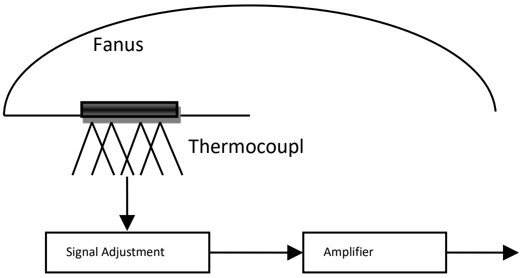


Figure 8. Schematic representation of a pyranometer

The black body is heated by the incident light and creates a voltage of about 22µV(mikro volt) / C (degree cantigrat) for a unit temperature increase on a thermocouple. This voltage value can be increased by placing more than one thermocouple on the base. The measured voltage is proportional to the total amount of radiation. The most commonly used pyranometer model is the Kipp&Zonen CM 11 (Figure 9). It has 100 thermocouples and measures the energy of rays between 305-2800 nm wavelength with 4-6 µV/(W/m2) sensitivity. It has a maximum measuring range of 0 – 4000 W/m^2. The most important disadvantage is that it needs supply voltage.

Figure 9. Kipp&Zonen CM 11 pyranometer.

Another pyranometer model is the Yankee Environmental Systems TSP 1 model. It is similar to the Kipp & Zonen model, but this model uses a platinum thin film resistor instead of a thermocouple. With this modification, the system measures the intensity of rays between 300 and 3000 nm wavelength with an accuracy of 3mV/(W/m^2). This system also needs supply voltage. YESDAS – 2 model is also a top model of TSP1. International Işık IL 1700 model; It detects light with sensors (photodiode) and creates a current in the amount of light it detects. The read current is given in terms of energy by physical calculations. These instruments can read current with an accuracy of 10-13 A. Since they are electronic devices (Figure 10), they need a power supply.

Figure 10. Yankee Environmental Systems TSP 1 pyranometer.

The IL1400A model is the handheld model of the IL 1700 model and is battery-powered. Yellotsolorimeter HD9021 model is Photovoltaic Battery Based pyranometer. In these pyranometers, the current generated by the light falling on the battery and the short circuit current of the battery is directly proportional to the solar radiation.

$$\propto = \frac{\mathbf{I_{KD}}}{\mathbf{I}} \quad \textbf{(6)}$$

These proportional values are scaled in terms of solar radiation. The biggest advantages of such pyranometers are that they are inexpensive, not sensitive to temperature and do not need an external power supply.

All these models measure total radiation. To measure scatter radiation, these instruments are shaded (Figure 11) and direct radiation is blocked. However, the position of the canopy must be constantly adjusted with the movement of the sun. When the scattered radiation measured using the canopy is subtracted from the total/global radiation measured without using the canopy, we find the direct incident radiation. These systems are used to calculate solar radiation falling on inclined planes. However, the calibration of these instruments varies with the surface angle, so manufacturers prepare calibration tables according to the surface angle.

Figure 11. Measuring Reflection Diffuse and Direct Solar Radiation.

Pyrheliometer

These devices are instruments that measure Direct/Beam radiation. It has the same system as the pyranometer, but; as seen in Figure 12, the system is placed at the bottom of a long pipe, so it only receives direct rays. At the same time, since it has an electronic mechanism that follows the sun and thanks to the long pipe, it eliminates the scattered and reflected rays. The scattered and reflected rays will be absorbed by the absorber surface in the pipe before they reach the sensor. These systems must follow the Sun in order to stay parallel to the Sun's rays continuously.

Figure 12. Preliometer

3.5 Geometric shape of the Earth and the angles made by the sun's rays on the Earth's surface

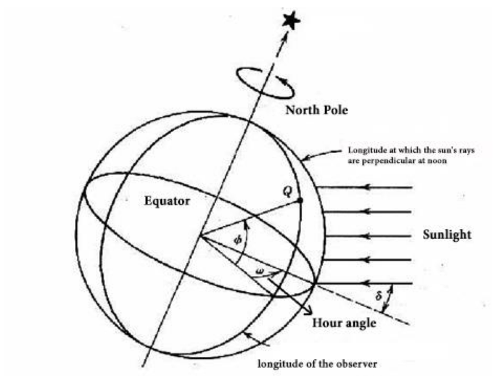
The Earth completes one revolution around the Sun in 1 year (365 days 5 hours 48 minutes = 365,242 days) and has a maximum angle of 23,45° with the elliptical axis. This angle changes for every day from 1 January. The sun's rays incident on the Earth's surface is therefore described by a series of angles relative to different reference points. Knowing these angles is important in calculating the position and radiation intensity of the Sun according to a coordinate determined on the earth.

Declination Angle (δ);

It is the narrow-angle that the rays coming from the sun make with the equatorial plane at noon (Figure 13). This angle changes throughout the year and

$$\boldsymbol{\delta = 23,45°.\sin\left[\frac{360}{365}(284 + N)\right]} \quad \textbf{(7)}$$

is given by the expression.



$$\boldsymbol{\delta = 23,45°.\sin\left[\frac{360}{365}(284 + N)\right]} \quad \textbf{(7)}$$

Figure 13. Declination and hour angles made by the sun rays coming to the Earth's surface

Here N is the number of days from 1 January. For example, for 17 February, N=31+17=48 (February is taken as 28 days).

Hour Angle (W);

It is the angle between the longitude of the sun's rays at noon and the longitude of the place under consideration.

It is an angle taken at noon (0), before noon (-), afternoon (+) (Figure 14).

$$\mathbf{w = 15(t_{Gs} - 12)} \qquad \textbf{(8)}$$

given by the expression. Here tGs are the sundial and its value is different for different positions (meridians) on the earth at the same time.

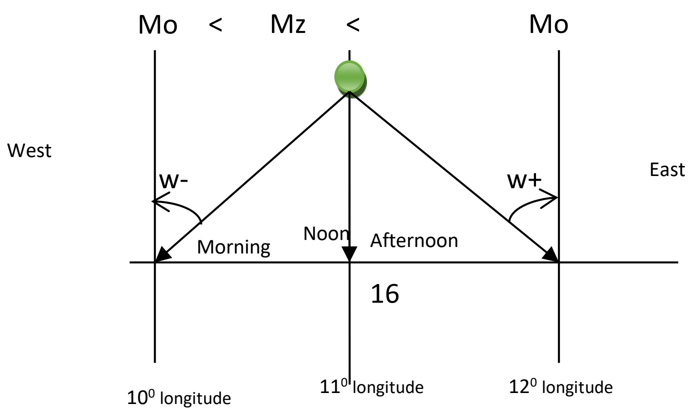


Figure 14. Representation of the hour angle in different meridians according to the position of the sun.

Sundial is different from local time. According to the sundial, 12 o'clock is the time of the smallest shadow at the current position. However, since local time is calculated according to certain reference meridians, it is the same everywhere, regardless of the length of the shadow within certain regions (time zones). Güneş saatini yerel saatte çevirmek için iki düzeltme yapılması gerekir. The first is the time correction between the meridian where the observer is located and the reference meridian from which local time is calculated (each meridian is 4 min. apart). The second is the time equation correction. This is the effect of temporal deviations in the rotation of the earth on the meridian where the observer is located [2,9,10]. According to this, the relationship between the sundial and local time

$$\mathbf{t_{Gs}} = \mathbf{t_{Ys}} + \frac{\mathbf{E}}{\mathbf{60}} \mp \frac{\mathbf{1}}{\mathbf{15}}(\mathbf{M_z} - \mathbf{M_0}) \quad \textbf{(9)}$$

given as. Where tYs is the local time (hours), E is the equation of time correction (minutes) caused by the irregularity of the Earth's speed as it moves around the sun and calculated by the following expression, Mz is the meridian (in degrees) where the time zone starts, M0 is the meridian (in degrees) where the observer is located. The ± in the equation is taken as (+) for M0 > Mz condition and (-) for M0 < Mz condition.

$$\mathbf{E = 9,87\,sin(2B) - 7,53\,cos(B) - 1,5sin(B)}$$

$$\mathbf{B} = \frac{\mathbf{360(N-81)}}{\mathbf{364}} \quad \textbf{(10)}$$

given as. N; is the number of days. Different expressions are used for the E value [5,12,13] in different sources. One of them,

$$\mathbf{E = E1 = 0,258\,cos(x) - 7,416\,sin(x) - 3,648\,cos(2x) - 9,228\,sin(2x)}$$

$$\mathbf{x} = \frac{\mathbf{360(N-1)}}{\mathbf{365{,}242}} \quad \textbf{(11)}$$

given as. However, if the E values are calculated from these two equations and the graph is drawn according to the day value, it is seen that there is no difference (Figure 15).

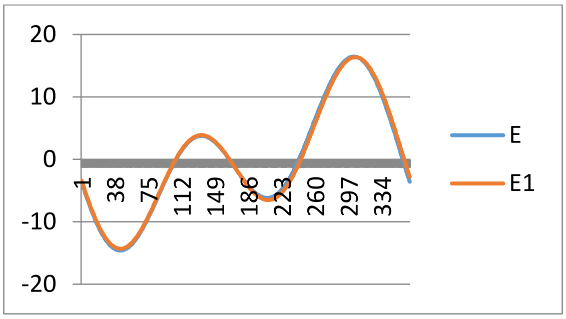


Figure 15. Comparison of time equation correction (E) values calculated by different sources.

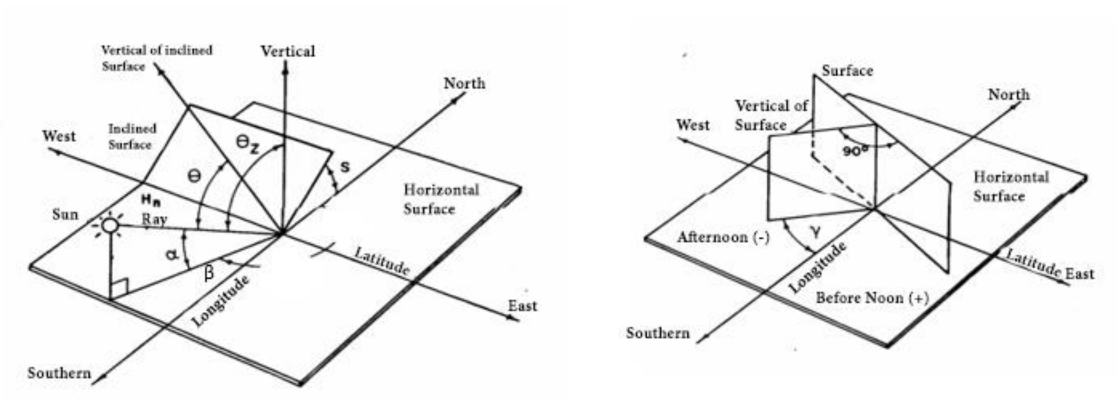


Figure 16. Angles formed by solar radiation on the Earth's surface.

Height Angle (α);

It is the angle between the solar radiation and the horizontal surface. According to Figure 16,

$$\alpha = \mathbf{90^0} - \theta_z$$

Accordingly, $\sin(\alpha) = \cos(\theta_z)$ will happen.,

Solar Azimuth Angle (β);

It is the angle showing the deviation of the sun's rays in the clockwise direction with respect to the north-south direction. It is (+) before noon and (-) in the afternoon. This angle is calculated using spherical triangles. Given as.

$$\cos(\boldsymbol{\beta}) = \frac{\sin(\alpha)\sin(\emptyset) - \sin(\delta)}{\cos(\alpha)\cos(\emptyset)} \tag{12}$$

To find this angle at sunrise, the elevation angle α=0° and It should be remembered that θz=90°.

Surface Azimuth Angle (γ);

It is the angle showing the deviation of the surface normal (vertical) perpendicular to the horizontal surface according to its length. For south-facing surfaces, γ = 0°. It takes a value of (+) on the surface oriented to the east and negative (-) on the surface oriented to the west. In systems that follow the sun, this angle is the same as the solar azimuth angle.

Zenith Angle (θz); It is the angle between the sun's rays and the vertical of the horizontal surface. According to Figure 16, $\boldsymbol{\theta_z = 90^0 - \alpha}$ happens.

Angle of Latitude (Ø);

The angle that the radius connecting a point on the Earth to the centre of the Earth makes with the equatorial plane.

Surface Angle (S);

It is the angle between the inclined surface and the horizontal. It takes a positive (+) value for the surface facing the equator (Figure 16).

Angle of Incidence (θ);

It is the angle between the normal of the inclined surface and the incident sun ray (Figure 16).

South Facing Inclined Surface Angle of Incidence (θt);

It is the angle between the normal (perpendicular) of the inclined surface facing south and the incident sun ray.

The angle of incidence (θ) for an inclined surface depends on many angles as shown in Figure 16.

Relationship of the angle of incidence with other angles. It is given by the expression.

$$\boldsymbol{\cos\theta = \sin\phi\,.\sin\delta.\cos S + \sin\phi\,.\cos\delta\,.\cos\gamma\,.\cos w\,.\sin S + \cos\phi.\cos\delta.\cos w.\cos S - \cos\phi.\sin\delta.\cos\gamma.\sin S + \cos\delta.\sin\gamma.\sin w.\sin S} \quad \textbf{(13)}$$

If our inclined surface is perpendicular to the horizontal surface (Earth's surface) (S=900), equation 13 is more simply given as.

$$\boldsymbol{\cos\theta = \sin\phi\,.\cos\delta\,.\cos\gamma\,.\cos w - \cos\phi.\sin\delta.\cos\gamma + \cos\delta.\sin\gamma.\sin w.\sin S} \quad \textbf{(14)}$$

If our oblique surface is both perpendicular to the horizontal surface (the Earth's surface) (S=900) and directly facing South (γ=00), Equation 13 is more simply given as

$$\mathbf{cos\theta = cos\theta_t = sin\phi\,.cos\delta\,.cosw - cos\phi.sin\delta} \qquad \textbf{(15)}$$

If our inclined surface is parallel to the horizontal surface (S=900), θ=θz will happen

$$\mathbf{cos\theta = cos\theta_z = sin\phi.sin\delta + cos\phi.cos\delta.cosw} \qquad \textbf{(16)}$$

Given as.

If our inclined surface makes an angle with the horizontal surface between 00< S <900 and faces directly south (γ=00), Equation 13 can be simplified as follows

$$\mathbf{cos\theta = cos\theta_t = sin\delta.sin(\phi - S) + cos\delta.cosw.cos(\phi - S)} \qquad \textbf{(17)}$$

Note: All these angles we have found are calculated assuming that there is no atmosphere. Because if the atmosphere is taken into account, it is necessary to take into account the refraction values of the rays coming from space as they enter the atmosphere. This is quite a complex task. Therefore, the atmosphere is treated as if it did not exist.

The duration of a place seeing the Sun in a day is called sunbathing time. The unit of sunshine time is given in degrees (°) or hours. In the meteorological stations of our country, the sunshine time is measured with a device called "heliograph". Measurements made with this device are not accurate as air humidity affects results. Today, in most meteorology stations, sun time measurements are made with devices called "solar meters" that work with solar cells. The sunshine time can also be found by calculating the sunrise angle.

While calculating the sunrise angle, we should consider our surface horizontally (S=00) and the sun elevation angle must be α=00. Since our inclined surface is horizontal, we can take the surface azimuth angle γ = 0. In this case, the zenith angle is θz=θ=-900.

If we substitute these assumptions in equation 14 and given that the clock angle for sunrise is negative (w=-wGD), the sunrise clock angle available as.

$$\mathbf{w_{GD} = -cos^{-1}(-tan\phi.\ tan\delta)} \qquad \textbf{(2)}$$

The sunset angle occurs when the zenith angle θz=θ=900 under the same conditions.

Given that the clock angle for sunset is positive, sunset time angle

$$\mathbf{w_{GB} = cos^{-1}(-tan\phi.\ tan\delta)} \qquad \textbf{(19)}$$

it happens. Daily insolation angle of sunrise and sunset hour angles are known

$$\mathbf{w_G = |w_{GD}| + |w_{GB}| = 2.\cos^{-1}(-tan\phi.\ tan\delta)} \quad \textbf{(20)}$$

is found in terms of angle. Since 150 corresponds to 1 hour, daily sunshine duration in sun hours

$$\mathbf{t_{Gsü} = \frac{w_G}{15} = 2\frac{\cos^{-1}(-tan\phi.\ tan\delta)}{15}} \quad \textbf{(21)}$$

is found as (clock). Since the centre of this period is midday, the sunrise time is the sundial.

$$\mathbf{t_{GD} = 12 - \frac{t_{Gsü}}{2}} \quad \textbf{(22)}$$

and sunset sundial

$$\mathbf{t_{GB} = 12 + \frac{t_{Gsü}}{2}} \quad \textbf{(23)}$$

as.

3.6 Amount of Radiation Perpendicular to the Horizontal Surface Outside the Earth

Solar radiation incident on a vertical surface outside the Earth is given by Equation 2. If we remember this expression, $I_0 = I_{sc}\left[1 + 0{,}034\cos(\frac{360.N}{365{,}25})\right]$

If we neglect the losses in the atmosphere, the rays coming perpendicular to a surface on our earth's surface as in Figure 17

$$\mathbf{I = I_0 cos\theta_z} \quad \textbf{(24)}$$

as. This value is the amount of light incident on the surface in one second. The amount of radiation perpendicular to the horizontal surface during insolation (if we neglect the losses in the atmosphere) is

$$\mathbf{H_0 = \int I.dt} \quad \textbf{(25)}$$

is given by the expression.

Here t= 180w/15π, if the variable is changed and integrated from - wGD = wGB up to wGD

$$\mathbf{H_0 = 3600.I_{sc}.\left[1 + 0,034\,.\cos\left(\frac{360\,.\,N}{365{,}25}\right)\right].\frac{24}{\pi}.(cos\phi.cos\delta.sinw_{GB} + \frac{\pi.\,w_{GB}}{180}.sin\phi\,.sin\delta)} \quad \textbf{(26)}$$

it happens. Here Isc=1367 W/m2, N is the number of days and other variables are in terms of angles and the unit of Ho is given as J/m2. The amount of radiation perpendicular to the horizontal surface (neglecting atmospheric losses) between two hours (w1<w2) is

$$\mathbf{H_0 = 3600. I_{sc}. \left[1 + 0,034 . \cos(\frac{360 . N}{365,25})\right] . \frac{24}{\pi} . \left[\cos\phi . \cos\delta . \sin(w_2 - w_1) + \frac{(w_2 - w_1).\pi}{180} . \sin\phi . \sin\delta\right]}$$
(27)

As

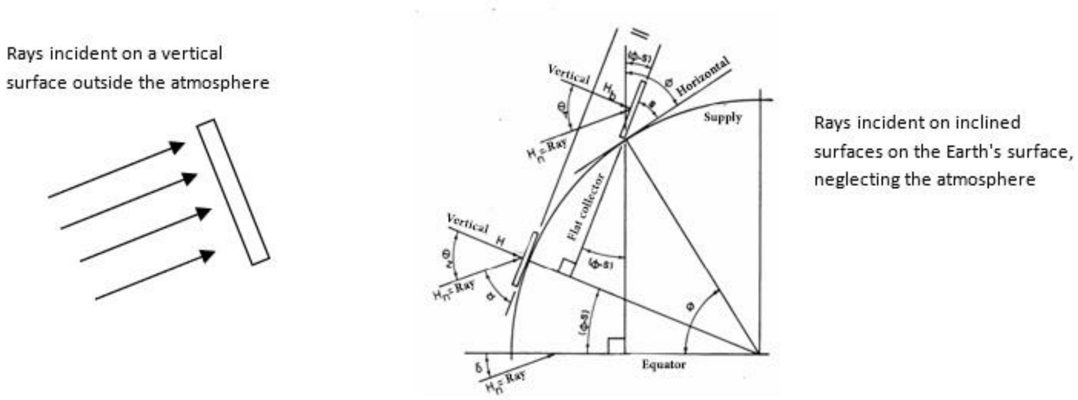


Figure 17. Calculation of total rays incident on inclined surfaces on the Earth's surface.

One of the most important inputs in solar energy applications is the measurement methods of radiation intensity. Irradiance is

usually measured with actinographs at meteorological stations. (Actinograph: It is a device used in meteorological stations to measure the intensity of radiation on horizontal and south-facing surfaces.) However, errors up to 50 per cent were found in the measurements made with this device. Therefore, solar meters are used in solar energy applications.

The theoretical calculation of the radiation intensity on the Earth's surface is important to analyse the efficiency to be obtained from solar energy systems and to have information about whether it will cover the investment costs. However, a universal equation has not yet been derived due to the fact that the ray's incident on the Earth's surface depends on a large number of meteorological and astronomical parameters. Instead, statistical results of data measured for at least 10 years are utilised for feasibility studies.

4. SOLAR ENERGY SYSTEMS

4.1 Historical Development

In 1839, Alexander Edmond Becquerel, professor of applied physics at the Natural History Museum in Paris, detected the first photovoltaic effect during his scientific studies on platinum layers [19]. Later, in the light of Becquerel's studies, Willoughby Smith found in 1873 that Selenium has a photoconductive structure. This event was instrumental in 1876 when William Grylls Adams and Richard Evans Day produced the first solid-state photovoltaic device from Selenium. In 1883, Charles Fritts made the first useful solar cell using selenium. However, the efficiency of this battery is around 1 per cent.

The use of solar cells as a commercial product started in 1931 with Bergmann's studies on Selenium solar cells [11,19]. With the production of the p-n junction in the 1940s, interest in solar cells increased rapidly. At the same time, p-n junction transistors and integrated circuits were produced and electronic devices gained a new dimension. The beginning of the use of solar cells in technological devices was achieved in the 1950s with the production of high-quality silicon layers. The efficiency of silicon solar cells produced from these layers has increased and reached an output power sufficient to feed simple technological devices.

In 1954, three friends named Daryl Chapin, Calvin Fuller and Gerald Pearson working in the Bell laboratory in the USA wanted to provide the power supply of the telephone system in the laboratory with solar energy, but they failed in the first trials because the efficiency of Selenium solar cells was 0.5%. Fuller, a chemist, doped silicon in a controlled manner in his studies and found that this new product was a better conductor. At the same time, the efficiency of p-n junction solar cells made with doped silicon has also increased and 6% efficient silicon p-n junction solar cells have been obtained with the research carried out over time. This event is a revolutionary result in the history of solar cells and the work of these three friends working at the Bell laboratory has been a turning point in photovoltaic technology and industry [11,20].

Solar cell technology, which has been growing and developing since the 1950s, is an alternative to the fossil fuels we use today. In solar cell technology, which made a great leap with its use in space research in the 1960s, R&D studies have gained great speed in these years. With the 1973 oil crisis, solar cells started to gain attraction as an alternative energy source all over the world. With the short-term financial incentives during the crisis period, solar cells have taken their place among power generation systems. Solar cells were first used in small applications such as calculators and wristwatches. In the 1980s, research to increase the efficiency of silicon solar cells was supported with various incentives and

20% efficiency was achieved in 1985. This efficiency rate has been the turning point for the development of solar cells. Over the next 10 years, the solar cell manufacturing market showed a large and steady development of 15% - 20%, with a growth of 38% since 1997 [11,21].

Today, photovoltaic modules (solar cells) made using solar cells basically have two different applications: grid-connected and off-grid (Figure 18). These applications; It is widely used in the operation of small power electrical devices, measurement stations and warning systems in places where electrical energy cannot be delivered, and space studies.

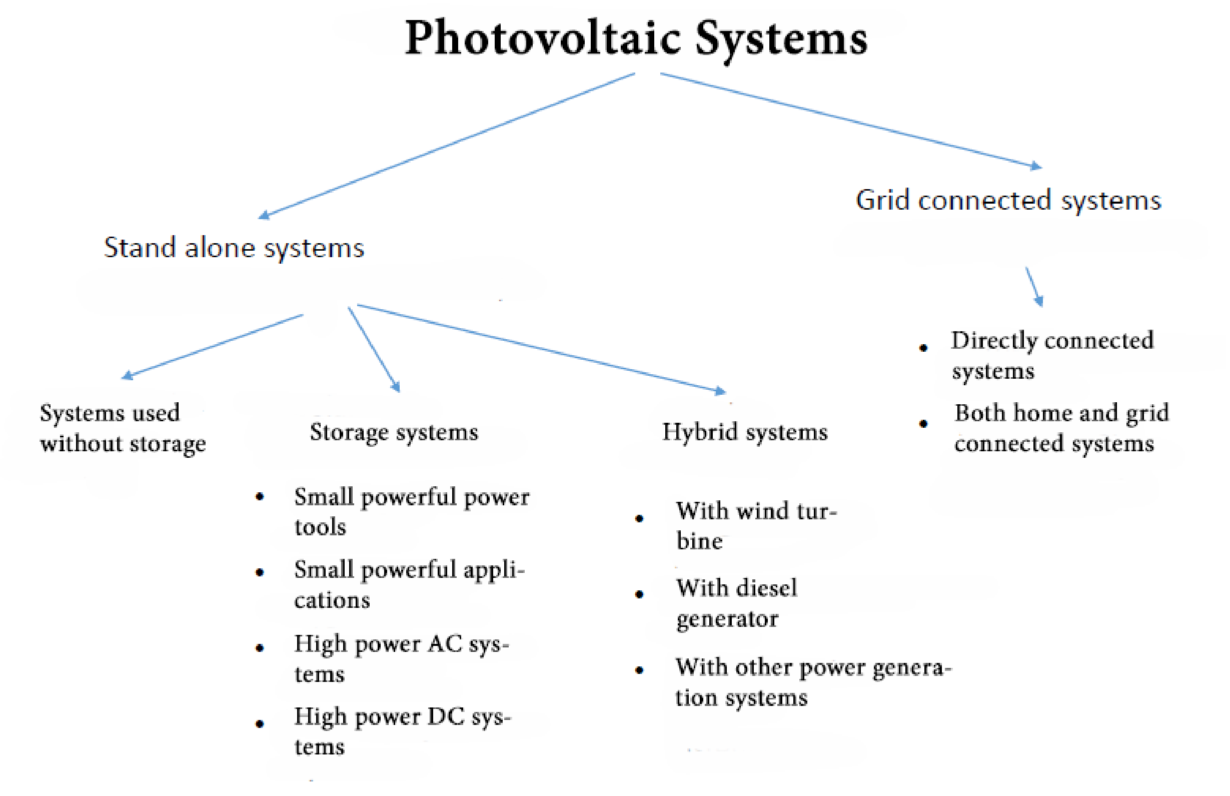


Figure 18. Areas of use of photovoltaic systems

4.2 Solar Energy and Its Future

Solar energy has surpassed energy analyst forecasts in the last decade and has been on the rise with all technological developments. As of 2019, 638 GW of solar power plants have been installed worldwide, surpassing the installed capacity of all other energy sources, including coal, oil and natural gas.

The rapid transition to solar energy is due to impressive public and private investments in renewable energy sources. Institutions and individuals have realised that the future lies in renewable energy sources. The investments made have reduced the costs of solar energy systems by more than 80% since 2010.

Despite this rapid rise, there are many aspects of solar energy that still need to be developed. Although the International Energy Agency (IEA) has steadily increased its projections for solar and other renewable energy in its World Energy Outlook, renewable energy growth appears to complement, rather than replace, fossil fuels. Under current national and international policies, IEA forecasts large increases in solar PV production. However, the "stated policy" forecasts also show continued growth for fossil fuels (especially natural gas).[22]

Solar energy is projected to account for about a quarter of the world's electricity demand by 2050. It is expected that 11% of all energy sources will be produced by solar energy and used in homes and workplaces, while 11% of the electricity demand in densely populated cities and regions will be produced by central solar power plants. [23]

4.3 Advantages and Disadvantages of Solar Energy

Solar energy is a powerful source of energy obtained from the sun's rays. The sun's rays are converted into electrical energy by means of solar panels.

While the energy obtained from the sun for an hour can meet the global energy need for a year, only 0.001 percent of this energy coming to the world can be used.

There is another reason why solar energy has become a popular topic when talking about renewable energy sources. From the periods when the investment was expensive or not very productive, investment has become cheaper and more productive.

In addition to decreasing investment costs due to increasing demands, panel technology has improved significantly thanks to various technological innovations, and solar energy has become a much more efficient and clean energy source thanks to solar energy storage systems.

One of the advantages of solar energy is that it is a renewable energy source. The fact that it can be used all over the world every day makes the sun different from other energy sources. According to some scientists, sunlight can be utilised for at least another 5 billion years. However, since you will meet some of your energy needs with the energy produced by solar panels, the amounts of energy bills will also change. In addition to the energy used, the energy produced in excess of use is also sold to various institutions and benefits our lives as an income.

Solar energy, which offers many areas of use in our daily lives, is also used to generate electricity or heat, to generate electricity in areas without access to the electricity distribution network, to operate water treatment systems in areas with limited access to clean water and to operate satellites in space.

Solar energy systems, which do not require much maintenance costs, also reduce maintenance costs by keeping them relatively clean. For this reason, it stands out from other energy sources. Solar panel manufacturers give an average warranty period of 20-25 years for their products. In addition, since there are no moving parts, wear and tear are less. Since other elements such as inverters and cables used in the system are not subject to frequent changes, the cost decreases considerably when compared on a yearly basis.

Installation costs come first among the disadvantages of solar energy. The sum of all expenses for solar panels, inverter, battery, cables and installation, and development activities to be made in response to the technological developments that will be experienced over the years may cause high costs during the installation phase. However, the dependence of the amount of energy production on the weather conditions adds to the disadvantages of solar energy systems.

Solar panels need to take into account that a few cloudy and rainy days can have a noticeable negative impact on the energy system, as solar panels need sunlight to collect solar energy effectively, as well as not being able to collect solar energy during the night.

Although energy production is easy in solar energy systems, efficient storage is quite expensive. The energy produced should be used immediately or the energy produced during the day should be stored in large-capacity batteries in cases of power cuts and in environments where it must be used during the night. The inclusion of high-capacity and high-tech batteries in solar energy systems can cause a significant increase in installation and maintenance costs.

The amount of energy desired to be produced is directly proportional to the panel power and the number of panels. Achieving this ratio is possible with installations to be made in large areas. If there is no plan to create an indoor car park, there is no other option but to install it in very large areas. Environmental pollution can be added to the disadvantages of solar energy systems. After the production of solar panels, some toxic substances and dangerous substances are used that will indirectly affect the environment, even if it does not risk the life of living things.

4.4 Usage Areas of Solar Energy

Solar energy systems are in many areas of our lives with the developing technology and in the near future, they will take place in all areas of our lives with solar energy panels that can be covered on almost all surfaces.

Especially the solar energy systems built on the lands of the enterprises in the industrial zones and the roofs of the factories are now very common power plants. In the same way, energy production with solar energy systems installed in places where electrical energy cannot be transported by lines has become quite widespread. The energy of agricultural irrigation systems is provided by solar energy systems in many areas. When the benefit-cost analysis is made, solar energy systems are widely used in the production of hot water in houses.

In regions where the sunshine period is long and the climate is mild, solar energy systems are used to generate electrical energy using solar panels and to heat the fruits and vegetables grown in greenhouses. In order to operate many traffic signs and lights at night, the batteries in the system with solar panels are charged during the day and are used as an auxiliary element to relieve traffic after dark and minimise the risk of accidents.

The first machine powered by solar energy was a printing machine tested for demonstration purposes at an exhibition in France in 1878 [18]. The sun's rays are focused on a water boiler to produce water vapour, the water vapour drives the steam turbine, and the steam turbine drives the printing press. These heat machines, called solar machines, were used especially in agriculture and water pumping processes.

Today, some of the devices used in solar heat applications;

- Solar collectors (planar, parabolic and cylindrical)
- Solar cookers
- Solar ovens
- Solar power plants
- Water distillation systems with the sun
- Solar drying systems
- Solar houses and greenhouses
- Solar pools
- Heat storage systems are.

Solar heat applications are made with the help of these systems and devices.

The main applications are:

- Water heating (for domestic and industrial purposes)

- Space heating (heating of houses, business centres and similar buildings)
- Cooling
- Thermal-chemical processes
- Drying (such as agricultural products, fish)
- Purification (such as obtaining drinking water from seawater)
- Electric energy generation
- Cooking food
- Pumping water
- Swimming pool heating
- Hydrogen gas production
- Solar greenhouses

One of the technologies used to take advantage of solar energy is solar cells. Solar cells (photovoltaic cells) are electronic devices that convert sunlight incident on their surface directly into electrical energy through the photovoltaic effect. In general, it can be defined as the appearance of a potential difference between two electrodes when light is incident on them. Practically, solar cells consist of a p-n junction made of semiconductor materials.

4.5 Solar Energy in Türkiye and the World

Looking at the data and targets of the IEA, a challenging process is expected to reduce CO2 emissions to zero in 2050 and meet a large part of the demand for renewable energy. However, between now and 2030, all available clean energy technologies, such as renewable energies, electric vehicles and energy-efficient building retrofits, need to be deployed on a large scale. Ongoing steps are required, such as halting sales of new internal combustion engine passenger cars by 2035 and phasing out all unreduced coal and oil power plants by 2040. In 2050, the global energy sector is expected to be largely based on renewable sources and solar energy will be the largest source of supply. This will become the only option to achieve a cleaner and healthier future.

Government support should be provided for policies in order to develop the renewable energy sector. Incentive policies realised in countries carry investment risks. Inadequate incentive problems may arise for investors with mobile policies and discontinuity. For this reason, investors may be reluctant to invest in renewable energy. In this context, renewable energy projects can be stopped and shelved. For this reason, a sectoral recession may occur, which was the case in the Netherlands. [24]

According to the data published by the Renewable Energy Investors Association GÜYAD at the end of March 2021, it is seen that the percentage ranking has not changed when the electricity generation by primary sources in 2020 and 2021 end of March data are compared. However, when we look at the production percentages, it can be concluded that the percentages of hydro and imported coal-based production decreased, while the percentages of production from lignite, natural gas and renewable resources increased.

Table 2. GÜYAD (Energy Investors Association) Electricity Generation by Primary Sources 2020 and 2021 March Data

Resources	2020 End of March Production (Gwh)	2021 End of March Production (Gwh)
Liquid Fuels	0,19%	0,10%
Stone Coal	0,77%	1,29%
Lignite	11,94%	12,54%
Imported Coal	21,48%	19,37%
Natural Gas	19,33%	29,03%
Hydro	29,06%	18,26%
Geothermal	3,22%	3,33%
Wind	8,95%	9,64%
Sun	2,67%	3,61%
Waste and rubbish	1,66%	2,07%
Other	0,73%	0,03%

As of the end of March 2021, Installed Capacity of Electricity Generation by Primary Sources When the data on the installed capacity of electricity generation by primary sources are analysed, the top three are hydro, natural gas and renewable. At the end of March 2021, total electricity generation was 79,341 GWh. At the end of March 2021, the total installed capacity of electric energy was 96,768 MW.

Table 3. Electricity Generation and Installed Capacity Development by Primary Sources in Turkey as of the end of March

Sources	End of March 2020 Productions (Gwh)	End of March 2021 Productions (Gwh)	Increase (%)	End of March 2020 Installed Capacity (Gwh)	End of March 2021 Installed Capacity (Gwh)	Increase (%)
Liquid Fuels	78	80	1,92%	314	314	0,00%
Stone Coal	591	1.030	74,20%	811	811	0,00%
Lignite	9.157	9.952	8,68%	10.101	10.120	0,19%
Imported Coal	16.477	15.370	-6,72%	8.967	8.987	0,22%
Asphaltite	631	590	-6,50%	405	405	0,00%
Natural Gas	14.829	23.031	55,31%	25.667	25.693	0,10%
Hydro	22.291	14.491	-34,99%	28.543	31.200	9,31%
Geothermal	2.471	2.645	7,04%	1.515	1.624	7,19%
Wind	6.863	7.649	11,45%	7.762	9.192	18,42%
Sun	2.046	2.864	39,98%	6.105	6.906	13,12%
Waste and rubbish	1.276	1.640	28,53%	1.181	1.516	28,37%

TOTAL	76.710	79.342	3,43%	91.371	96.768	5,91%

When the installed capacity data are analysed as a percentage and compared to 2020 data, it is seen that the change in the data is very small. In addition, the top five ranking of installed capacities on the basis of resource at the end of March 2021 is as follows: Hydro (31.24), natural gas (26.55), renewable (geothermal, wind, solar, waste and refuse) (19.88), lignite (10.45) and imported coal (9.29). As of the end of March 2021, the share of Solar Energy in Total Electricity Generated was 3.61%. As of the end of March 2021, the share of Solar Energy in Total Electricity Energy was 7.14%.

Table 4. Solar energy generation and installed power rates

2021	PRODUCTION (Gwh)	INSTALLED POWER (MW)
Sun	2,864,2	6.906
Total	79,341,3	96.768
%	3,61	7,14

Looking at the share of Solar Energy in the Total Electric Energy Generated as of 2020 by months; When the share of Solar Energy in Total Electric Energy Generated is compared to March 2020 and 2021, it is seen that it increased from 3.6% to 4.04%.

Table 5. Solar energy produced in Türkiye and its share [25]

SOLAR ENERGY PRODUCED IN OUR COUNTRY AND SHARE IN TOTAL PRODUCTION													
YEAR 2020	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL PRODUCTION (GWh)
SUN	548,0	609,0	888,7	1070,8	1217,8	1230,6	1332,5	1313,0	1160,0	1010,0	774,1	565,0	11718,7
TOTAL	27077,1	24929,0	24703,4	20341,4	20892,4	23624,4	28776,9	28932,3	27643,1	25446,3	25702,9	27361,8	305431,4
%	2,02	2,44	3,60	5,26	5,83	5,21	4,63	4,54	4,20	3,97	3,01	2,03	3,84
Values for 2020 are temporary and include unlicensed productions.													
YEAR 2021	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL PRODUCTION (GWh)
SUN	744,3	994,1	1125,8										2864,2
TOTAL	27018,5	24443,7	27879,1										79341,4
%	2,75	4,07	4,04										3,61
Values for 2021 are temporary and include unlicensed productions.													

According to the news published by Anadolu Agency on 21 June 2021, Turkey's installed capacity in solar energy is 7070 MW, of which 6450 MW is unlicensed and 620 MW is licensed. Konya, which has 843 MW of this capacity, ranked first as the city with the highest installed power in solar energy. In solar energy, which is considered as the most prominent example of distributed electricity power in Turkey, Ankara has 383.8 MW, Şanlıurfa 370 MW, Kayseri 333 MW, İzmir 291 MW, Afyonkarahisar 244.6 MW, Kahramanmaraş 232 MW, Manisa 217 MW, Mersin 201 MW and Denizli 194 MW installed capacity.[26]

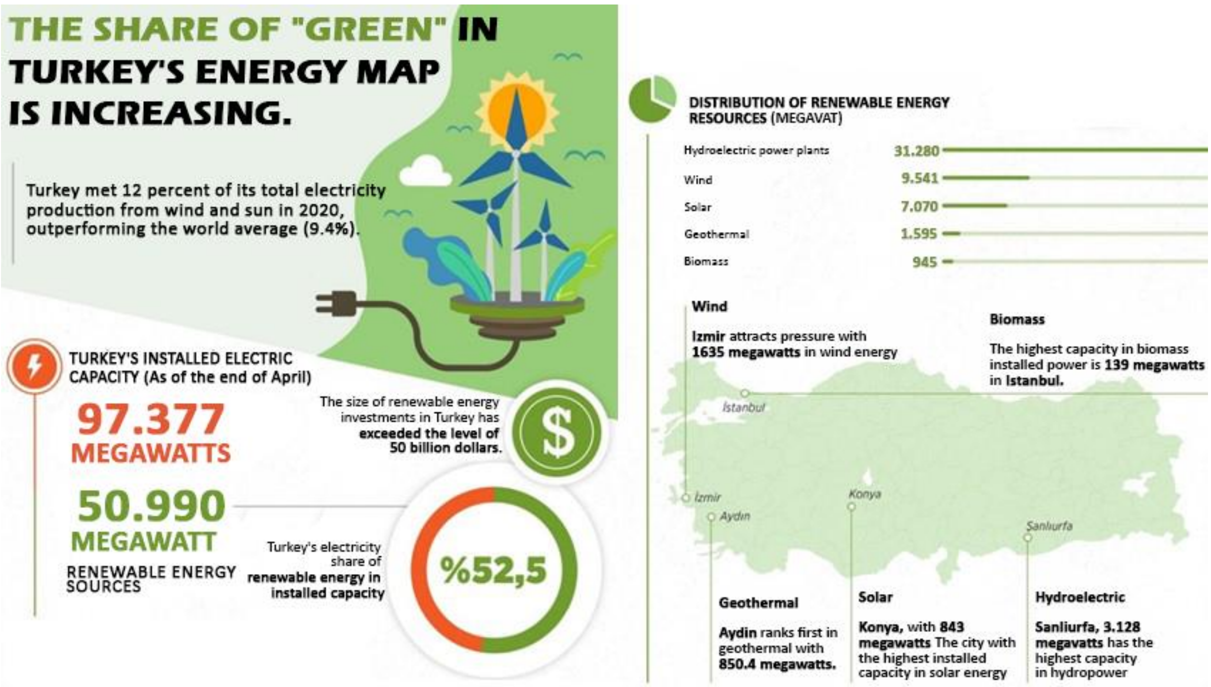


Figure 19. Türkiye's installed capacity in solar energy[26]

Turkey is located at latitudes 36 / 42° and lies between latitudes -40° / 40°, the so-called "Sun Belt".

Our country is more fortunate than many countries with its solar energy potential due to its geographical location (Figure 20).

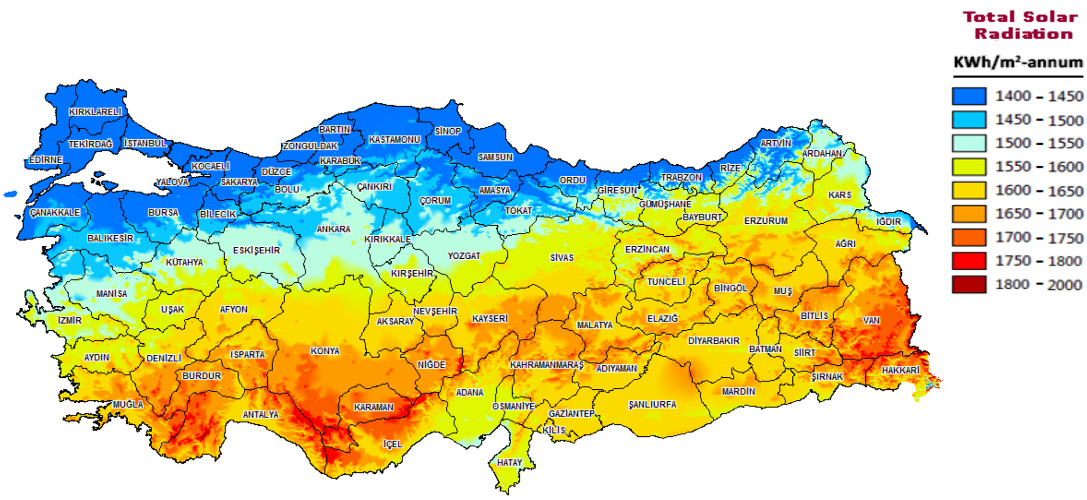


Figure 20. Solar Map of Türkiye

Approximately 170 million MW of energy comes from the sun to the earth every second. Considering that Turkey's annual energy consumption is 100 million MW, the solar energy coming into the world in one second is 1.7 times the energy production of Turkey. The solar energy falling on Turkey in a year is approximately 3,517 x 10 ^{15} MJ (1,527 kWh/m^2.year) [4,14,15].

According to the study conducted by the General Directorate of Electrical Power Resources Survey and Development Administration (EIE), using the sunshine duration and radiation intensity data measured in 1966-1982 available in the General Directorate of State Meteorology Affairs (DMI), the average annual sunshine duration of Turkey is 2640 hours (daily average). 7.2 hours), the average total radiation intensity was found to be 1311 kW/m2-year (average daily 3.6 kWh/m2) [16].

Today, the institution that regulates energy activities in our country is T.C. It is the General Directorate of Energy Affairs under the Ministry of Energy and Natural Resources. According to the new GEPA data prepared by the Ministry of Energy and Natural Resources between 2018-2019, the annual total sunshine duration is 2,741 hours (average 7.5 hours per day), and the total annual solar energy received is 1,527 kWh/m^2.year (daily average is 4.18 kWh/day). m^2.day) [15].

In the measurements made by the General Directorate of Energy Affairs, the monthly values of the sun rays falling on our country and the sunshine duration are given in the Table, the monthly values of the sun rays falling on the regions and the sunshine duration are given in the Table [8,16].

Table 6. Monthly values of sun rays falling on Turkey and sunshine duration

MONTHS	MONTHLY TOTAL SOLAR ENERGY		SUN TIME
	kcal/cm^2-month	kWh/m^2-month	hour/month
JANUARY	4.45	51.75	103.0
FEBRUARY	5.44	63.27	115.0
MARCH	8.31	96.65	165.0
APRIL	10.51	122.23	197.0
MAY	13.23	153.86	273.0
JUNE	14.51	168.75	325.0
JULY	15.08	175.38	365.0
AUGUST	13.62	158.40	343.0
SEPTEMBER	10.60	123.28	280.0
OCTOBER	7.73	89.90	214.0
NOVEMBER	5.23	60.82	157.0
DECEMBER	4.03	46.87	103.0
TOTAL	112.74	1311	2640
AVERAGE	308.0 cal/cm^2-day	3.6 kWh/m^2-day	7.2 hour/day

Table 7. Monthly values of solar radiation falling on regions in Turkey and sunshine hours

REGION	TOTAL SOLAR ENERGY (kWh/m²-year)	SÜNBATHING DURATION (hour/year)
SOUTHEASTERN ANATOLIA REGION	1460	2993
MEDITERRANEAN REGION	1390	2956
EASTERN ANATOLIA REGION	1365	2664
CENTRAL ANATOLIA REGION	1314	2628
AEGEAN REGION	1304	2738
MARMARA REGION	1168	2409
BLACK SEA REGION	1120	1971

According to the data of the General Directorate of Energy Affairs, in the first nine months of 2020, our installed power based on solar energy in our country is 6361 MW and the change in installed power according to years is shown in Figure 21 [17].

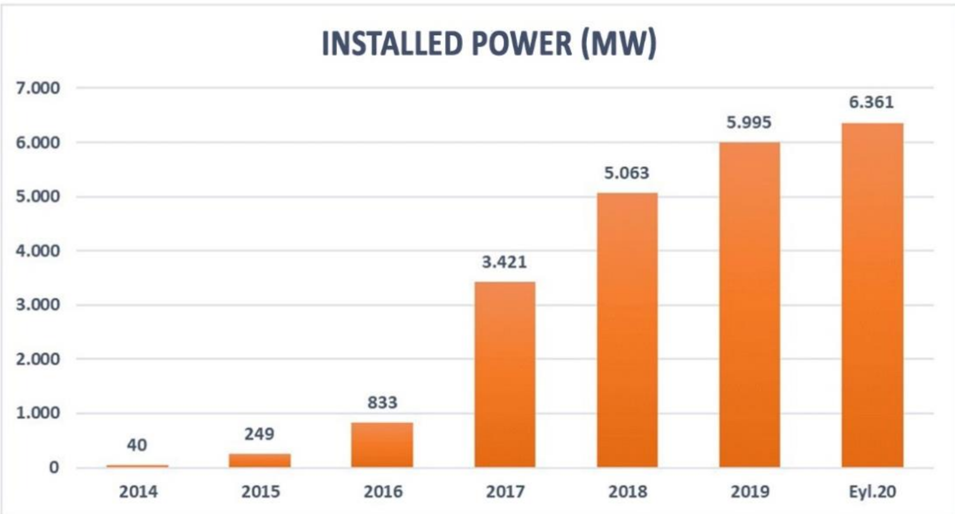


Figure 21. Our Installed Electricity Based on Solar Energy for 2014-2020

As seen in the Figure 21, solar electricity production in our country increased rapidly starting in 2014 and increased by 15800% in 6 years with new investments. The Karapınar Renewable Energy Resource Areas (YEKA) competition (YEKA GES1), which was held on 20/03/2017, was carried out according to the Allocation against Domestic Production (UPL) method and the YEKA Right of Use Agreement was signed on 15/09/2017 with Kalyon Güneş Teknolojileri Üretim Anonim Şirketi, which won the lowest bid (6.99 USD-cent/kWh) in the competition.

The Company established the first integrated and largest Solar Panel Production Factory in Turkey and the region with a capacity of 500 MWp/year in Başkent Organised Industrial

Zone. In the factory; silicon ingot, wafer, solar cell and solar module production are all carried out together. The total domestic contribution rate of photovoltaic solar modules produced at the factory is 76.42 per cent as of today. Activities were also started in the R&D Center, which was established in an integrated manner with the factory. In the R&D Center, R&D activities on solar energy technologies will be carried out for at least 5 subjects for 10 years.

Within the scope of the YEKA Regulation, the first electrical energy generation facility is being installed in Konya / Karapınar based on solar energy. A total of 1000 MWe / 1300 MWm capacity electric power generation plant will be established in Karapınar. This facility is expected to generate at least 2 billion kWh of electricity each year.

In addition, in the competition announcement published in the various announcements section of the Official Gazette dated 03/07/2020 and numbered 31174, it was decided to hold 74 separate YEKA competitions, each of which will be 10 MWe, 15 MWe and 20 MWe (YEKA SPP 3). The competition, which is determined as the fourth YEKA application, will be based on solar energy and will be carried out according to the Domestic Goods Allocation against Use (YMKT) method. It is planned to create a connection capacity with a total power of 1000 (thousand) MWe determined in 36 provinces based on solar energy sources.

With the Presidential Decree No. 1044 dated 09/05/2019, since solar energy-based production facilities, except for public institutions and organisations, will only be carried out as roof and facade applications, our solar potential with roof and facade applications has been investigated and it is predicted that a total of 2,000 - 4,000 MW solar module systems can be installed on roofs in the next 10 years.

In the research conducted by the General Directorate of Energy Affairs, the roof areas that can be evaluated in our country can be grouped as shown in Figure 22.

Figure 22. Roof areas that can be utilised in our country

However, roof applications are used not only for electricity generation but also for thermal technologies. These include solar water heating systems and building cooling systems. As of 2019, approximately 537,000 residences and 289,000 industrial establishments benefited from such systems by using 19,600,000 m2 of planar collectors in our country. In addition, the amount of electricity produced using concentrator systems has reached 10MW.

4.6 Solar Energy Policies throughout the World

It can be said that almost all countries in the world produce more or less electricity with solar energy. However, in official statistics, off-grid power plants that are not connected to the interconnected system of nations are generally excluded from the statistics. Looking at the distribution of grid-connected, in other words, on-grid systems in the world, China is the leader with an installed capacity exceeding 78 GW. The People's Republic of China is followed by Japan, Germany, the USA, Italy, the United Kingdom (UK and other countries affiliated to the UK) and India.

Table 8. Top 20 List of Solar Power Plant Installed Capacity in the World by Countries [27]

Sıra	Country	Update	Installed Power (MW)
1	China	December 2020	254.355
2	United States of America	December 2020	75.572
3	Japan	December 2020	67.000
4	Germany	December 2020	53.783
5	India	December 2020	39.211
6	Italy	December 2020	21.600
7	Australia	December 2020	17.627
8	Vietnam	December 2020	16.504
9	South Korea	December 2020	14.575
10	Spain	December 2020	14.089
11	United Kingdom	December 2020	13.563
12	France	December 2020	11.733
13	Netherlands	December 2020	10.213
14	Brazil	December 2020	7.881
15	Türkiye	May 2021	7.170
16	South Africa	December 2020	5.990
17	Taiwan	December 2020	5.817
18	Belgium	December 2020	5.646
19	Mexico	December 2020	5.644
20	Ukraine	December 2020	5.360

4.7 Solar Energy Policies in Türkiye

According to the Türkiye Solar Energy Potential Atlas (GEPA) prepared by the Ministry of Energy and Natural Resources, the average annual total sunshine duration is 2741.07 hours and the average annual total radiation value is calculated as 1527.46 kWh/m2. The general potential outlook and monthly average global radiation distribution in GEPA are given below [17].

It is a fact that positive developments have taken place in energy policies in Türkiye in recent years. As of 2018, it can be said that Türkiye has started to diversify its energy sources, especially in the production of electrical energy, thus reducing the proportion of sources that provide energy production through imports, which is a positive development for the Turkish economy.

In addition, it can be stated that Türkiye has made serious moves in recent years in terms of water heating collectors and thus, it is among the leading countries in the world, the share allocated to R&D expenditures has increased year by year and this is a positive development [28].

4.8 Türkiye's Solar Energy Parameter Values

Türkiye's main energy sources are oil, lignite, coal, natural gas, geothermal and hydro energy. According to 2008 data, Türkiye's own production can only meet 48 per cent of its entire energy needs. According to the reports prepared by many research institutions, approximately 60 per cent of the world's energy needs will be met from renewable sources in 2060. The World Bank estimates the commercial volume of the solar energy sector as 4 trillion USD in the next 30 years. When the distribution of 2012 and 2030 total electrical energy generation is analysed, it is seen that the solar energy potential is underutilised today. The estimated solar electricity generation for 2030 is shown as 5% [29].

Table 9. Comparison of Annual Total Electric Power Generation Estimates by Installed Power Source in Türkiye in 2012 and 2030 [29]

Source	2012		2030	
	TWh	%	TWh	%
Natural Gas	103	43	145	23
Local Coal	65	27	197	32
Hydroelectric	58	24	94	15
Wind and Geothermal	7	3	72	12
Solar	-	-	28	5
Nuclear	-	-	71	12
Others	6	2,5	12	
Total	239		619	

Türkiye, which is located in the sun belt and therefore rich in solar energy gain, is in a more advantageous position than many countries in terms of solar energy potential due to its geographical location, although it has not yet fully utilised this potential. According to the study conducted by the General Directorate of Renewable Energy by using the sunshine duration and radiation intensity data of the General Directorate of State Meteorological Affairs, Turkey's average annual total sunshine duration is 2,640 hours (daily total of 7.2 hours) and average total radiation intensity is 1,311 kWh/m^2-year (daily total 3.6 kWh/m^2) [14].

Türkiye has a high solar energy potential of 110 days and if the necessary investments are made, Turkey can generate an average of 1,100 kWh of solar energy per unit m^2 per year. Considering that approximately 170 million MW of energy comes to the earth from the sun every second, it is seen that the solar energy coming to the earth in one second is 1,700 times the energy production of Turkey. Turkey is in a more advantageous position than Germany, which ranks first in the world in terms of production.

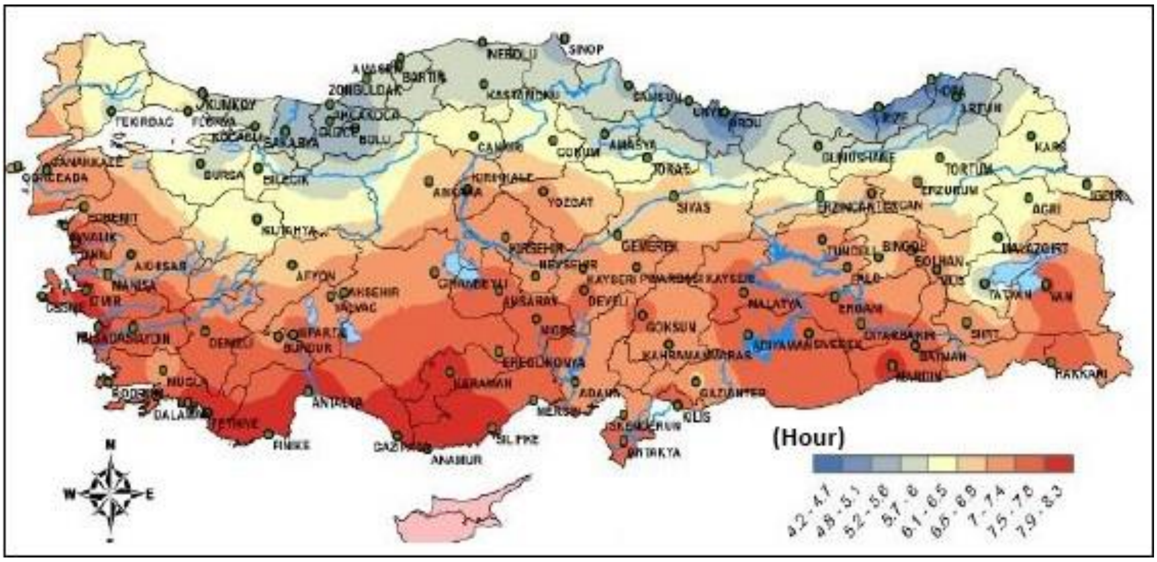


Figure 23. Annual Average Daily Sunbathing Time in Türkiye (1985-2013)

Türkiye's Solar Energy Potential Atlas (GEPA) has been prepared and put into use by the General Directorate of Renewable Energy in order to reveal Türkiye's solar potential. This atlas was mapped using the Solar Radiation Model, an internationally recognised model, and Geographic Information Systems (GIS) techniques. In order to calculate the parameters to be used in the model and to calibrate the model, 22 years of solar measurement values measured at the General Directorate of Renewable Energy and State Meteorological Works stations between 1985-2006 were used [14].

According to the Solar Energy Potential Atlas (GEPA), Türkiye's annual solar energy technical potential is approximately 405 billion kWh (DNI> 1800 kwh/m2 -year) and its economic potential is approximately 131 billion kWh (DNI> 2000 kwh/m2 -year). When the sunshine hours values of Türkiye are analysed, it is seen that the lowest value of the average daily sunshine hours is 3.75 hours in December and the highest value is 11.31 hours in July[29].

Figure 24. Sun Hours in Türkiye (Hours)

When the Global Radiation Values (kWh/m2 -day) of Türkiye are analysed, it is seen that the highest rate of global radiation values is reached in June with 6.57 and the lowest rate is reached in December with 1.59 [29].

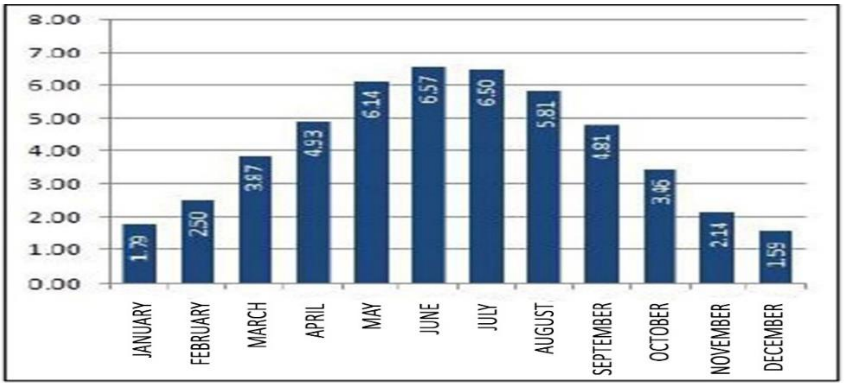


Figure 25. Global Radiation Values in Türkiye (KWh/m2-day)

When the distribution of Türkiye's solar energy potential and sunshine duration values by regions are analysed, it is seen that the region receiving the most solar energy is the South Eastern Anatolia Region with 1,460 KWh/m2 -year, followed by the Mediterranean Region with 1,390 KWh/m2 -year. The region receiving the least solar energy is the Black Sea Region with 1,120 KWh/m2 -per year.

Table 10. Distribution of Türkiye's Annual Total Solar Energy Potential by Region

Region	Total Solar Energy (kWh/m2-year)	Sunbathing Duration (hour/year)
Southeastern Anatolia Region	1460	2993
Mediterranean Region	1390	2956

Eastern Anatolia Region	1365	2664
Central Anatolia Region	1314	2628
Aegean Region	1304	2738
Marmara Region	1168	2409
Black Sea Region	1120	1971

However, these values were found to be lower than the actual potential of Türkiye, which was later realised through studies. Since 1992, the General Directorate of Renewable Energy and the State Meteorological Service has been carrying out solar energy measurements in order to measure solar energy values more accurately. As a result of the ongoing measurement studies, Türkiye’s solar energy potential is expected to be 20-25% higher than the previous values [14].

With these irradiation intensities, solar water heaters can operate at full capacity throughout the year in the part of Türkiye that is located in the Southeastern Anatolia and Mediterranean regions and covers 17% of its surface area. In a part of Türkiye covering 63 per cent of its surface area, the year-round operation rate of solar water heaters is 90 per cent and in a part covering 94 per cent of the country, the operation rate is 80 per cent. Almost everywhere in Türkiye, solar water heaters can operate at full capacity for up to 70 per cent of the year. For this reason, solar energy collectors are used extensively in all regions, especially in the southern parts of the country and the Aegean coasts, to obtain hot water. There are solar collectors in 3-3.5 million houses in Türkiye, mostly in the Mediterranean, Aegean and South East Anatolia regions. All of these collectors cover an area of 18 million m2 and approximately 1 million m2 is added to this area every year. According to the data of the General Directorate of Renewable Energy, the amount of energy produced in 2007 was over 420 thousand tonnes of oil equivalent. In addition, the use of photovoltaic cells in some industrial applications, space heating applications (solar architecture) and electricity generation is becoming increasingly widespread [29].

Although Türkiye is one of the few countries in the world with high potential for electricity generation from solar energy, the biggest reason for the inadequacy of studies in Türkiye is that the costs of obtaining electricity from solar energy are quite high. This high cost is one of the most important reasons limiting the commercial utilisation of this renewable energy source. Solar electricity generation is at the level of pilot applications with an installed capacity of 1,000 kW. If the kW cost, which is currently 3,000 dollars, decreases to 1,500 dollars, solar electricity generation applications will become widespread in our country. According to various studies, it has been calculated that there is a solar energy potential equivalent to approximately 56,000 MW thermal power plant capacity in Türkiye and if this potential is utilised, an annual average of 380 billion kWh of electrical energy can be produced [29].

Although the current use of solar energy is mostly for hot water supply, developments in terms of solar energy sources should be closely monitored in the coming years and studies should be carried out to rapidly utilise the potential as long as electrical energy production can compete with other energy sources. Due to the decrease in costs and the incentives implemented by developed countries such as the EU and the USA, studies on obtaining electricity from solar energy are increasing rapidly in the world. Including renewable energy uses such as solar energy in the energy policies of the country will reduce energy imports and reduce environmental pollution caused by fossil fuels [29].

5. WORKING PRINCIPLE OF SOLAR ENERGY SYSTEMS

The working principle of solar panels used in solar energy systems is based on the principle of electron movement, i.e. photovoltaic effect, which occurs in materials on which light falls. Photovoltaic cells, i.e. solar panels, are equipment consisting of semiconductor materials that convert the solar energy falling on it directly into electrical energy.

A solar panel roughly consists of silicon cells, glass housing unit, protection and fixing frame, direct current and alternating current cables used to transfer the electric current generated on the solar panel.

Silicon is a nonmetal with conductive properties that allow it to absorb sunlight and convert it into usable electricity. When light strikes a silicon cell, it causes the electrons on the silicon cells to be mobilised, initiating the flow of electric current. This is known as the "photovoltaic (PV) effect" and describes the overall functionality of solar panel technology.

Using silicon-based solar cells, we can convert sunlight directly into electricity. With sunrise, the rays hit your solar panels and the solar panels convert these rays into direct current electrons. The electrons go from the solar panel to an inverter. The inverter converts direct current into alternating current. Alternating current is the type of current that enables the operation of many electrical devices we use in our daily lives.

Photovoltaic system types are divided into 3 main groups according to the configurations they contain. These are; on-grid systems, off-grid systems, photovoltaic hybrid systems. These three systems are separated from each other by the equipment they contain.

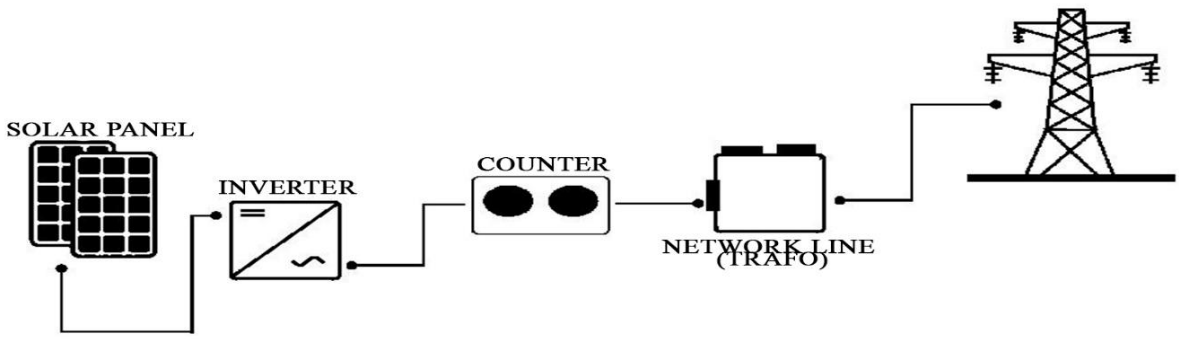


Figure 26. Grid-connected PV systems [30]

Grid Connected (On-Grid) Photovoltaic Systems: A grid-connected solar photovoltaic (PV) system is a system that generates electricity using PV modules and delivers the electricity it generates to the Grid, provided that there is electricity in the Grid. Basic components of a grid-connected Solar PV power system, solar PV modules, inverters, junction box (DC/AC), power conditioning unit, AC distribution board and transformer, switchgear, and switchyard. In a grid-connected system, solar energy generated during daytime hours is supplied to the grid without any energy storage.

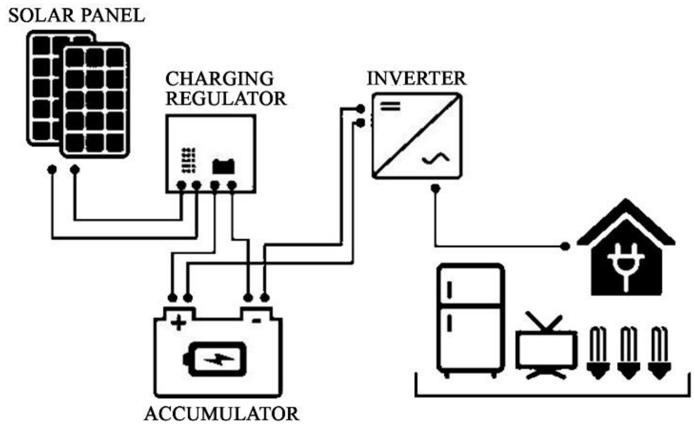


Figure 27. Off-grid PV system [30]

Off-Grid Photovoltaic Systems: Off-Grid systems are also known as stand-alone systems. These systems store the electrical energy generated by solar PV modules in storage devices such as batteries. The energy stored in the batteries can be used when there is a demand for the power supply or at night when there is no sunlight. More precisely, these systems are used in remote locations where there is no electricity supply, energy shortage or no access to the Grid.

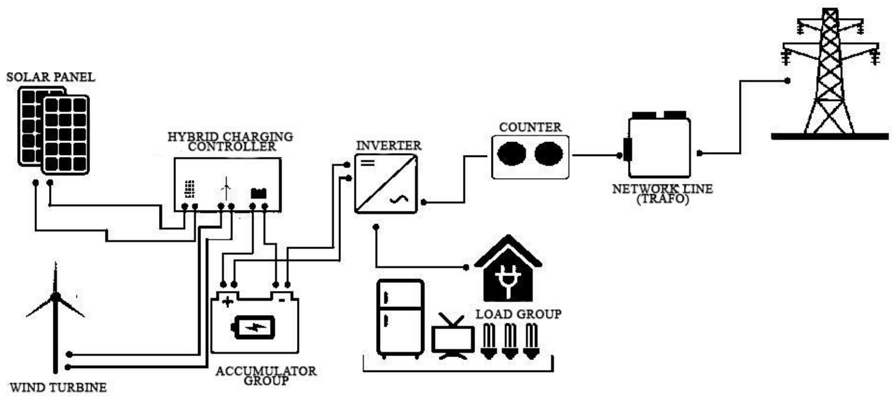


Figure 28. Hybrid PV system [30]

Photovoltaic Hybrid Systems: Electric energy production of photovoltaic solar panels and small wind turbines varies according to climatic conditions. Therefore, they are not a very rich source of energy production on their own. Combining systems (wind and solar) is more effective in the production of electrical energy. This solution is called a hybrid system. According to many renewable energy experts, a small hybrid electricity system offers many advantages when wind and solar PV are combined in one system [31].

5.1 Elements of Solar Energy Systems

5.1.1 Solar Cell

A solar cell is a photovoltaic device that converts light directly into an electric current. Working as a semiconductor diode, the solar cell converts the energy carried by sunlight directly into electrical energy by utilising the internal photoelectric reaction. Solar cells operate based on the photovoltaic principle, i.e. when light falls on them, an electrical voltage is generated at their terminals [30].

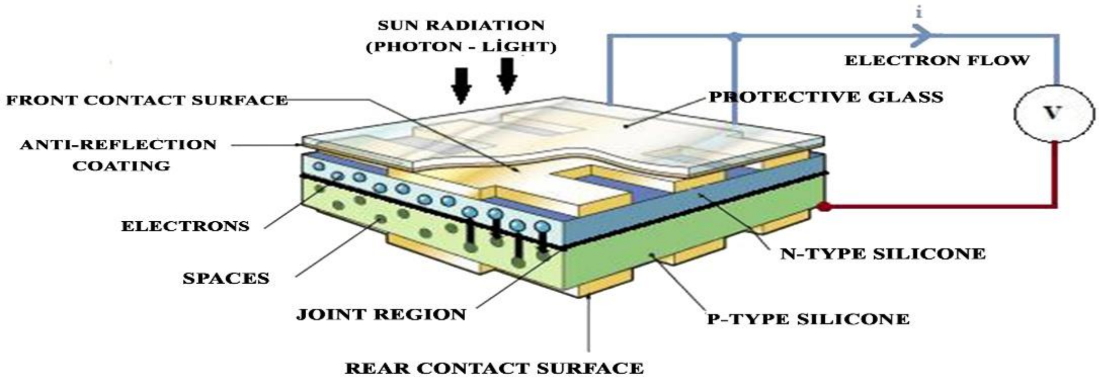


Figure 29. Photovoltaic cell structure and working mechanism [30]

The materials used in solar cell construction are as follows;

- Crystalline silicon,
- Amorphous silicon,
- Gallium arsenic,
- Cadmium telluride,
- Copper indium diselenide,
- Optical concentrator cells.

Photons are generated when sunlight hits the semiconductor surface and the electrons inside the atom are released. Photons contain different amounts of energy for each wavelength in the solar radiation spectrum. When the photons come onto the solar cell, some of them are exactly reflected, some of them are absorbed by the solar cell, and some of them pass through the solar cell. Photons absorbed by the solar cell generate electricity.

5.1.2 Solar Panel

A solar panel is an energy source that contains many solar cells to absorb solar energy [31].

Figure 30. Solar Panels

The solar panel consists of solar cells to absorb the sunlight coming on it. The efficiency of a solar panel is determined by the rate at which the cell in which it is used converts sunlight into electricity [32].

5.1.3 Inverter

An inverter, known as an electrical power conversion element, is also called an inverter. Inverters are power electronics elements used to obtain AC voltage with constant or variable amplitude and frequency by processing the voltage received from any DC source. In short, the inverter is a device that allows us to use 220 volts or 380 volts of energy produced by solar panels in solar energy electricity generation systems [33].

Figure 31. Inverter

5.1.3 Connection Elements

MC-4 Connector: It is a special element used to connect the cables of solar panels to each other and provides IP67 class tightness at the connection points.

MC-4 Branch Connector: It is a special connector used for parallel connection of solar panels and used for connecting multiple panels to each other. The MC-4 Branch Connector, which provides IP67 class sealing at the connection points, is specially produced for outdoor use and has high UV resistance.

MC-4 Diode Connector: The MC-4 diode connector, is a protection element placed on the cable to prevent the shaded panels from affecting the others in a solar energy system consisting of solar panels connected in parallel, which allows electrical energy to pass in only one direction (from the panel to the outside), is suitable for outdoor use and has high UV resistance as it provides IP67 class tightness at the connection points.

Cable: When designing a solar energy system, the cable cross-section should be carefully calculated according to the system power and cable quantity to be installed. All factors must be taken into consideration, as incorrect cable selection may result in efficiency losses and cables with inappropriate current carrying capacities and types may also pose a fire risk.

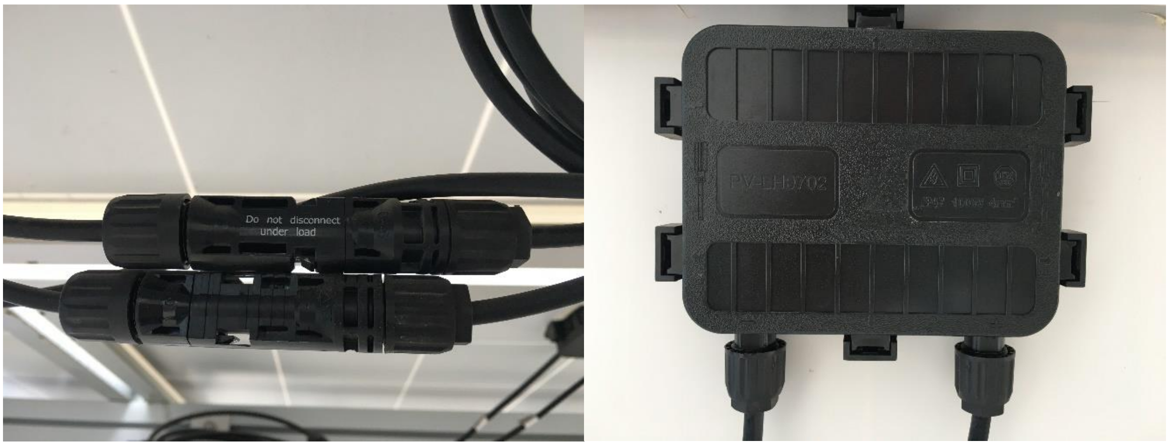


Figure 32. Connection Elements

Fuse: The fuses that will protect the system can be connected to the regulator output in order to disconnect the solar energy system and the battery block to which they are connected. The fuse to be installed must be selected in accordance with the system power. The fuse selected above the maximum current value may damage the system, and the fuse selected below this value may cut the circuit continuously.

5.1.4 Battery

A battery is an energy tool that stores electrical energy and makes it available when needed. In Solar Energy electricity generation systems, the energy produced by solar panels is stored in the battery group with charge control devices. The energy in the batteries can be converted to 220 volts with an inverter. With the developing technology, gel battery has become one of the most preferred battery types in solar energy systems by differentiating from other battery types.

Gel Battery: Gel batteries, which replace lead acid batteries and stand out compared to other batteries in terms of efficiency, are in the dry battery class. The gel battery contains electrolytes in a gel consistency, not liquid. The gel consistency inside the battery is obtained by homogenous mixing of sulphuric acid and sooty silica. Gel batteries are resistant to high temperature and vibration in terms of their properties. For this reason, they are intensively preferred in renewable energy sources such as maritime, wind energy, and solar energy.

The most important feature that distinguishes the gel battery from other battery types is that it offers deep discharge. When the gel batteries are recharged after being fully discharged, the feature that the chemical structure in its structure is not damaged is called deep discharge. In this way, gel batteries, which stand out with their longevity, do not cause inefficiency and durability.

Thanks to the gel consistency of the electrolyte contained in it, the problem of evaporation is eliminated thanks to the gel electrolyte in the gel batteries, which operate with high efficiency even at the lowest or highest temperature, and there is no need to add pure water to the battery.

Gel batteries, which offer high values in contrast to the low energy production capacity of the flooded battery, provide an energy level of 80 amps. In this respect, it has a performance approximately 75 times higher than other batteries.

Gel batteries are environmentally friendly. Gel batteries have fewer leakage problems seen than aqueous batteries depending on usage; It is more resistant to vibration, liquid contact, abrasion and impact. Gel batteries can be used for many years.

5.1.5 Charge Control Unit

Adjusting the current from the solar panel prevents the battery from being fully charged or completely discharged. According to the current value required for the consumer, it is necessary to select the type that can work harmoniously in the system. In addition, the battery charge regulator must be compatible with the battery voltage. Direct current output can be taken from the charge regulator. Most regulators have a screen that displays numerical information about the state of charge. Many regulator manufacturer companies have determined the regulator to be selected according to the panel power and added it to their catalogues in tables[34].

Figure 33. Charge Control Unit

5.1.6 Mounting Elements

Solar power plants can be installed on grounds with different static properties. In order for the power plant to be long-lasting, static calculations related to the ground to be installed should be made carefully. Solar power plants can be installed with aluminium and steel constructions. However, not every design or construction is suitable for every power plant. In particular, it should be ensured that the power plants installed on the roof or on large balconies called terraces should be ground surveyed and if it is to be drilled, the insulation should be done very well or the construction should be installed with concrete blocks. The material of the construction to be made of the ground that will carry the power plant will lead to the possibility of steel or aluminium. The outer coating of the prepared construction according to the climatic conditions will ensure its long life.

Figure 34. Mounting Elements

5.2 Connection Types and Calculation of Installed Power

Connecting multiple solar panels in series, parallel or mixed mode is an effective and easy way to not only create a cost-effective solar panel system but also to help us add more solar panels in the future to meet our growing daily needs. The type of solar panels, the amount of solar energy desired to be produced, the charge regulator, battery and inverter and other system components are the factors affecting the connection types.

When higher voltage is required from each panel in the solar power plant, the solar panels are connected in series and when higher current is required, the panels are connected in parallel.

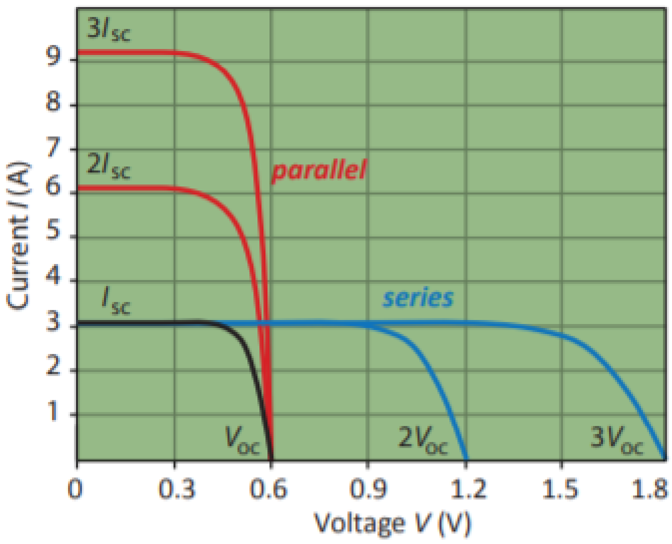


Figure 35. I-V curves of solar cells connected in series and parallel [37]

Both types of connection can be applied if both a higher voltage and a higher current are required; this means that some of your solar panels should be connected in series, while others should be connected in parallel.

Installed power: It refers to the sum of the rated (labelled) power of electrical energy consumers in a facility [35].

The installed power in solar power plants is found by multiplying the total number of panels in the system by the power of a panel. The installed power expressed as Wp can be calculated by the following simple formula.

Installed Power of the System = Total Number of Panels * Power of 1 Panel

For example; Private Ankara Chamber of Industry Technical College Vocational and Technical Anatolian High School. There are 80 solar panels of 275 W and 40 solar panels of 310 W.

The installed power of the system is 34.4 kWp and the inverter power is 27.3 kWe.

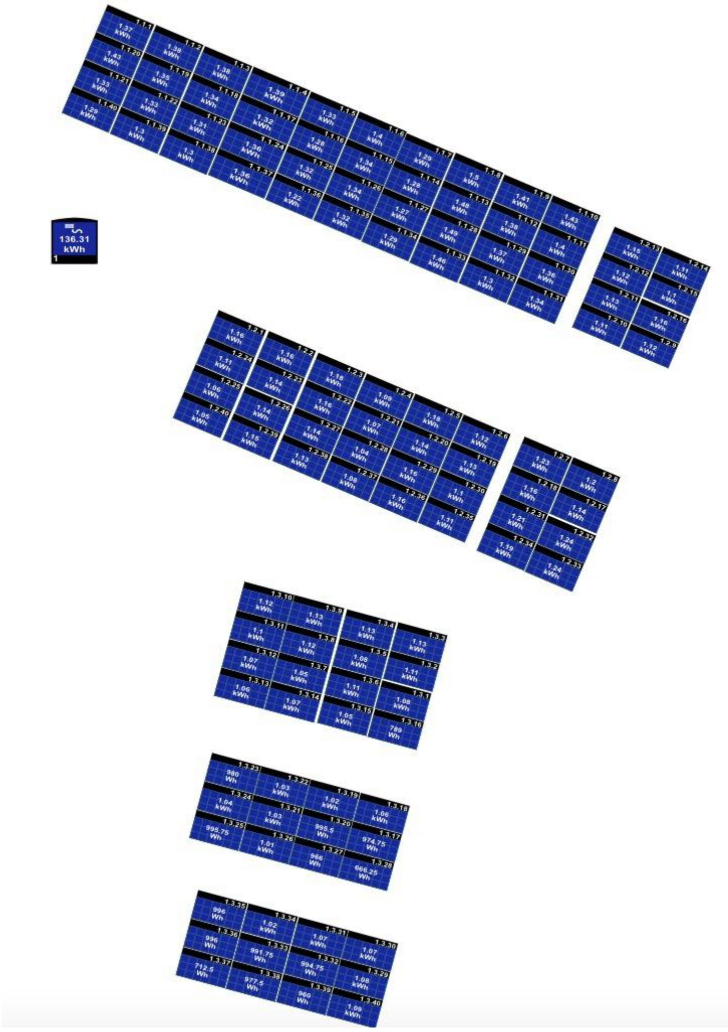


Figure 36. Private Ankara Chamber of Industry Technical College Vocational and Technical Anatolian High School Panel Layout Plan

The calculation is as follows.

Installed Power of the System = Total Number of Panels x Power of 1 Panel

= 80 x 275

= 22.000 W = 22 kW

= 40 x 310

= 12.400 W = 12,4 kW

Installed Power of the System = 22.000 + 12.400

= 34.400 W = 34,4 kWp

6. CELL TYPES

6.1 Photovoltaic Method

Photovoltaic cells are electrically connected in series, or parallel to obtain higher current, voltage or power level. Photovoltaic modules contain photovoltaic cells that are attached to each other in such a way that they are impermeable to environmental factors. Photovoltaic panels contain two or more Photovoltaic modules connected by electrical cables. Photovoltaic arrays, on the other hand, are power generation equipment containing a certain number of Photovoltaic modules or panels [39].

6.2 Crystalline panels

According to their crystal structures, solar energy panels are divided into two; monocrystalline and polycrystalline.

6.2.1 Monocrystalline

Monocrystalline solar panel, one of the oldest and best-known solar panels, consists of a single crystal structure. All solar cells are seen as one solid color. One of the prominent features of monocrystalline solar panels, which has the highest efficiency rate in the range of 19-20%, is that it saves space. Monocrystalline solar panels are preferred solar panels for having long-lasting structures and can be guaranteed for an average of 17-20 years. Despite its high efficiency, its high cost pushes the monocrystalline solar panels into the background. Since it is made of long-lasting and durable material, the initial investment costs are high, but it can meet this cost with its efficiency over many years. The visual figure of the Monocrystalline Solar Panel is presented in Figure 37.

Figure 37. Monocrystalline Solar Panel

6.2.2 Polycrystalline

Solar panel cells made of polycrystalline silicon, consist of rectangular cells, and have a highly recognizable outer view which is called multi-crystalline silicon. The colors of polycrystalline solar panels are blue. Unlike monocrystalline solar panels, their production costs are less.

Nevertheless, polycrystalline solar panels, which are less efficient when compared to monocrystalline panels, are preferred because of their low cost. The efficiency rates of polycrystalline solar panels are in the range of 18-19%. The visual figure of the Polycrystalline Panel is presented in Figure 38.

Figure 38. Polycrystalline Solar Panel

Polycrystalline solar panel heat tolerance is lower than monocrystalline solar panel. This situation negatively affects the efficiency of polycrystalline solar panels. Nevertheless, they are preferred due to their lower installation costs.

6.3 Thin Film

Thin Film Solar Panels are rarely used in solar power plants due to their low efficiency. Although the rate of preference is low in specific areas, their costs have been reduced depending on the production factors, and can they be used in larger areas due to their structure. Thin-film solar panels, which are very affordable, can be preferred for the external wall of buildings. These panels, which have a very advantageous structure for mass production factors, can wear down more and deform faster than other panels.

6.4 Flexible Panel

Flexible solar panels are types of panels made of a lighter and flexible material compared to other existing solar panels. It is a product that is mostly used in areas that require an important design, such as boats, marines, electric bicycles, and provides a significant advantage in pitched roofs. Flexible solar panels may provide ease of use without damaging the insulation of the roof on inclined surfaces where installation is difficult.

Flexible solar panels become prominent not only because they are easily transported since they are lighter than other solar panels, but also have a special effect on the surface which they are applied. Additionally, they may be supplied with different power options.

6.5 Transparent

Transparent solar panels are produced to prevent the penetration of sunlight, to a certain extent, by covering the outer surfaces of buildings such as plazas and shopping malls whose outer surfaces are completely made of glass. With this purpose, employees will be able to work without being distracted by sunlight during working hours and energy production will be provided.

At the same time, the possibility that the generated energy may be stored in batteries, as well as being used when required, make transparent solar panels a very advantageous type of investment. Nevertheless, their efficiency is not very high.

Yet, the case of covering all buildings, whose exterior surface is completely made of glass, or extending the usage periods by covering products such as mobile phones, tablet computers that use a certain amount of charge, make these panels become prominent.

6.6 Hybrid

Solar cells can convert 15% of the energy from the sun into electrical energy, most of the remaining energy is converted into heat energy, causing the solar cell to heat up. Each 1^{o}C temperature increase in the solar cell, reduces electricity production by 0.45%.

While the ideal operating temperature of solar cells is calculated as 25^{o}C, the temperature of the solar cell operating in an area with an ambient temperature of 25^{o}C may rise up to 45^{o}C. Hybrid systems have been developed to cool the solar cell and to take advantage of this heat. Thus, electricity, hot water and air are obtained in that way. While on the one hand, cooling solar cell provides an increase in efficiency, on the other hand, heat energy becomes available for usage.

In hybrid systems, panels are cooled with water or air channels integrated under the solar panel, and the circulation of the water in the panels integrated with the water channels is provided with the help of a pump. At the same time, the energy of the heated air is transferred to the water via the energy transfer unit, which is then, directly used for indoor heating.

While ensuring the increase in efficiency by preventing the possible faults that may occur from the growing electrical energy production and overheating by reducing the panel heat, as well as operating the system in a more stable way by obtaining both electrical and heat energy through a single system make the hybrid systems become prominent, the installation costs which are approximately 25% higher, make the investors take a step back. Nevertheless, when its efficiency is considered, it will undoubtfully cover the installation cost in a short time.

7. FACTORS AFFECTING THE PERFORMANCE OF PHOTOVOLTAIC SYSTEM

The maximum electrical energy that can be produced in solar power plants is determined during feasibility studies. After the installation and commissioning of the plant, if the value of the maximum electrical energy that should be produced is less than the one calculated beforehand, it means that there are losses in the system. It is more important to foresee these losses before they happen rather than preventing them. As, if all possible interventions are done in a conscious manner, maximum efficiency may be obtained from the system in the shortest time. Otherwise, the desired performance or expected income will not be obtained from these systems whose installation costs are high. Meteorological stations used in solar power plants provide some data. The result of the analyzes of the meteorological data such as temperature, radiation, wind value obtained from stations that have been made meaningful, guides users to see the level and the efficiency rate of the system while it is operating. According to the analyzes, interventions done in a conscious manner are very important to minimize the losses that may happen.

Apart from the meteorological factors mentioned, losses that may arise from the design of solar power plants such as shadowing, material quality, mismatches between parts and inverter losses may also affect the system efficiency. Percentages of Module Energy Losses are presented in Figure 39.

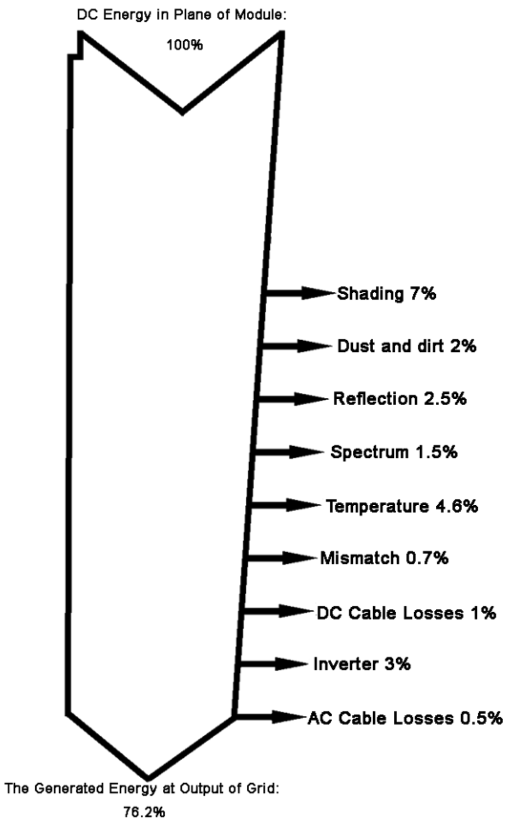


Figure 39. Percentages of Module Energy Losses

7.1 Location

In solar power plants, the amount of sunlight falling on the panel surface per day is directly proportional to the value of the electrical energy obtained. One of the most important steps of the feasibility studies to be carried out before the installation phase is to make the panel layout and system positioning in the most accurate way. Solar power plants designed as fixed rows or stands, may cause the panels to shade by preventing each other's radiation due to height and positioning errors.

Apart from the possibility of panels that may shade each other, some other shadowing cases may arise depending on the characteristics of the area where the solar power plant is installed. Nevertheless, not positioning the panels regarding the rise and set of the sun every day will also lead to great losses. Staying away from very tall and narrow spaced placement in panel installation will reduce these losses [40].

7.2 Orientation and Surface Angle

The more the surfaces of the panels in solar power plants are exposed to sunlight, the higher will be the production efficiency. Another way to keep this radiation at the maximum level, is by determining accurately the tilt of the angles of the rows in its design. The efficiency will be high in solar power plants positioned with accurate tilt, whereas it will be lower in solar power plants positioned with an inaccurate one.

In solar power plants, losses that occur in case of deviation of the radiation coming from the sky between the orientation and surface angle losses are called spectrum losses, and the reflection losses of some of the rays falling on the panel surface without being converted into energy are called reflection losses. It is possible to conclude that the surface angle is inaccurate if the back reflection value is above 4%. Angle Measurement Values of the Panels are presented in Figure 40.

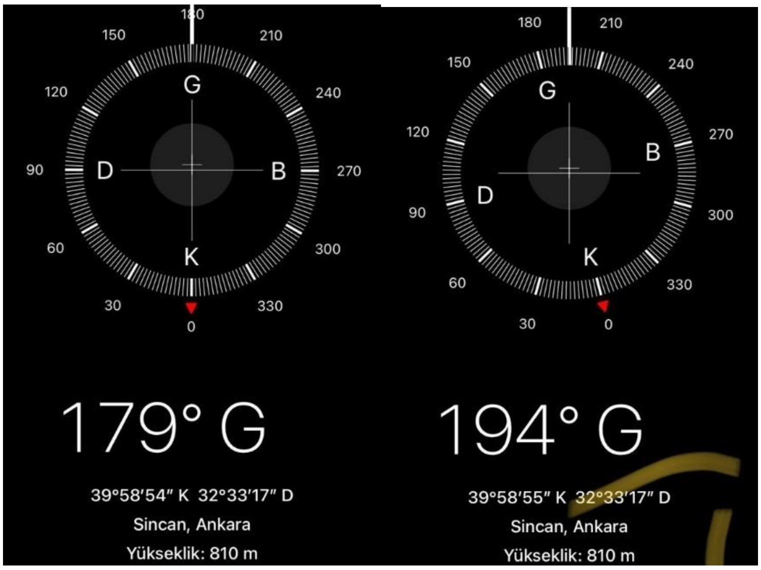


Figure 40. Angle Measurement Values of the Panels

7.3 Shadowing

Shadowing losses represent the voltage difference between the shaded and not shaded parts of panels in solar power plants. This situation, which occurs in the area where the switchboard is installed or in cases where the panels are positioned inaccurately, may be explained with horizon shadowing and panel row shadowing.

Figure 41. Example of Shadowing

The shadowing caused by natural physical features specific to the area where the power plant is installed (such as mountains and hills) is named as "horizon shadowing" while panels that shade each other in a power plant is named as "panel row shadowing". Example of shadowing is presented in Figure 41.

7.4 Panel Type

The panel type chosen during the installation phase of solar power plants directly affects the efficiency analysis. Inaccurate choices may lead the plant to great losses. Factors such as climatic conditions, warranty features of the panels and product certificates should be evaluated very well during the feasibility phase.

The cell efficiency of polycrystalline solar panels, which are among crystalline panels, is between the range of 18-18.6%. While these panels are more easily found and their cost is lower than monocrystalline panels, their low temperature tolerance and efficiency compared to other panels reduces their popularity.

Monocrystalline solar panels become prominent for their efficiency, compared to polycrystalline panels. While the fact about the high installation cost of monocrystalline solar panels pushes those panels into the background, their temperature tolerances and efficiency ratios in the range of 19-20.6% make them preferrable.

We encounter several parameters when the efficiency of solar energy panels is analyzed. While designing, it is very important to choose the panel after the feasibility study is done completely and the climatic conditions, power plant positioning, panel layout and physical characteristics of the area to be installed are determined. While designing, it is very important to complete the feasibility study, determine the climatic conditions, power plant positioning, panel layout and the physical characteristics of the area to be installed, and then choose the panel.

7.5 Temperature Among Modules

As the temperature rises in solar panels, the power taken from the panel decreases. In other words, an inverse relationship between power and temperature is seen. The panel temperature values, which increase in direct proportion to the daily radiation amount, decrease the efficiency. To prevent this situation, various cooling techniques may be used and developed. In this way, the efficiency obtained from the solar power plant throughout the day will increase.

7.6 Solar Panel Cleaning

Contamination of solar energy panel surfaces due to various physical factors will cause a decrease in efficiency, despite the possibility of high radiation during the day. Panel's exposure to dust, sludge, bird droppings, or snow that covers panel surfaces during winter, may be the examples of these physical factors. To increase efficiency, panel surfaces should be checked and cleaned frequently.

Cleaning operations may be done with human power or remote cleaning automation systems that may be developed for this purpose. The image of the Contaminated Solar Panels is presented in Figure 42.

Figure 42. Contaminated Solar Panels

8. FACTORS AFFECTING EFFICIENCY IN PHOTOVOLTAIC ENERGY SYSTEMS

There are basically four reasons that affect efficiency in a SPP (Solar Power Plant) system. These may be the climatic effects, environmental effects, characteristic and structural features of the solar panels to be used in the system, and losses (installation losses) of the devices which are used to assemble the system. These four reasons are in fact interconnected. Ignoring one may cause major changes in the system's power generation. Therefore, in the region where the SPP will be installed, these parameters should be thoroughly examined beforehand, and all interactions should be considered. In this way, the power to be produced by the system may be estimated more accurately [41].

Having full knowledge on the meteorological data of the region where the SPP will be installed, is very effective in terms of calculating the panel efficiency. Therefore, knowing the changes in these parameters during the year (estimation based on at least 10 years of measurements) will give more accurate results in daily and annual power generation forecasts of SPP. The parameters that should be measured or known together with their reasons are listed below.

8.1 Climatic Effects

8.1.1. Parameters Affecting Panel Surface Temperature (Operating Temperature)

As the panel surface temperature increases, the open circuit voltage, and Vmpp value decrease significantly, which in fact, causes power loss. Climatic parameters affecting panel surface temperature are;

Temperature: increase in ambient temperature directly affects the temperature of the panels, increasing temperature decreases the open circuit voltage and Vmpp value.

Wind speed: The wind speed creates a cooling effect on the panels, which increases the open circuit voltage of the panels and Vmpp value.

Humidity: When humidity is estimated together with wind speed, it allows us to know accurately the change in the surface temperature of the panels.

Radiation amount: The radiation falling on the panel surface has more than one effect. Nevertheless, considering its effect on the surface temperature, the constant amount of radiation coming onto the surface will increase the panel surface temperature until it reaches thermal equilibrium. As the amount of radiation increases, the time for the panels' surface temperature to reach equilibrium increases together with the temperature value.

Figure 43. Measurement Sensors

Having knowledge on these four parameters in advance, will enable us to have information about the operating temperature of the panels. Thus, panel temperature will be measured instantly and the change in the expected efficiency will be seen directly. The image of the Measurement Sensors is presented in Figure 43.

8.1.2 Parameters Affecting the Amount of Radiation Falling on Panel Surface

The radiation falling onto the panel surface, changes the short-circuit current and Impp value in direct proportion. The increase in the amount of radiation creates a positive effect by increasing Impp value in power generation, as well as creating a negative effect by increasing the panel surface temperature. Therefore, panels should be estimated together with their surface temperature.

Rain Precipitation Time: Cloudy weather during precipitation will reduce the amount of radiation. This will reduce the power output by lowering the Impp value.

Snowfall duration, snow density: During snowfall, the weather is brighter than a rainy one. Nevertheless, snow accumulates on panels and prevents them from getting light. Due to the tilted surface, the snow will mostly slide downwards. This will shade some of the panels and will cause a decrease in the efficiency. To avoid from these factors, panels need to be cleaned, although this will bring an extra cost. In order to calculate this cost in feasibility studies, it is important to know the snow density and its melting duration.

Cloud density: The cloudy weather, and the shadow of the clouds that falls on the panels completely or partially will reduce the amount of radiation. That will decrease the power generation by decreasing Impp value.

Duration of Solar Insolation: Having some knowledge on the amount of light falling on the panels in a year / day is the most important parameter in estimating / calculating the amount of power to be produced.

Knowing these four parameters in advance will enable us to have information about the radiation that will fall on the panels. Thus, measuring the radiation falling on the panel instantly will allow to see the change clearly in the expected efficiency.

8.2 Environmental Effects

As environmental and climatic effects have similarities, they may be changed as their formation is artificial. The most important point to note here is to predict the shadowing of the structures on the SPP during the year around the region where the plant will be installed. If possible, there should not be a structure (natural or artificial) that will create a shadow around the area where the SPP will be installed. If there is, this should be removed beforehand, or the installation plan should be made accordingly to minimize the effects of this shadow. The image of Environmental Effects is presented in Figure 44.

Figure 44. Environmental Effects

In addition, urban changes / formations that may occur over the years in the region where the SPP is installed should be limited by the authorized institutions in a way that they do not overshadow the SPP.

In addition, the infrastructure in the region where the Solar Power Plant is planned to be installed should be examined carefully as infrastructure opportunities or deficiencies affect the investment cost.

8.3 Characteristics and Structural Properties of Solar Panels

Before the SPP installation, parameters mentioned above should primarily be examined on the field, and the panel selection should be determined in accordance with their characteristics and structural properties. The p-n junction parameters that affect the efficiency such as parallel-series resistance and capacitive properties, which are formed during the construction stage of cells, are not examined here.

As the output voltage is adjusted according to the lowest voltage in a panel series coupled in series, it is important to use panels of same characteristics in a SPP. Maximum yield cannot be obtained from a SPP with panels of different structures or properties.

8.3.1 Panel Surface Temperature

Considering the panel efficiency under standard conditions, monocrystalline panels show the highest efficiency. Nevertheless, polycrystalline panels worked with higher efficiency according to the observations made in the experiments conducted on different panels in Kocaeli, Tekirdağ, Karabük, while the efficiency of monocrystalline and polycrystalline panels was nearly equal in the experiments conducted in Erzincan [42,43,44,45]. This demonstrates that the selection of panels may vary from one region to another. In fact, this variation results from the characteristic properties of the panels rather than regions. The variation in surface temperature is seen in Figure 45, assuming the light intensity is constant. According to this, with the increase in the surface temperature, Vmpp and Voc decrease (approximately as exp), while Impp value and Isc increase slightly.

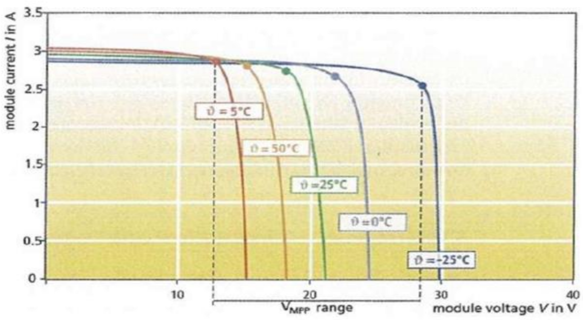


Figure 45. The Change in the Surface Temperature

The changes of the values of Impp(T), Vmpp(T), Isc(T) ve Voc(T) with temperature are given as such;

$$\begin{aligned}
I_{sc}(T) &= I_{sc} \times [1 + \alpha_{Isc} \times (T_{cell} - 25)] \\
I_{mpp}(T) &= I_{mpp} \times [1 + \alpha_{Impp} \times (T_{cell} - 25)] \\
V_{oc}(T) &= V_{oc} \times [1 - \beta_{Voc} \times (T_{cell} - 25)] \\
V_{mpp}(T) &= V_{mpp} \times [1 - \beta_{Vmpp} \times (T_{cell} - 25)]
\end{aligned} \qquad (28)$$

Here, αIsc, αImpp, βVoc, βVmpp are the coefficient of the short-circuit current, maximum operating current, open-circuit voltage, and maximum operating voltage temperature, respectively. Cell temperature (Tcell), changes with ambient temperature and solar radiation variation, and is given as such:

$$\mathbf{T_{cell} = T_{ambient} + \left(\frac{T_{nom} - 20}{0{,}8}\right) \times G} \qquad \textbf{(29)}$$

Here, Tnom is the temperature of the heat released in the cell that comes from the part of the radiation that does not transform into electricity on the cell/PV module. Tnom given as "nominal cell operating temperature", is defined/measured for the ambient temperature being 20°C, solar intensity 0.8 kW/m2 and wind speed 1m/s. G is the solar radiation intensity given as kW/m2.

The lower is the βVmpp temperature coefficient of the panel used, the less variation will be seen in Vmpp value. Therefore, panels with a small βVmpp temperature coefficient should be selected for SPP to be installed in regions with high temperature difference. In this way, the efficiency loss due to temperature difference will be kept at minimum level. Yield calculations made with different panels at different temperatures [46] are given in table 11.

Comparison of solar panel efficiency at different temperatures

Table 11: Comparison of solar panel efficiencies at different temperatures

Temperature (Ambient C°)	Monocrystalline Yield (%)	Polycrystalline Yield (%)	Amorphous Yield (%)
25	15	14	10,36
30	13	12	9,6
35	12,8	11	9
37	11	10,2	8,3
40	9,9	9,2	7,9
45	7,65	7,5	7,46

As seen in Table 11, the difference observed in efficiency at low ambient temperature decreased rapidly with increasing ambient temperature. In fact, this is due to the variation of Vmpp value with temperature. This accordingly demonstrates that amorphous thin-film solar cells have lower βVmpp temperature coefficient than monocrystals. A similar study was conducted in Pakistan [47].

8.3.2 The Amount of Radiation Falling on the Panel

Figure 46 is a graph that shows the I-V variation of a panel as the light intensity on the panel variates.

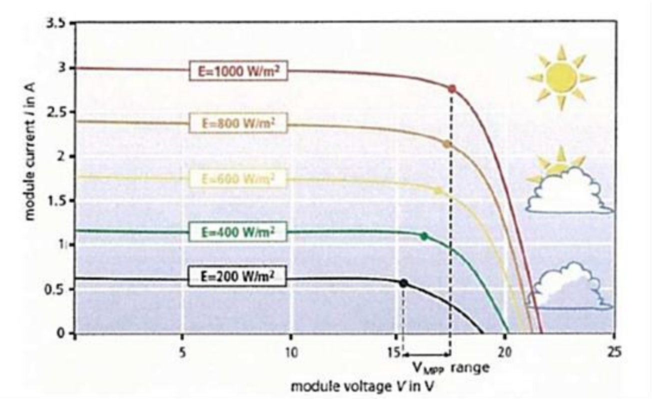


Figure 46. I-V Variation of the Panel

The variation in the light intensity in a short-circuit current (Isc), open-circuit voltage (Voc), maximum operating points for current and voltage (Impp and Vmpp) can be observed in Figure 47. The way these values variate with the light intensity is given.

According to this, while the values of Voc and Vmpp increase as exp and become saturated as the light intensity increases, the values of Isc and Impp variate linearly with the light intensity.

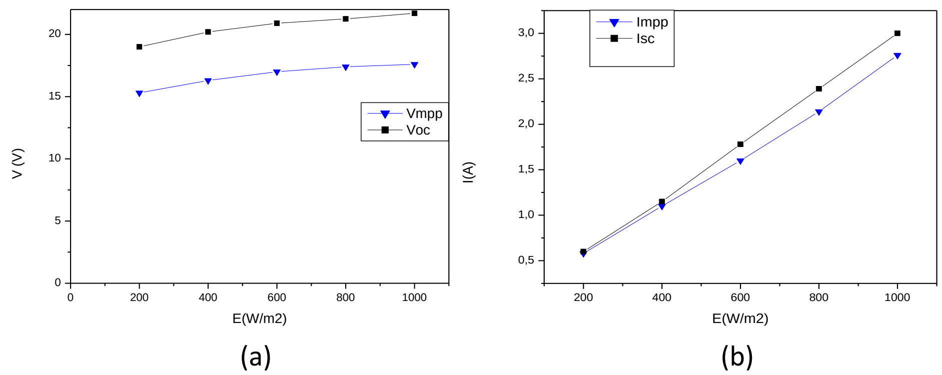


Figure 47. Isc and Impp Values

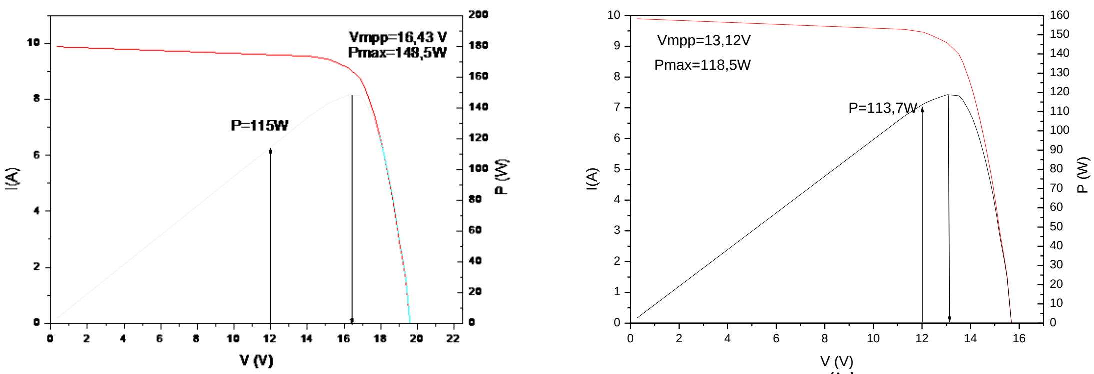
In order to keep the light intensity at optimum level, panels should be placed in a way they face the sun for the longest period of time and receive the most direct sun's rays. Directing panels to the sun by using solar tracking systems is the easiest way to do this. Nevertheless, these systems are not preferred due to the high maintenance and repair costs and the need for larger space, as their installation in the field should be done in such a way that they do not shade each other in all directions. Instead, to achieve higher efficiency in a smaller area, single-axis solar tracking systems may be used. Nonetheless, as those systems are always in constant motion, several malfunctions occur, and their maintenance-repair processes are long and costly.

One way to avoid such breakdowns and maintenance-repair processes is to design the construction in a way that it easily allows to be positioned at three different angles to receive the sun's rays perpendicularly in summer, winter, and spring seasons. (Adjusting the panel tilt manually in every four months).

8.3.3 Surface Area and Vmpp Value

Considering the power generation per unit area for different panel types, the highest power per unit area is in Monocrystalline, polycrystalline, thin-film copper indium solenoid, thin-film amorphous silicon and thin-film cadmium panels, respectively [43]. Panels that provide the highest efficiency in the lowest areas should be selected to obtain the optimum efficiency in limited areas. Nevertheless, it is not possible to obtain the optimum efficiency if Vmpp value is different from the inverter that is being used or the desired output voltage. This will increase the cost.

The I-V and P-V graphs of a serial module that consists of 33 cells with the same surface area and open circuit voltages of 0.59V (Figure 48 (a)) and 0.48V (Figure 48 (b)) are given as an example, respectively.



(a) (b)

Figure 48. The Graphs of I-V and P-V Serial Module

As seen in Figure 48, for 12 V DC output, although the maximum power generation is lower than in Figure 48 (a), using the module in Figure 48 (b) will increase efficiency. Therefore, together with the area covered by the panel, care should be taken to ensure that the Vmpp value of the module should be the desired output voltage or its multiples.

8.4 Installation Losses

Losses occur on the cable, inverter, battery, cable connections, grounding connections, and transformers used in a SPP [48]. To minimize these, material selection and detailed calculations are required to be done appropriately. A correct calculation will allow the power generation forecasts to be more accurate.

9. ENCOUNTERED TECHNICAL FAULTS

Technical faults encountered in Solar Power Plants may be listed in 5 different types. These are; Insulation Errors in electricity transmission, Inverter and Compact Switch Faults, Solar Panel and Solar Connector Faults, Medium Voltage Faults, Relay Coordination Faults.

9.1 Insulation Faults

Various conductors are used both in the transmission of the DC voltage produced in the panels of Solar Power Plants to inverter and in the connection of the AC voltage produced in the inverter to the grid. Insulation materials are used to prevent conductors from coming into contact with each other and short circuits, and to protect cables from external factors. Insulation properties vary according to the type of the material used. Insulation in cables is crucial for life safety and system protection. An example of Solar Power Plant Circuit Diagram is presented in Figure 49.

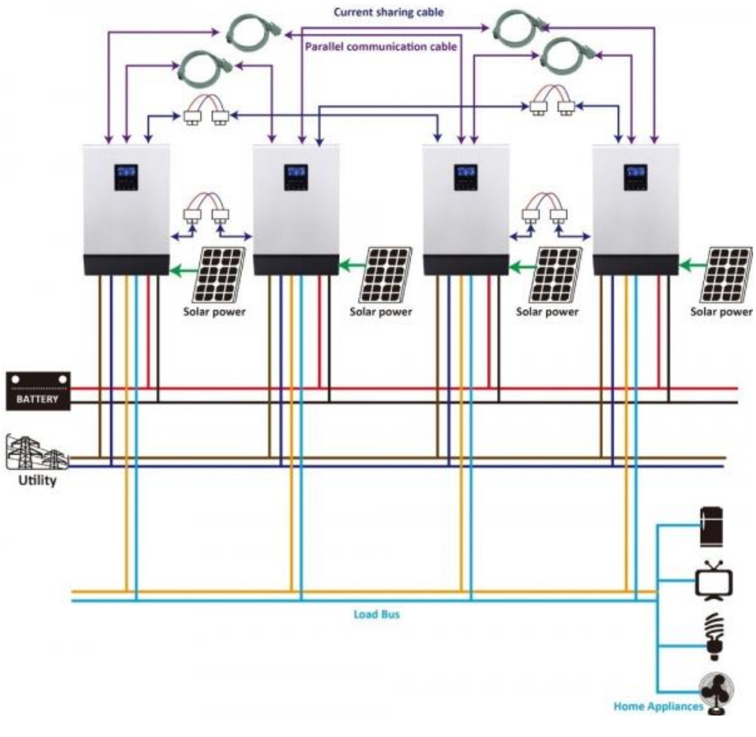


Figure 49. An example of Solar Power Plant Circuit Diagram

The most common error in Solar Power Plants is Insulation errors and are generally caused by an incorrect and loose connection made during the installation process, installation of cables without tolerance, the damages given to the cables by the corners of cable trays and rodents, and lastly the deformation of the insulating layer for exposing the cables to high and low temperatures. Insulation errors cause short circuits and equipment faults or deactivation in the inverters or solar panels to which the connection is made. After resolving the failure, an insulation test should be done in accordance with the IEC 62446-2016 Standard. Cable insulation should be more than 2 mega ohms at least, and its values must be consistent with each other. In order to maintain the damaged cables, repairing may be done for the ones above the ground but it is necessary to span cable again for the ones below the ground. Rodents may damage DC cables by gnawing them, as they build their nests near the underground hot cable channels and hide in there in winter. In terms of maintenance and repair, the Solar Power Plant area should be sprayed to keep rodents out of the plant. Image concerning Insulation Errors is presented in Figure 50.

Figure 50. Insulation Errors

9.2 Inverter and Compact Switch Faults

In order to produce electricity from solar energy systems, auxiliary elements are necessary just like in all other systems. These systems, which enable the use of DC energy as AC, occupy an important place in our lives.

Inverter: Converts the DC energy produced from the solar panel to AC. It is the most important production equipment of the installed systems. It is diversified as On-Grid and Off-Grid.

• On-Grid Inverter: These inverters, also called on-grid, convert the DC energy obtained from the panels to AC energy. On-Grid inverters should be used if the systems to be installed will be grid-tie and have a purpose to make sale.

• Off-Grid Inverter: In these systems, the energy produced through the process panel is transferred directly to the batteries for storage. Off-Grid inverters are used to transfer the energy to the system by converting the DC energy obtained from the batteries into AC energy.

9.2.1 On-Grid Systems

These systems work directly through grid connection without the need for a battery. As a two-way system, it allows to feed back the excess energy to the grid and draw it in case it is needed. As high-priced batteries will no longer be necessary, these systems may reduce both the cost and the number of maintenance operations.

9.2.2 Inverter Selection

Inverter selection should be made according to the number of panels used in the field and the number of strings that these panels will create. The computability of the inverter with other materials is crucial for energy production. Technical faults and breakdowns may occur in case the inverter is of low quality and does not have an appropriate voltage. The number of inverters will show differences according to the size of the project and the brand selected [49].

It is important that the maintenance and repair of inverters is done according to the maintenance manuals determined by the equipment manufacturers. Differences may occur in the mounting connections or ventilation systems among brands. The connection of string inverters made incorrectly or at an inappropriate torque value may cause terminal block burnout over time. Especially the cleaning of air filters and the maintenance of fans in central inverters should be repeated every year. Ventilation, cleaning, and maintenance of the inverter kiosk in central inverters are important.

Overheating problems in the switches used in solar power plants may only be eliminated by maintaining the connections properly. Performing thermal tests and visual controls of all connections at the Solar Power Plant site at least once a year will prevent possible fire risk and production losses [50]. The image of a Compact Switch Thermal is presented in Figure 51.

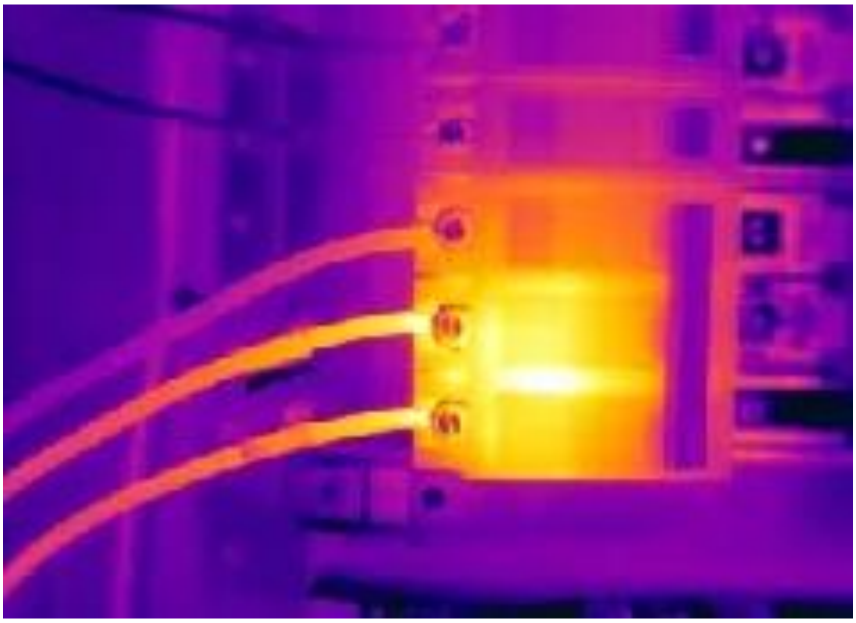


Figure 51. Image of a Compact Switch Thermal

9.3 Solar Panel and Solar Connector Faults

Most of the common faults seen in solar panels consist of broken connections, corrosions, broken glasses, broken cells, and coating defects etc. The term “Hotspot” means any hot spot that occurs on the panels including cracks, scratches, bird droppings and broken cells as well as manufacturing defects. That heat causes a decrease in the production capacities and affects the side cells negatively preventing them from producing energy. It is possible to detect these faults with the help of portable thermal cameras. Nevertheless, these manual detections may take a lot of time, or it may not be possible to measure fields with unsuitable land structure, areas with rooftop application or extremely large production areas. Mostly, in these situations, thermal faults in panels can be detected with the help of aircrafts equipped with high-resolution cameras in a very short time. Systems detecting malfunctions by means of drones with HD thermal cameras and multi-axis flight capability are called “Multicopter with a Camera System”. The spectrum and amount of the thermal radiation based on the surface temperature of the object, enables the camera to display the temperature on the panel surface. The thermal imaging application and the temperature values of solar panels are presented in Figure 51.

Short-circuits in cells and diode short-circuits are the types of faults encountered in solar panels. Short circuit in cells usually occurs during the production phase or due to the quality of the panels after their assembly in the field. As the result of this, the solar panel, instead of producing energy, consumes that energy by converting it into heat. This type of faults reduce the overall energy production as well. The structures of solar panels are simply identical to a PN junction and are called “diode”. Diode short-circuit faults may occur in solar panels as well [51]. The image of a Solar Panel Thermal Camera and its Temperature Value is presented in Figure 52.

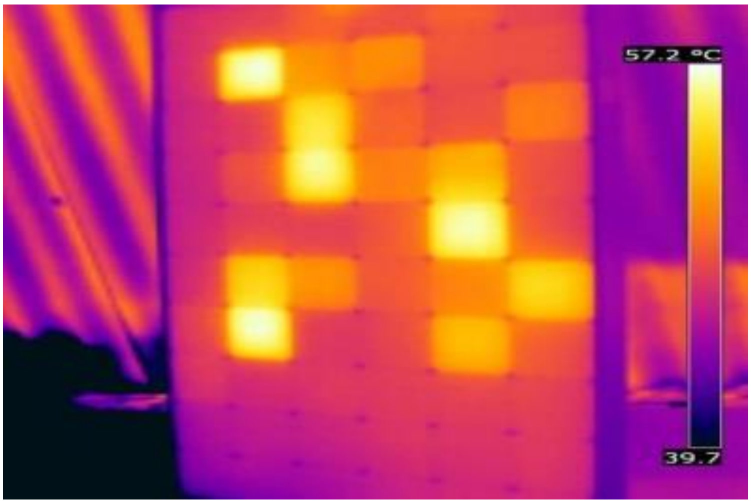


Figure 52. Thermal Camera Imaging of a Solar Panel and its Temperature Value

Another malfunction encountered in Solar Panels is the cable faults inside the junction boxes. Panel efficiencies drop below the nominal efficiency due to these reasons especially in summer. The case of incompatibility seen in connectors as "mismatch" may cause the failure of the connectors. Those connectors burn out due to incompatibility problems and pose a fire risk for the Solar Power Plant site. The image of a connector that burn out due to incompatibility is presented in Figure 53.

Figure 53. Connector That Burnt Out Due to Incompatibility

9.4 Medium Voltage Faults

Faults that happen in medium voltage systems establishing the connection of the Solar Power Plants to a grid, cause a significant amount of production losses. The time needed for the repair / supply of transformers and breakers may extend to 1 month, and the size of the risk it poses is significant. Periodic maintenance should be carried out by expert personnel in order to prevent malfunctions in transformers and breakers. Testing transformer protections in maintenance is of great importance. Transformers without protection may easily cause phase faults due to the pulses that come from the grid. The transformer should be repaired in the factory if phase burns occur. It is recommended to perform oil-gas analyzes, measure the turning ratio and winding resistances in oiled transformers. Measuring contact transition resistances is also important to detect possible arc formations.

9.5 Relay Coordination Faults

Relays are the equipment that protect the system from abnormal conditions in energy systems. The deterioration of the energy quality supplied from the grid or the energy quality within the system above certain tolerances may give damage to systems. To prevent it, relay coordination should be done in the field. Otherwise, pulses given to / received from the grid may cause unexpected malfunctions and explosions. Whether the hierarchical breaker protections work according to the relay coordination, and whether the relay settings are made correctly can be understood by checking the pulses coming from the grid.

10. MAINTENANCE, REPAIR AND OPERATION ACTIVITIES OF A PHOTOVOLTAIC SOLAR POWER PLANT

Generally, maintenance and repair are classified in two groups. These are: planned and unplanned maintenance and repair.

Planned (Preventive/Periodic) Maintenance and Repair: The aim is to pre-plan and prevent failures in a plant as well as ensuring its operating at an optimum level. Unscheduled (malfunction) maintenance: Performed in response to malfunctions.

10.1 Planned (Preventive/Periodic) Maintenance and Repair

Planned maintenance minimizes the maintenance and repair requirements caused by malfunctions. The planning of the preventive maintenance takes place according to various conditions. These conditions include points such as the selected technology, environmental conditions of the system, warranty conditions and seasonal variations. Scheduled maintenance is usually performed at scheduled intervals in accordance with the manufacturer's recommendations and equipment warranty requirements. The table below shows the commonly adopted periodical maintenance dates by manufacturers.

Table.12 Periodic Maintenance Table [52].

NO	PERIODIC MAINTENANCE DESCRIPTION	MAINTENANCE PERIOD	1. MAINTENANCE		
			DATE	APPROVAL	EXPLANATION
1	I-V Curve Measurement	Once in a year	1-30 April		
2	DC Hotspot Controls with Thermal Camera	Once in a year	1-30 April		
3	Solar Panel Cleaning	Twice a year	1-14 April		
4	Measurement and Controls for Inverters	Once in a year	1-30 March		
5	Grounding Measurements	Once in a year	1-30 Sept.		
6	Lightning Protection System Measurements	Once in a year	1-30 Sept.		
7	Measurements and Controls for Construction	Once in a year	1-30 Sept.		
8	LV Electrical Installation Measurement and Controls	Once in a year	1-30 March		

9	MV Electrical Installation Control-HV Business Responsibility	Monday, 20-25th of Every Month			
10	Transformer Maintenance	Once in a year	1-30 March		
11	HV Cell Maintenance	Once in two years	1-30 March		
12	Compensation Control	Monday, 20-25th of Every Month			
13	Billing Control	Monday, 20-25th of Every Month			
14	Camera System Maintenance	Once in a year	1-30 May		

Again, the regulatory maintenance events that are within the scope of planned/preventive maintenance in a PV plant, and the correct attitude as well as the planning the type of maintenance to be applied according to this road map were described in the table below.

Table 13. Maintenance Planning Table [53]

	Corrective Techniques					
	Artificial Intelligence	Water Cleaning	Dry-Cleaning	Snow Cleaning	Technical Maintenance of Equipment	Shadowing Reduction
Events						
Snow accumulation				+		
Dust Particulate Deposition		+	+			
Shadowing	+					
Equipment Failure					+	
Corrective Tasks						
Change					+	
Fix					+	
Remove		+	+		+	
Repair					+	+
Code						+

10.1.1 Panel Cleaning

PV panel hygiene is the most important factor affecting the system efficiency. As dust and other accumulated particles prevent solar radiation from reaching the target cells, a drop in the voltage as well as some other problems are observed when panels are dirty. This situation causes an energy loss of a rate of 7% in the least dusty regions, whereas it may go up to 50% in regions like the Middle East where movement of desert sand is seen. Panel Cleaning is easy (Figure 54).

Figure 54. Panel Cleaning

The time between cleaning activities will vary significantly from one region to another according to the level of module contamination. Nevertheless, the general practice consists of the necessity to clean the panels twice a year for their efficiency. The field, and the floor covering type of its surrounding, as well as the local precipitation patterns are the factors that determine the frequency of module cleaning. The recording of the power outputs of the clean and dirty panels based on a 16-month measurement period can be seen in Table 14. The power produced with clean panels in the relevant region is 8.7% higher.

Table 14. Difference Between Powers Generated by a Solar Energy Plant with Clean and Dirty Panels [54].

NO	MONTH-YEAR	CLEAN PANELS	DIRTY PANELS	PERCENTAGE DIFFERENCE
1	Nov.13	11.365	10.717	5.7
2	Dec.13	10.809	10194	5.69
3	Jan.14	11.344	10685	5.81
4	Feb.14	12.382	11865	4.18
5	Mar.14	11.735	11343	3.34
6	Apr.14	12.196	11569	5.15
7	May.14	11.862	11412	3.79
8	Jun.14	11.048	11035	0.12
9	Jul.14	0.9201	0.9355	-1.67
10	Aug.14	0.7544	0.7619	0.99
11	Sep.14	0.6810	0.7106	-4.35
12	Oct.14	12093	0.6631	45.17
13	Nov.14	0.9560	0.6026	36.97
14	Dec.14	10479	0.9785	6.62
15	Jan.15	10487	0.9821	6.35
16	Feb.15	12037	11.512	4.36
17	TOTAL	10612	0.9687	8.72

Manual cleaning is one of the most efficient cleaning techniques for small-scale Solar Power Plants [55]. A worker's need for a soft swab and water to clean the panels is considered as the most primitive technique [55]. The use of water jets and brushes with detergents may be considered as a way of a better cleaning technique for tough dirt. (Figure 55) [56].

Figure 55. Manual Panel Cleaning

Active Cleaning technique, starting with mechanical methods, corresponds to all cleaning techniques that require constant power to perform the work. It is equipped with mopping, brushing and air spray.

A system consisting of a central processor, a gearbox, and a stepper motor rotate in a way to light the solar radiation to the surface of the solar panel module. The 180 degrees rotating brush rotates due to gravity force and cleans the solar panel surface. The other cleaning process of the brush is performed at 360 degrees at different times [57]. Electrostatic shields cleaning techniques, on the other hand, are based on the wave theory. According to that, air dust-laden elements are carried transversely with the movement caused by the electric area [58]. The electrostatic dust removal system consists of two parallel electrodes, and each electrode induces mutually a negative electrode in charged elements. It is made of very specific chemical components that can be placed in a certain place present on the surface of a negative charge solar panel. Dust is deposited on the positive electrode after extraction. As a result, a non-contact cleaning is performed, and the performance of each solar panel module is increased by 90% [59]. In the last sub-section of active cleaning, robotic cleaning system consisting of electric motor and brush has shown a great effectiveness in reducing the amount of water consumed (Figure 56) [60].

Figure 56. Panel Cleaning with Robot

Panel cleaning task is inexpensive and simple; therefore, it does not require any special equipment and expertise. The high electricity outputs may recover the amount of water consumed and labor costs of the cleaning process. Nonetheless, the areas that require panels to be cleaned more than twice a year, choosing different automation techniques and dry cleaning may allow to reduce costs. In the technique of water cleaning, the process should be performed with water that contains a very small number of dissolved solids. Adding soap or other cleaning agents can cause residues on the top surface of solar panels and, that will result in malfunctions and degradation. Some chemical detergents leave marks on the glass assembly, causing light deviation and other malfunctions. Cleaning panels with transported or mains water may cause limescale deposits. Thus, using de-ionized pure water may be considered as appropriate.

On the other hand, dry cleaning is considered as a higher-level technology that replaces water cleaning. Nonetheless, dry cleaning is disadvantageous, as, it will require other hardware (robots, electronics) and technical personnel who constantly is required to control the machine performance, maintenance, and monitoring.

Not only dust and bird droppings affect the power output of a solar power plant. Snow accumulation on solar panels installed in cold regions greatly reduces the overall power output [61].

Due to the large structural differences between dust and snow, techniques used to reduce the negative impact of dust/debris do not work to remove snow from the surfaces of solar panel [62].

The outlined eight techniques below demonstrate the methods to reduce power generation losses by increasing the angle of tilt and shifting the accumulated snow faster in solar panels.

Snow Accumulation Reduction Methods

- ✓ Increasing Tilt Angle at Night
- ✓ Rear Projection
- ✓ Surface Covering
- ✓ Heating
- ✓ Electrostatic Surface
- ✓ Thermal Collector
- ✓ Venturi Deflector
- ✓ Mechanical Cleaning [63].

This activity is done at night (when solar radiation and solar panel outputs are switched off); here, the panel will quickly return to the position it produces energy the next day.

As the snow is always removed from the back of the solar panel, rear surfaces will have difficulty in absorbing the scattered light. This will reflect from the back of the panels and help increase the temperature on them and thus, will accelerate the snow melting process. This will melt the snow in front of the panels [64].

The function of surface coatings is to absorb the sun's rays to break up the snow cover, reduce adhesion and increase friction. Alternatively, heating processes are the simple methods used to remove snow from solar panels. These are divided into two parts:

Heating with Voltage Application: By utilizing the resistance properties of solar panels, a voltage source is applied to generate heat after the snow falls on the ground [65].

External Heating Source: This is made by adding external resistive heaters to the front or back surfaces of the panel [66]. This strategy provides faster and more focused snow removal by reducing heat losses coming from the cold surrounding environment.

The Thermal Collector process is a technique that helps the solar radiation heat up the collector and thus, transfer the heat through conductive paths to the panel and, to the snow as well. Heat is transferred from a vertical metal panel (Figure 57) [67].

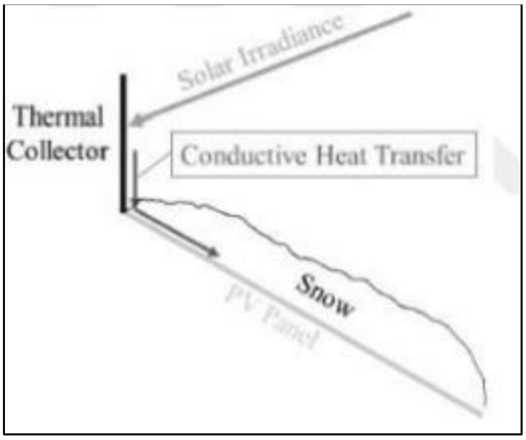


Figure 57. Thermal Collector

The Venturi Deflector, a simple but without any moving parts, uses unidirectional wind to push air down the front of the solar panel and thus, prevents snow accumulation [68].

Chemical treatment (spraying brine and salt) is effective in defrosting, but this may somehow degrade the solar panel module. [69].

All techniques presented here require the mounting of additional electro-mechanical equipment to the carriers of the panels except for the surface coating. On the other hand, techniques with electrostatic force and heating initiators can reduce the overall power output of the system by taking some of the power produced to run the equipment.

The following should be considered while performing panel cleaning:

- Environmental and human factors (Autumn residues and pollution from local agricultural and industrial activities).
- Weather Conditions: No cleaning is required during rainy seasons.
- Dust carried from deserts by wind and becoming visible after rain.
- Dust caused by traffic jam.
- The accessibility to the location of the facility according to weather forecasts.
- The availability of water and cleaning materials.

10.1.2 Module Connection Integrity

The system needs to be checked once a year for module connections, and topics such as visual control, thermal control, connection looseness. The humidity and temperature level of the geography may cause corrosion and rust. It is important to check the module connection integrity. Monitoring the current in each string and comparing it instantaneously with other strings is necessary to detect faults in each module string. If array-level monitoring is not used, the maintenance contractor should periodically check connections between modules in each array, at least annually.

10.1.3 String Combiner Box

String combiner boxes may also be adversely affected by factors such as water, dirt, and dust, depending on geographical conditions, and may endanger the integrity of the system which may cause a decrease in efficiency. Additionally, its connections may loosen due to yearly temperature changes. Loose connections may affect the overall performance of the solar system. Any accumulation of water, dirt or dust may cause corrosion or short circuit inside the junction box. In cases where array-level monitoring is not used, the maintenance contractor is required to perform the periodic controls of the integrity of the fuses in the junction boxes, combiner boxes and the ones in the module junction box in some instances, at least annually. (Figure 58).

Figure 58. String Combiner Box

10.1.4 Hot Spots

While monitoring the performance of the systems prosecuted at array level, a periodic control with thermal cameras is required for systems with central inverters that are not monitored in this way. This method is helpful in identifying these common problems, especially in regions with continental climate, where the large difference between day and night temperature causes weak and loose connections in junction boxes and inverter connections. Thermography may also detect hot spots inside the inverter components and on modules that are not performing as expected. It is important for an expert to use a thermography at least once a year in order to detect problems in advance. Additionally, the number of examples concerning the controlling of hot spot by unmanned aerial vehicles carrying thermal cameras or infrared sensors has been increasing each day (Figure 59).

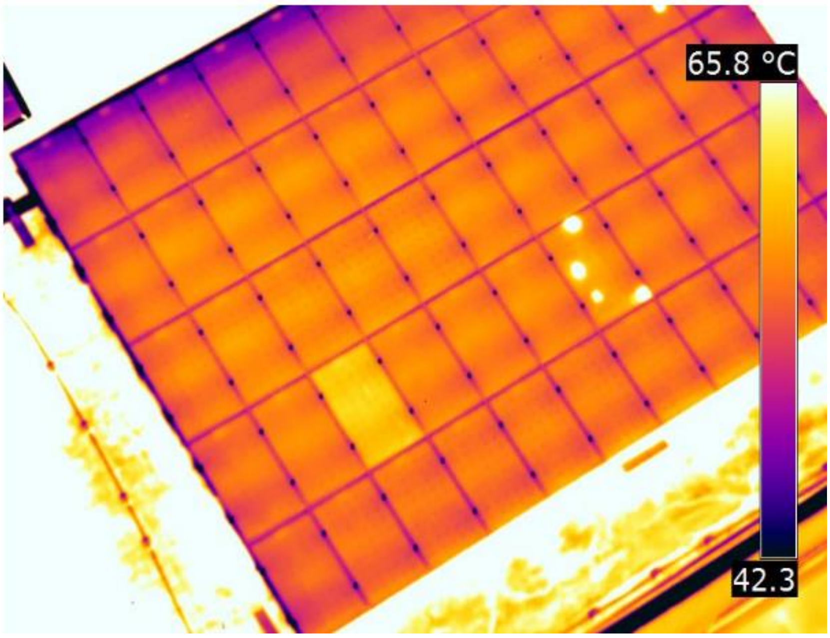


Figure 59. Thermal Camera Image of a Panel

10.1.5 Inverter Maintenance

In general, inverter faults are the most common cause of system outages in photovoltaic power plants. In order to maximize efficiency and minimize unplanned maintenance and repair costs, inverter maintenance and controls are recommended to be done periodically. Overheating, leakage current, insulation, communication, overvoltage, overcurrent, grid, frequency, fan, and low voltage faults that may occur in inverters are required to be eliminated by expert and experienced teams.

Regular preventive maintenance for an inverter needs to include minimum:

- Visual Control
- Cleaning / replacing the cooling fan filters
- Removing dust from electronic components
- Tightening any loose connection
- Any additional analysis and diagnostics recommended by the manufacturer

10.1.6 Transformer Maintenance

The maintenance of a transformer starts by disconnecting the electricity from the grid after the necessary occupational safety measures are taken. At the same time, the grounding process of the grid, as well as the star point of the phases, needs to be performed. Entering inside the transformer cabinet without considering these measures may lead to fatal results. Performing the maintenance and necessary controls at least once a year, is of great importance in terms of efficiency, safety and stability of the system, transformer, its grid, and plant. As the power of transformers increases, so do their sizes. Calculations concerning factors like the necessary amount of oil, the number of windings, and the required winding thickness size are done regarding the size of transformers.

Controls to be done during the transformer maintenance process are as the following:

- Bushings, cable heads, transformer surface are controlled with a thermal camera.
- Leakages that may occur in the transformer and the level of oil inside it are controlled. The quality and level of oil are the most important criteria affecting the life expectancy of transformers.
- Oil leaks in bushing seals are controlled.
- The bolts on the transformer are tightened one by one.
- High voltage cable head-bushing bolts are tightened.
- Low voltage cable head-bushing bolts are tightened. (Bushings may sometimes have cracks).
- Arc horns are controlled. In case of blackouts, electrical arcing may occur.
- Starpoint ground is measured.
- The transformer provided that the cable heads are thoroughly dried, can be wiped with thinner.

Oil quality measurement is made, oil is added if necessary [70].

10.1.7 Structural Integrity

Module stands, cable ducts and other connections installed for the solar power plant are required to be controlled periodically in terms of mechanical integrity and corrosion indication.

10.1.8 General Compliance Check Of The System

Communication systems that are connected from outer part and providing communication within the plant, are required to be checked in terms of their signal strength and connection. All remaining systems in a solar power plant including the closed-circuit camera systems and other security systems, as well as auxiliary power supplies and lighting systems, need to be regularly checked and maintained.

10.1.9 Vegetation Control

Weeds and bushes that may appear on the land where the plant is installed may prolong the intervention process in case of emergency. In these circumstances, a possible fire may intensify the flames. Flowering plants may accumulate on the panels due to pollen and affect system performance negatively. Trees pose a shadowing risk, and their leaves may obscure panels. Against all risks that may arise in this way, the plant should be subject to land control once a year.

10.2 Unplanned (Fault) Maintenance Repair

Unplanned maintenance is performed in response to malfunctions. In the case of unplanned maintenance, the key parameters are diagnosis, response speed and repair time. Under these circumstances, the shortest possible response is the preferred one in order to increase energy efficiency and minimize losses that may happen. Response time is required to be planned clearly before the maintenance-repair process and have to be performed regarding the location of the plant by considering whether the plant is manned or not. For a well-designed and built plant, inverter failures may be considered as the most unplanned maintenance problem encountered. Fixing the fault remotely may be possible depending on the nature of it. This option may clearly be preferred, if possible.

Other common unplanned maintenance requirements include the following:

- Tightening loose cable connections
- Replacing blown fuses
- Repairing lightning damages
- Repair of equipment damaged during module cleaning or by intruders.
- Troubleshooting SCADA errors
- Fixing mounting structure errors

10.2.1 Spare Parts

In case of equipment failure, to facilitate rapid response, an inventory of spare parts of a minimal number is required to be stocked. As the cost concerning spare parts is high, their purchases need to be justified as, they not only reduce the plant downtime and but also prevent revenue loss. The optimal spare parts strategy will depend on the size of the plant, the local availability of those spare parts, and the potential concerning the sharing critical equipment among several facilities under collective ownership.

In general, an adequate supply of the following essential components is necessary:

- Mounting of building components
- Junction / combiner boxes

- Fuses
- DC and AC cabling components
- Communication equipment
- Modules (in case of module failures)
- Spare inverters (if string inverters are used) or components according to manufacturer's recommendations in case central inverters are used.

10.2.2 Performance Monitoring, Evaluation And Optimization

To optimize system performance, ensuring the operating of the plant components efficiently throughout the life of the plant is necessary. It is important to monitor constantly the solar power systems in order to maximize their availability and efficiency. A SCADA system can monitor the real-time efficiency of the solar system and continuously compare it with the theoretical efficiency to evaluate whether the system is operating at its best. This information may be used by the maintenance contractor to determine the general condition of the system, and to plan emergency repair or maintenance activities like cleaning.

10.3 Troubleshooting And Repair

Periodic maintenance, while keeping the system efficiency at the highest level, prevents the occurrence of costly breakdowns and prolongs the life of the solar power plant. The application of tests in accordance with international standards and norms for maintenance and repair is necessary for the systems to operate safely and efficiently. The following maintenances are applied for solar power plants.

- Control, Testing and Measurements
- Photovoltaic Panel Maintenance
- Inverter Maintenance
- Transporting System Maintenance
- DC Panels and Cabling Maintenance
- AC Panels and Cabling Maintenance
- Transformer and MV Cell Maintenance
- Control of Wire Fences
- Weed and Pest Removal
- Control of Drainage Channels and Manholes
- Security-Lighting System Maintenance
- Control Cabin Maintenance
- Communication and Remote Monitoring System Maintenance
- Lightning Protection System Maintenance

- Creation and Recording of Power Plant Documents
- Panel Washing and General Cleaning

Compulsory and optional measurements are made during the maintenance and repair process. These tests are as the following:

10.3.1 Earthing And Continuity Tests

In our country, grounding applications and operations are required to be performed in accordance with the “Regulations on Grounding in Electric Power Installations” provisions. Definitions related to grounding are given in the relevant regulation.

Earth: It is the expression of the earth as matter and place where the electric potential is zero at every point. Example: humic soil, clay soil, sandy soil, mud, rocky land.

Grounding conductor: It is a conductor laid outside the ground or insulated inside the ground that connects a device or facility part to be grounded to a grounder.

Grounding busbar (grounding bonding conductor): It is a grounding busbar (conductor) to which more than one grounding conductor is connected.

Grounding: Connecting an electrically conductive part to the ground through a grounding facility.

Grounding: It is all the tools, orders and methods used for grounding.

Potential equalization line (equipotential bonding): It is the connection conductors used to provide potential equalization.

As in all electrical facilities, the suitability of grounding in solar power plants is important in terms of human health, safety of the facility and fire risks. All equipment used in electricity generation, distribution and consumption points must be connected to the ground and to each other in order to be at equal potential.

The best safety measure against electric current is grounding. The busbar where the grounding system in large buildings and facilities is collected, is called an equipotential busbar. The collecting of the conductors that come from the base and the ones coming from the metal body devices is done with the equipotential busbar.

Figure 60. Equipotential Busbar

In places where protective earthing and/or equipotential bonding are connected on the DC side, electrical continuity tests should be performed on all these conductors and the correctness of the main earthing terminal connection also should be checked.

In solar power plants, leakage current protections and lightning grounding are very important. A break in grounding and equipotential bonding may give a serious damage to the system. Accordingly, grounding measurements of the equipotential busbar, construction and solar panels should be carried out by means of the megger device. Recording these measurements will help detect problems that may occur in the future.

As a result of this test and control:

- Via shock effect, the damage that leakage currents give to human health and equipment will be prevented.
- Periodic checks of lightning protection equipment will be made.
- Insulation-related problems will be identified.

10.3.2 Polarity Tests

Before performing panel tests, switching off the system, or connecting string overcurrent protective devices, it is important to perform a polarity check for the safety and protection of the connected equipment from being damaged. If reverse polarity is found on an array, bypass diodes and modules need to be checked for any damage resulted from this fault.

10.3.3 Open Circuit Voltage (VOC) and Short Circuit Current (ISC) Measurements

The purpose of the open circuit voltage (VOC) measurement is to check if the module strings are connected correctly and if the expected number of modules in the string are connected in series with each other. Panels have a different open circuit voltage under each amount of light. Skipping an interconnection or connecting by mistake the wrong number of modules in an array are among the common errors that can be made, especially in large systems, and open circuit voltage can quickly detect these errors.

Panels have different short-circuit currents for each amount of light. The purpose of the short-circuit current (ISC) measurement is to ensure the correct operating characteristics of the system and verify that there is no major error in the Photovoltaic string cabling. Two test methods are available (short circuit test and run test), and both provide information on the correct operation of Photovoltaic strings. A short-circuit test is preferred, as effects from inverters may be excluded whenever it is possible.

10.3.4 Function Tests

The switchgear and other control apparatus must be tested to ensure they are properly installed and connected, and functioning.

10.3.5 Insulation (Hipot) Tests-Iec 62446

Insulation errors are common in solar power plants. These errors mostly appear in case of wrong and loose connections or through damages given by rodents. Also, pulling the cables tight and damaging the cables with the sharp edges of the cable trays are among the causes of these errors. In the test measurements, the cable insulation values should be consistent with each other. Also, the damages that occur during the cabling installation of the system are determined at this stage (Figure 61).

Figure 61. Cable and Cabling Damages

In the measurements of solar panels and ground insulation resistance, it is necessary to measure the insulation resistance between the panel and the ground by subjecting the solar panels to a voltage of 1,000V. This test is important to prevent leakage in the panels and not to harm people, as well as not allowing inverters to be disabled. [71].

As a result of this test and control:

- Preventive maintenance of cables done periodically,

- Detection of insulation error between photovoltaic panels and ground,
- Detection of a phase-ground error that may occur on the AC-DC current side of solar panels,
- Detection of problems affecting the insulation resistance, causing the inverters to be disabled,
- Production-related errors of all electrical equipment will be detected.

10.3.6 Measurement Of All Panels With Drone And Hand Thermal Due To Hot Spot Effect That Occured In Photovoltaic Modules Iec 62446/Iec61215

The temperature distribution in solar panels must be balanced. Temperature differences that may occur in the panels will reduce the performance of the solar plant, and also cause power losses. To prevent energy production losses, hot spots need to be identified.

Hot spots in AC and DC panels, inverter connections, cables, incompatibilities in connector junctures, and photovoltaic modules can be detected with thermal cameras in a quick and reliable way. By this means, the energy production performance will be at the highest level.

Solar panels may be damaged due to manufacturer’s defect, assembly error or during the operating process. This damage or errors cause point puncture. This situation is called “the hot-spot effect”. Hot spots may also occur after solar panels are activated. Hot spots cause an increase in cell temperature. If the current produced by any of the cells is lower than the current produced by the other ones, when the photovoltaic modules are connected in series with each other, the panel switches to the load state and creates a reverse voltage. In this case, cells convert the energy into heat instead of producing electrical energy. Thermal temperature differences in hot-spot cells may reach very high degrees. As a result of high temperatures, cells may completely deteriorate. This situation may negatively affect the operating efficiency of the photovoltaic panels and even, cause the modules to burn.

Examining photovoltaic cells mounted separately has difficulties. The panels are usually found on the roofs of buildings, or the installation area is very large. Visual or hand thermal controls take time. These controls may be done in shorter time with the help of drones and thermal cameras. The hot spots on the panels are reflected in the thermal image with different colors according to the environment. These images are detected by thermal cameras fixed onto the top of drones. Problems mostly in panels, transformers, inverters, and other connection points are detected via hand thermal.

Figure 62. Controls with a Drone

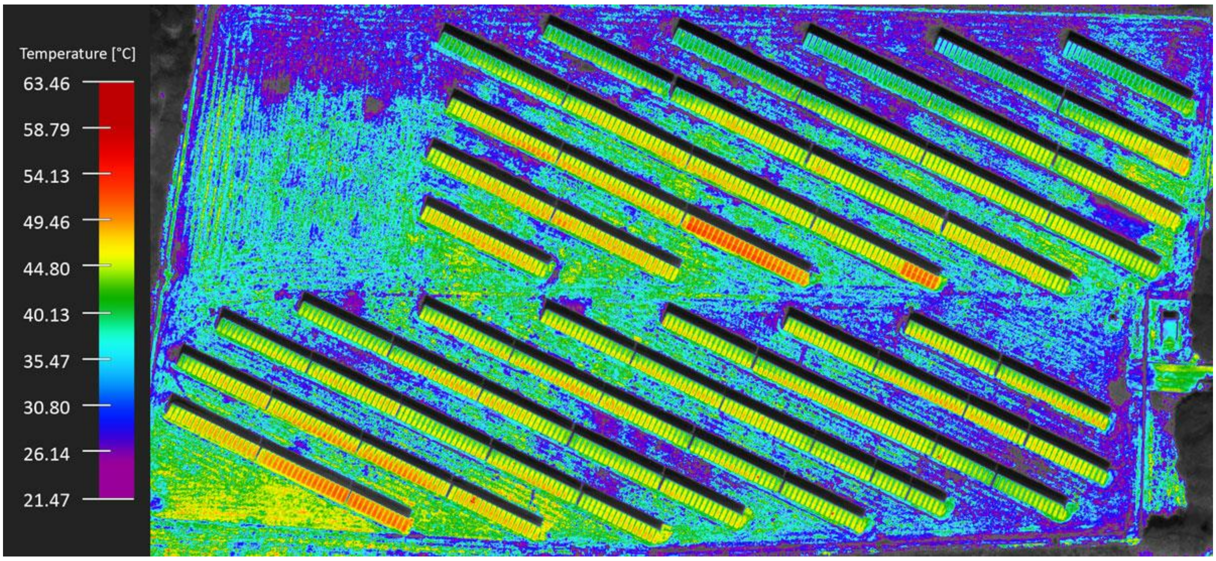


Figure 63. Control With a Drone and Thermal Camera

As a result of this test and control;

- ✓ Unexpected rises in the temperature of panel materials such as bypass diode, junction-box,
- ✓ Situations causing hot spot effect
- ✓ Scratches, cracks, damages, moisture, and broken cells observed on solar panels,

- ✓ Cells with manufacturing detects,
- ✓ Damage caused by shadowing, bird droppings and environmental factors,
- ✓ Points that may pose a fire risk,
- ✓ Devices transported in an unbalanced way
- ✓ Problems caused by mounting errors and panels that have never been put into use,
- ✓ Conditions of temperature differences in cables, collection panels, connection points, inverters and power units may all be identified.

10.3.7 I-V Curve Measurements For Photovoltaic Modules And Arrays (Iec 60891)

Each panel has its own current-voltage (I-V) curve. Therefore, this means that each string in the solar power plant will also have its own unique (I-V) curve. In this way, the information about the real power and production values of the power plant will be obvious for all. Thanks to (I-V) measurements, problems such as LID (Light Induced Degradation), PID (Potential Induced Degradation), micro-crack, degradation, as well as some other unseeable flaws in photovoltaic modules and module arrays may be detected. These measurements can be made in the entire solar power plant, or by selecting a certain number of panels or for parts with low performance [72].

As a result of the test and control of the I-V graph measurements for photovoltaic modules and module arrays;

- It is possible to get informed about the real strength of the panels. Their consistency may be checked with the data of the plant,
- Whether there is a loss due to LID,
- Whether there is a loss due to PID,
- Whether any cut (originating from mouse or rodent), ground contact and leakage in DC cables is present
- VOC, ISC, Vmpp, Impp, Pmax Measurement results,
- Array performance measurement,
- Module / Array occupancy rate,
- Identification of module / string defects or shadowing problems,
- Contamination-related problems on the module,
- Problems caused by by-pass diodes,
- Possible faulty connections and insulation faults in panel series can be detected [73-74].

LID (Light Induced Degradation): It means the performance loss of photovoltaic modules in the first hours after their exposure to the sun.

PID (Potential Induced Degradation): As a solar panel works, sodium ions react with the potential formed on the conductive layer and glass surface, and a positive charge accumulates on the panel surface. This interaction is called PID, and the loss it creates is called PID loss.

10.3.8 El (Electroluminances) Imaging Test Of Solar Panels-Iec 61215/Iec61646

Electroluminescence imaging is a method that provides information about the crystal structure on the cells that compose the module by analyzing the light in the upper infrared wavelength emitted by the photovoltaic modules as a result of voltage feedback.

If photovoltaic modules are not transported and assembled properly after their manufacturing, structural defects occur in their cells. Since it is fatiguing and costly to detect these defects in the laboratory environment, it would be more appropriate to detect them in the power plant area. As a result of electroluminescence test and control;

- Cases occurred in the manufacturing process of cells and modules such as;
- Broken cells,
- Technological errors,
- Micro and macro cracks,
- Solder defects,
- Ohmic contact failures,
- The faults and non-operating areas that occur during the assembly phase may be detected.

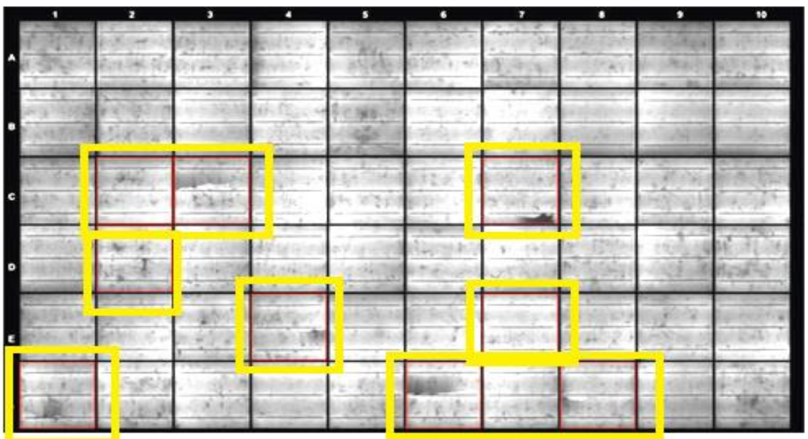


Figure 64. Electroluminescence Test and Control

10.3.9 Photovoltaic System Simulatıon Using Real Values

Based on the recorded radiation and panel temperature data of the power plant, simulation is performed on the software by using the PAN files of the panel provided by the manufacturer, and the amount of energy to be produced is determined and compared with the energy produced.

According to these results, the system is evaluated whether an overlooked situation such as transformer, inverter etc. losses is present, and a general production expectation profile is formed. As a result of this test, whether a system-wide problem occurred or not occurred may be controlled. Through this calculation, the performance of the solar power plant is measured, and its performance value is determined. As a result of this simulation test and control; Information such as:

- The amount of power that the plant is required to produce according to the data obtained,
- Performance evaluation of the power plant, are obtained.

10.3.10 Safety Labels

In solar power plants, warning labels should be made concerning the proper functioning of the system, response safety, system identification and life safety.

All signboards and labels must be indelible, clear, easily visible, non-removable, fixed and legible throughout the life of the PHOTOVOLTAIC system.

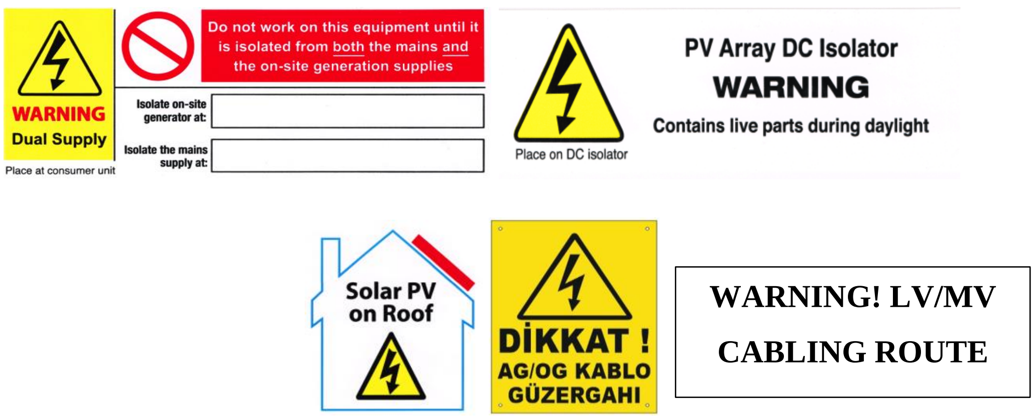


Figure 65. Example of Safety Labels

10.4 Example Of Maintenance Procedure

Tablo 15. Maintenance Procedure Table [75].

NO	PERIODIC MAINTENANCES	MAINTENANCE PERIOD	MONTH
1	Solar Panel Cleaning	Twice a year	April
2	Current-Voltage Measurement	Once a year	April
3	Grounding Measurements	Once a year	September
4	Measurement and Controls of Inverters	Once a year	March
5	DC Hotspot Controls with Thermal Camera	Once a year	April
6	Lightning Protection System Measurements	Once a year	September
7	Measurements and Controls for Construction	Once a year	September
8	LV Electrical Installation Measurements and Controls	Once a year	March
9	Transformer Maintenances	Once a year	March
10	MV Electrical Installation Controls-HV Operation Responsibility	At the end of each month	
11	Compensation Control	At the end of each month	
12	Billing Control	At the end of each month	
13	HV Cell Maintenances	Once in two years	
14	Camera System Maintenance	Once a year	May
15	Field Control	Once a year	

The lights falling onto the solar panels are converted into energy via those panels and stored in large solar cells or batteries. The systems performing this activity are called Solar Power Plant (SPP). “SPP” is the abbreviation of Solar Power Plant.

Different methods are used to detect defective/faulty panels in SPPs. As these methods require technical personal, equipment and excessive time, SPP operators and personal seek alternatives to replace these fatiguing activities. Since the usage areas of UAVs have expanded, they have started to be used actively in SPPs. The measurement process performed by technical personnel and equipment taking between 2-4 or more days, can now be accomplished with a single flight, thanks to our system [76].

Though solar power plants do not require frequent maintenance, their efficiency and durability increase when their periodical maintenance and cleaning are done.

Solar panels are proof against natural disasters such as rain, snow, and hail, due to their manufacturing properties. The data sheets of the panels purchased clearly mention the resistance of the panels to disasters such as wind and snow. It is necessary to choose the solar panels according to the properties of the region where they will be used [77].

General objectives of SPP Operation and Maintenance Activities:

- Identifying the problems causing degradation in the Solar Power Plant,
- Elimination of the identified problems,
- Detailed reporting and clarity [78].

10.4.1 Solar Panel Cleaning

A dirty panel is one of the most important problems that cause degradation in solar power plants. It may cause a decrease your production efficiency of 10-15% [79].

- **How to Clean a Solar Panel?**

Cleaning the solar energy producing panels is important in terms of maintaining efficiency. Pure water and some alcohol cleaners are utilized for panel cleaning. Alcohol-based cleaners are preferred to prevent frost formed on solar panels, especially in winter due to cold weather. Cleaning agents of this type are frequently used in terms of preventing frost, even though they inhibit the sun's rays by leaving water stains on panels. Regardless of seasonal conditions, cleaning panels with pure water stands for the most common cleaning method.

Deionized pure water is required to be used for the cleaning of panels. Water of this type, on the other hand, is completely free of dissolved objects. Unlike cleaning agents containing alcohol, deionized pure water does not leave any stains on the panels. Thus, not any obstacle is present for the sun's rays to reach the panel and get absorbed after cleaning. Additionally, cleaning in this way has contributions to safety. Since deionized pure water is not conductive, high voltage risks and corrosion hazards are eliminated while cleaning the panel.

The solar panel cleaning is required to be done in the evening or early morning when panels are not hot. Otherwise, surface cleaning may not be possible as the panels will be hot. It is recommended to clean solar panels in every change of season in order to maintain efficiency.

❖ Points to be Considered During Solar Panel Cleaning

- Electricity is produced through solar panels. Therefore, cleaning solar panels always brings the risk of being caught in high voltage. In order not to get caught in the current, panels are strongly required to be cleaned with non-conductive deionized distilled water. In this way, occupational safety will be ensured.
- Solar panels in household areas and industrial facilities may be positioned high. In order to eliminate the danger of falling from high, it is necessary to get support from extension pipes.
- Walking and stepping on the panel are strongly forbidden during cleaning. Small cracks may occur on the panel due to the weight of human body. There is a high probability of serious problems, especially electric shock, due to rainwater leaking into cracks or liquids used for cleaning.
- Detergents and products containing chemicals are not advised to be used to purify solar panels from dust and dirt.
- Panel cleaning is required to be done at the beginning of each new season. Special solar brushes should be used for panel cleaning.
- It is important to have solar panels maintained at regular intervals.
- It is strongly requested to ensure both the temperature of the water and of the panel to be same during cleaning. Pouring cold water on the hot panel may cause thermal shock and thus, panels may become unusable [80].

❖ What are the Effects of Solar Panel Cleaning on Efficiency?

The efficiency obtained from solar energy varies depending on various factors. The type of material used to generate electrical energy, the quality of the workmanship in the panel installation, environmental factors, dirt on the panel, and design are among the factors that affect the efficiency. By paying attention to these factors, it is possible to achieve the highest possible level of efficiency. The desired amount of electrical energy may be obtained from the panels that are maintained and cleaned properly.

Dust and dirt resulting from environmental conditions, adhere to panels and prevent the sun's rays from penetrating the surface. Panels need to be cleaned since photovoltaic cells, cannot produce solar energy without fully receiving the sun’s rays. The efficiency is reduced by 30% in case panels are not cleaned. It is recommended that panels are required to be cleaned properly at a lower cost with deionized water [81].

Contamination Reasons of Solar Energy Panels:

- Lime stains resulting from cleaning done improperly with transport water.
- Resin and organic secretions falling from trees.
- Carbon black and joint resulting from industrial air pollution.
- Carbon black and joint resulting from heating and cooling ventilations.
- Dust and exhaust gases coming from stabilized roads and railways.
- Bird and pest droppings.
- Traces of salt and ammonia in power plants installed near livestock farms and sea.
- Fractures, micro-cracks, and corrosion caused by a wrong chemical treatment as a result of incorrect applications done by inappropriate equipment and personnel [82].

❖ **The Importance of De-Ionized Pure Water in Solar Panel Cleaning**

Demineralized water, also known as ionized water, is a high-quality water, obtained by eliminating the cation and anion ions found in it. In order to obtain it, the production needs to be done with equipment that requires expertise in the demineralization or deionization plant.

- No residue can be found on the surfaces. Therefore, it will absorb the sunlight well,
- Since its conductivity is low, the possibility of being caught to high voltage during cleaning is less,
- Since it does not feed plants and grass as does water, it does not allow organisms that may shade panels to grow,
- Drying is not required,
- It not only keeps panels clean for a long time, but also prevents substances such as dust and pollen from adhering on them.
- It stays as new as its first day for many years and does not corrode. Therefore, it is long-lived.
- Panels that are cleaned continuously and regularly work 30% more efficient than other panels,
- Therefore, the usage of Ionized Pure Water is preferred in the world for solar power plant cleaning [83].

❖ **Advantages for Solar Power Plant Cleaning:**

- The use of de-ionized pure water in the cleaning of solar power plant prevents them from corroding and thus, they remain as new as their first day for a long time.
- Cleaning panels with de-ionized pure water will be 20% more efficient than other cleaning methods.
- Cleaning panels with de-ionized pure water, prevents dust, pollen, and external factors from adhering onto the panels and thus, they remain clean for a longer period of time.
- Cleaning a solar power plant with de-ionized pure water will prevent its panels from corroding. By this way, no residue will be found on any of the panels, thus sun's rays will be absorbed more efficiently.
- No drying is required when a solar power plant is cleaned with de-ionized pure water.
- De-ionized pure water should be free of all minerals and have a value very close to zero.
- The method of cleaning solar power plants with de-ionized pure water is common in the whole world.

10.4.2 Current (I) – Voltage (V) Measurement

IV-Curve Measurement– IEC 60891: After doing the IV Curve measurements of all solar panel arrays in the field, it becomes possible to detect whether problems such as LID, PID, micro-crack, degradation etc. occurred or not. These measurements, apart from serving as a logbook, will enable to see the degradation rate of panels in future controls. The answer to the question concerning any production deficit occurred in the solar power plant can be obtained with the help of this test.

Errors about Current (I) – Voltage (V) Measurement are as the following:

- It is possible to get informed about the real strength of the panels. Their consistency may be checked with the data of the plant,
- Whether there is a loss due to LID,
- Whether there is a loss due to PID,
- Whether any cut (originating from mouse or rodent), ground contact and leakage in DC cables is present,
- Whether there is any error in the by-pass diodes of the solar panels,
- The situation of the effects of shadowing losses on performance rate
- Possible faulty connections and insulation faults in panel series can be detected [84].

10.4.3 Earthing Measurements

One of the most important points in solar power plants is grounding. Grounding values must be measured annually and recorded. If a leakage current occurs due to a disconnection in the equipotential circuit when a lightning strikes the plant, serious damages will occur. It is required to perform the measurements with the Megger device regularly every year and record them [85].

Groundings: The grounding of the panels must be connected to the distribution table of the building to provide equipotential bonding. Grounding values are required to be at the value mentioned in the project. The making of this measurement is absolutely required.

All additional points are required to be grounded using a cable with a section mentioned in the project. Cable lugs are used, and tightening should be done during grounding process. The use of smart screw is not allowed, and the grounding cable should never be connected to the construction.

Cables are required to be attached to the construction using copper material. In order to prevent overheating, bends of cables should not be 90 degrees or less than that. It is important to bend them at a wider angle to form an oval turn [86].

Since the application areas of Photo-Voltaic systems are always designed to cover the entire surface, they are required to be integrated with the existing TT grounding system. Nonetheless, according to DIN VDE 0100-712, it is mandatory to have an automatic device that opens the circuit in installations fed with a cable/conductor.

Solar panels must be grounded with solid copper and flexible copper conductors, regarding their installation location.

During the grounding process of the Solar Panels, corrosion may occur at the connection points due to the use of different materials.

In order to prevent this problem, connection terminal, bolt, cap nut, stainless washers are necessary to use.

In these areas, a grounding system designed according to IEEE 80 2000 should be installed in order to prevent step and touch voltages that may occur due to short-circuit fault currents [87].

Grounding is of great importance in all electrical installations, especially in solar power plants. It is of great importance in both leakage current protections and general protections, especially in case a lightning hits the plant. A disconnection in grounding and equipotential bonding can give serious damages to the system. In this context, both the grounding measurement of the equipotential busbar with the Megger device and the grounding measurements of the construction and solar panels should be recorded and necessary measures should be taken in case of problem occurrence. [88].

10.4.4 Measurement And Controls For Inverters

Inverter, known as an electrical power conversion element, is also called a power transformer or converter. Inverters are power electronic circuits that are used to obtain AC voltage with constant or variable amplitude and frequency by processing the voltage received from any DC source. In other words, inverters are devices that allow us to use the 220 volts or 380 volts energy that solar panels produce in solar power generation plants. Solar panels produce DC energy. In order to use the generated energy in homes and workplaces, this energy is required to be converted to AC energy. Inverters just do that. They convert the DC current into AC as well as adjusting the voltage, and they enable the usage of the energy produced by solar panels.

Inverters are not only used to prevent interruptions, fluctuations, imbalances, harmonics, etc. that occur in the system, but also to enable an efficient and effectively operating system.

An inverter device, which cleans the voltage fluctuations and peaks coming from the network by passing it through the filter circuit, reduces the number of failures in engine and mechanical parts caused by these effects, and minimizes the repair and maintenance costs of these, and extends their life. In addition, inverters allow savings by reducing reactive energy. In addition to these, inverters are used to draw the energy with desired characteristics from storage systems like batteries.

As a result of the increase in the need and demand for these systems, especially thanks to the studies related to the benefits of renewable energy sources like Solar Energy and Wind Energy, stable inverters with higher quality types and having more features are produced in order to make the energy obtained from wind and solar energy systems suitable for usage.

Devices with microprocessor or low voltage control, alarm and warning outputs, overload protection and static regulation are offered to the market by manufacturers. Since there is no inrush current, devices that do not harm the grid, operate at minimum and maximum ranges.

Inverters are divided into two groups regarding their usage purposes. These are:

- Off Grid Inverters (Solar Systems with Battery)
- On Grid Inverters

Off-grid Inverters (Inverters that are used where there is no grid circuit): These inverters are mostly used in systems with Accumulator-Battery. These applications are mostly seen in places where it is very costly to bring a network line such as; farm houses, highland houses, and GSM base stations.

On-grid Inverters (Inverters that are used where there is grid circuit): On-grid inverters are used in solar power plants connected to a grid [89].

Microprocessors are becoming a popular choice for residential and commercial facilities. Like power optimizers, micro-inverters are module-level electronics, thus they are installed in each panel. Nonetheless, unlike non-converter power optimizers, micro feeders convert DC power to AC directly at the panel, thus eliminating the need for an inverter. Apart from this, if a panel is shaded by one or more panels, or in case it operates at a lower level due to level conversion, the performance of the rest of the panels are not in danger. Besides, micro inverters monitor the performance of each panel, while string inverters show the performance of each string. This, both makes microarrayers better for installations with shadowing problems and with panels installed in multiple planes facing various directions. Micro-inverter systems may be more efficient, but they usually cost more than string inverters [90].

There are many reasons for Solar Power Plant (SPP) failures and efficiency losses. Some inverter and panel failures may be based upon manufacturing. The damaging of the materials because of workmanship errors not only during their transportation phase to Solar Power Plant site, but also during its installation phase, result in malfunctions and efficiency losses as the plant starts operating. Design errors before the installation, cause SPP failures and efficiency losses as well. Some disruptions occurring during the operation of the solar power plant also cause SPP failures and efficiency losses. Since some of these faults are considered as user error and negligence, unfortunately, especially in solar inverter faults, sometimes warranty conditions cannot be applied.

A few encountered problems in the field are listed as the following:

- The excessive amount of dust in Solar Inverter Fans,

- The storage of material preventing air circulation in the area where solar inverters are installed,
- In case the equipment protecting the SPP field from lightning loses its protection feature,
- The excessive amount of contamination on solar panels,
- Occurrence of burns on solar panels, called hot spots, due to bird droppings, snails, leaves, and similar substances adhering to panels.
- Birds nest under the panels, in places where solar inverters are installed, as these places are warmer than the surrounding environment in winter.
- The growth of the vegetation in SPP areas,
- The overgrowth of grass and vegetation in areas where switchboards and solar inverters are installed,
- Constructing structures such as chimneys, huts, and porches in a way that they cause shadowing on solar panels after their installation on a roof and field.
- Continuously forgetting materials that cause partial shadowing on panels such as hose, brush etc.
- Spanning the cables of antennas, cameras, and similar devices to the area where panels are located on the roof,
- Animals such as birds, mice, snakes nesting on SPP boards,
- Non-professionals intervening in SPP boards rather than experts.

These situations cause failures in inverters, panels, and boards and thus, become out of warranty. In order to prevent a malfunction due to these reasons, necessary precautions are highly required to be taken during routine controls.

The main duty of an inverter is to convert DC voltage to AC. During this conversion, the inverter is required to use a symmetrical sine wave, equal amplitude and the frequency should not be distorted. Additionally, the output voltage is desired to be obtained via a low harmonic. The output voltage may either be variable or fixed. Nevertheless, the output voltage being variable or fixed may cause different harmonics to come into existence. To eliminate this, either fixable or adjustable frequency values are chosen. A variable DC input voltage is used to obtain a variable output voltage. To do this, the inverter gain is required to be kept constant. As an alternative way, in case the DC input voltage is fixed and unadjustable, a variable output voltage may be obtained by changing the inverter gain. Nowadays, inverter models, systems that perform switching in fundamental frequency as switching strategy, or PWM (Pulse Width Modulation) techniques are frequently used [91].

Maintenance / Repair Of Inverters

- Maintenance and Controls
- Greasy dirt problems
- Fibre-Yarn Dust Problems
- Erosion Problems
- Industrial Dust Problems
- Cable and Installation Problems

AC motor drives have a wide range of faults and a variety of alarm and error messages. The relevant protection functions are activated after the detection of the fault. After that, those faults appear on the digital keypads of drives. Though it may vary, the most common six errors may be read via digital keypad or communication system.

AC motor drives are made of various electronic materials such as IC, resistor, capacitor, transistor, cooling fan, relay etc.

These components cannot be used continuously or forever. These components have a limited lifespan and, even under normal operating conditions, they will one day be damaged or complete their life. Providing preventive maintenance will be possible by operating AC motor drives in the most appropriate conditions.

It is necessary to regularly check the AC Motor drie in terms of any abnormality that may occur while it operates. Resetting via keypad or input terminal must be done after 5 seconds, when the fault is cleared. After the power is turned off, capacitors need to be fully discharged: 5 minutes for drives less than 22 kW, and 10 minutes for drives over 30 kW. It is required to check whether the discharging process is fully done. To do this, “+” and “-” busbars may be measured. According to this measurement, the voltage is required to be less than 25 VDC [92].

10.4.5 DC Hot Spot Controls Via Thermal Camera

Hotspot Measurements Done with Drone and Hand Thermal

Standard: IEC 62446 / IEC 61215

Hotspots may occur after solar panels are activated. This control can be performed by using both a drone and hand thermal [93].

Solar Panels can be damaged by manufacturer's error, assembly error or during operation. These damages or faults are called hotspots and may cause faults up to puncture. In addition, making thermal measurements in electrical components can provide early detection of many serious faults. For this reason, this control may be performed with both a drone and hand thermal.

- With high resolution thermal cameras, each panel is checked one by one without taking any collective shots, the problematic ones are photographed, and the defects are classified.
- To detect the problem in panels with problems; junction boxes, cables and connections are checked and photographed with thermal cameras.

As a result of thermal measurements made on panels, it becomes possible to get information on the following subjects:

- Whether there are any damaged cells in solar panels,
- Whether there is an unexpected rise of temperature in panel materials like the bypass diode or junction box,
- Whether environmental factors that cause shadowing give any damage to solar panels,
- Whether there are arrays that are not activated,
- Whether there is any problematic rise in the temperature in the inverter and electrical infrastructure,

Information about these points can be obtained [94].

Solar Panel Bypass Diode Failure: A bypass diode failure is one of the important faults in the solar panel. This malfunction causes a certain part or the entire of the solar panel, or the whole string to not function completely. To detect it, a thermal camera is used to find the problematic bypass diodes.

Impacts of Solar Panel Bypass Diode Faults: Bypass diode failure causes high efficiency losses. This affects the pay off period of solar power plants.

- In case the bypass diode failure is not detected, there may be a risk of production loss and fire.
- The faulty bypass diode may be considered as a minor problem. However, it causes serious fires.

Apart from the weather conditions, malfunctions that occur in the panels are also among the conditions that affect the life of solar panels. Conditions such as hot spot, diode faults, and shadowing affect the life of solar panels. In order to prevent these situations, the required maintenance for panels should be done both annually and monthly.

10.4.6 Lightning Prevention System Measurements

Photovoltaic systems producing renewable energy carry the risk of lightning due to the installation location and area. The protection of buildings and photovoltaic systems is important in terms of increasing the operating time of the facilities, and for the safety of investments. Determining the length of lightning attractors and positioning them according to the protection angle provide the protection of these areas from lightning. These lightning attractors are required to be connected to each other with a conductor, and to the earthing line.

The failure of photovoltaic systems and frequency converters is usually caused by high voltages resulting from lightning strikes. In these cases, the user of the photovoltaic system is faced with a high repair cost as well as the damage caused by the system interruption. In order to prevent these damages, it is highly required to use lightning and high voltage protection designed in accordance with each other [95].

10.4.7 Measurements And Controls For Construction

Constructions are required to be checked once a year. Deteriorations may occur in the construction due to reasons such as wind and snow. Constructions are made of galvanized material. Ruptures may occur over time in connection points of metals. As well as using profiles with standard structures such as box, pipe, L etc. in hot-dip galvanized steel type construction structures, C and U types may be used in the cold-formed steel products. There are issues to be considered in the construction calculations of cold-formed steel products, which are the most preferred product in solar power generation plants, as they provide ease of dimensioning for different static situations and are easily assembled without welding [96].

10.4.8 LV (Low Voltage) Electrical Installation Measurements And Controls

Low voltage networks have voltages between 1 Volt and 1000 Volt (1kV). These networks consist of power lines from distribution transformers to electricity consumers (subscribers). As low voltages are easy to insulate and protect, they are installed close to subscribers. Since voltage drop and power loss are high in low voltage transmissions, low voltages are used in distribution networks rather than transmission. In our country, the low voltage value is between 220 V and 380 V for subscribers. Electrical installations in our homes are low voltage. All the electrical appliances used in homes operate with low voltage [97].

In low voltage measurements:

- Real values of the panels can be compared to the values of factory.

- An observation can be made on whether there is an efficiency loss due to micro-cracks in solar panels, or not.
- Insulation problems in DC cables, insects gnawing, DC leakages can be detected.
- The presence of any by-pass diode damage in solar panels can be determined,
- Damages that may occur due to shadowing can be assessed,
- Whether panel array connection failures are caused by faulty and inefficient connections, may be determined [98].

10.4.9 MV (Medıum Voltage) Electrical Installation Measurements And Controls

Medium voltage networks are the type of networks, whose effective intensity is between 1000 V to 36 kV (including 36 kV). These networks are used in the process of interconnecting high and very high voltage networks to low voltage networks. Directly supplying high voltage electrical energy to subscribers is not suitable in terms of insulation and safety. For this reason, high voltages are reduced to appropriate values and connected to medium voltage networks. Medium voltage networks are used to transport electrical energy to small cities and industrial areas. Medium voltages are connected to the distribution transformers at the entrance of cities and distributed to subscribers. In medium voltage networks in Turkey, voltages of 10, 15 and 33 kV are used. In ETLs used in medium voltage networks, line voltage is established according to the length of the line. According to this, it is appropriate to use 3 to 10 kV voltages for lines up to 10 km, 10-20 kV for lines between 20 and 30 km, and 20-35 kV for lines between 30 and 70 km, while high voltages are used for lines exceeding 70 km [99].

10.4.10 Transformer Maintenances

Kiosk cells are the second important point in SPPs. Kiosk cell is composed of measuring cells, breaker cells, counter cells, AC distribution panel, and transformer.

The cells are required to be maintained regularly.

- XLPE Cable connections checks, temperature tests with thermal device, and torque tests.
- Relay function tests, temperature pressure and Buchholz relay tests.
- On-off tests and settings of the breaker cell.
- AC distribution board torque tests.
- Thermal tests of cable connections.
- It is necessary to perform tests such as the transformer oil control and transformer protection relay controls [100].

Controls to be Performed during Transformer Maintenance:

- Cable heads, bushings and transformer surface are checked with a thermal camera.
- Transformer oil level and the occurrence of any oil leakage are checked,
- Oil leakages that may occur in the gaskets of bushings are checked,
- The bolts found on the transformer are checked one by one.
- Earthing of the Starpoint is measured.
- Transformer cable heads are wiped with thinner and dried thoroughly.
- Silica gel replacement is done.
- Oil quality measurement is made.
- High and low voltage cable heads, and bushing bolts are tightened.
- Arc horns are controlled. In case of blackouts, electrical arcing may occur.
- If there is a transformer room, the cooling fans in it are checked.
- Winding measurements are made.

Transformer Control:

The control of transformer indicators: Winding temperature indicator, oil temperature indicator, oil level and pressure controls are made.

The control of transformer gaskets and bolts: Tank cover, bushings, and gaskets of the tank are checked. Worn or cracked gaskets that cannot function should be replaced with new ones. The bolt in the transformer whose gasket has been changed should be checked at the next periodic maintenance.

The control of transformer's metal body: Checks are made against leaks, wear, and corrosion. Rusty areas are cleaned, and maintenance is performed by applying primer and paint.

The control of transformer cooling system: Cooling fans are controlled. It is necessary to check whether the fans are working properly or not. Make sure that the defective fans have the same characteristics as the removed ones. This is important for the stability of the system.

The control of transformer oil: Mineral oils are used to protect the transformer against moisture. The oil used in the transformer starts to deteriorate due to various reasons over time. During maintenance, 1.5 litres of transformer oil should be sampled and subjected to oil tests. It is important to change the oil that has lost its properties. In order to keep the oil life longer in transformers with expansion tanks, the air dryer should be checked during periodic maintenance. It is important to replace the air dryer if it has turned pink, which should have been blue under normal circumstances.

The control of transformer bushings: The bushings at the medium and low voltage output are controlled. Broken and cracked ones need to be replaced. Dirty bushings should be cleaned from dust and dirt by wiping them with a damp cloth, and the distance between the arc horns in the medium voltage section should be controlled according to the voltage used.

The control of transformer connections: Grounding connections are required to be checked in conductors connected to bushings. Loose or oxidized connections that are not making a proper contact need to be regulated. While the transformer is under load, during the controls that need to be performed with a thermal camera, a fault detection can be made by checking the temperatures of the connection points.

Transformer Controls and Measurements:

It is examined within the scope of the conditions determined by manufacturers, and according to a certain regulation.

- Regulation on Health and Safety Conditions in the Use of Work Equipment
- Electrical High Current Facilities Regulation
- Electrical Installations Earthing Regulation

Transformer controls and measurements are required to be carried out at least once a year. These controls and measurements are made by the High Voltage Electrical Control Team and Engineers.

Transformer measurements are made during periodic controls. The most basic aim is to prevent any damage and death that may occur due to lack of control and inspection.

Transformer Measurements:

- Transformer Turning Ratio Test
- Transformer Winding DC Resistance Test
- Transformer DC Insulation Test
- Transformer Grounding Test
- Thermal Camera Measurements
- Interrupter Tests
- Cable Test [101].

10.4.11 HV Cell Maintenances

High voltage operating responsibility is also called "transformer responsibility". The beginning and methods of this service are applied within a certain regulation. The responsibility of transformer management has been established to prevent loss of life and property, and to proceed in a certain order. In order to be responsible for high voltage operation, it is necessary to have an ICE (Independent Consulting Engineer) certificate. There are some regulations to reduce the damage at high voltage points. Electrical engineers who want to be responsible for high voltage operation are required to receive training in this field.

The continuous cell testing and maintenance eliminates the possibility of problems and ensures the prevention of these problems them from occurring by providing a problem-free operation of the system. Risk of failure is zeroed if necessary care is taken concerning the cable heads, during installation. Similar considerations are also required to be applied to grounding switches. While performing cell testing and maintenance, expert teams first review and inspect them, cut off electricity and apply grounding in accordance with the cell instructions. Within the scope of security measures, the problems that cause malfunction are identified. During these maintenances, all cables are tested, and the grounding system is meticulously inspected. Whether the tested cables can perform the energy conversion adequately or not, is checked.

The maintenance of the transitions and resistors that provide the transmission of the contacts in the transition direction is necessary for the separator systems in the cell to function properly. During cell testing and maintenance, the contacts and cell surfaces should be checked and cleaned, if necessary. After that, the control of the body section, and the grounding control is a step that needs attention. Main connections need to be inspected, maintenance and cleaning of insulators are required to be overhauled. Ensuring the transmission of the signals from the main center is necessary, and their ability to transform energy needs to be calculated. It is necessary to check whether the insurance system is functioning properly or not. It is necessary to check the durability of the cables and the metal parts of the panel in the cell. These metal parts are required to be checked for the rotten parts they may contain. Cells need to be overloaded with excessive energy in order to be checked. While checking the possibility of electrical leakage, it is also necessary to check bolts. It is important to take precautions to prevent electrical leakage that may occur, and to apply these maintenance and tests regularly in order to be sure of the connection points of the cables. During the cell test and maintenance process, which will ensure the longevity of the cell, the cleaning of the surface and interior should be done with thinner. [102].

10.4.12 Compensation Control

Being sure that the inverters are installed correctly in a Solar Power Plant, does not mean that the need for compensation is eliminated. As we mentioned above, even if there is no penalty due to the high active power produced during the daytime, SPPs that switch to consumption during night hours face a penalty because the active consumption is very low, but the reactive consumption is higher than this active consumption. The Solar compensation relay, which can precisely catch the point at which production is switched to consumption (from day to night) in the SPP, starts compensation by using the stages connected to it, and does not allow the system to be penalized, by reducing the reactive power drawn from the network. Capacitive penalty is generally encountered in SPPs. The reason is the inverters and the underground cables used in the system. Inverters are capacitive both day and night. Nonetheless, the capacitive generated during daytime, is generally ignored as it remains lower than the active. The capacitive rate that occurs at night is too large to be ignored. Therefore, shunt reactors must be connected to the reactive power compensation relay as a step when compensation is made in these systems. Solar relay, which is produced to take a current reference from medium voltage, allows less shunt reactors to be connected to the compensation system, considering the reactive loss of the transformer, and makes the compensation system more economical. In these systems, compensation with shunt reactor drivers is not a very accurate method. The main reason for this is that the reactors are connected to the driven devices as a single phase.

Nonetheless, as it is known, the MV windings of transformers are triangular, that is, there is no neutral. Therefore, a single-phase load driven on the LV side will affect the two windings together on the MV side, and as a result, the relay and driver pair that wants to reset the reagent will enter a loop continuously. As a result, the reactors will be driven at almost full load and their active consumption will cost almost as much as the penalty. Instead of these, controlling the reactors and capacitors sensitively over the relay, even if they are single-phase, will reduce the imbalance in the MV windings of the transformer due to compensation, and the system will become more efficient.

The loads that need to be compensated in these plants are the reactive losses of the transformer, underground cables, inverters, and the loads that can be found in the guardhouses inside the plant [103].

10.4.13 Billing Control

The pay off in the solar power plants is around 6-7 years. For many common houses, even 2-3 KW capacity may be sufficient. Each KW capacity cost is around 1,300-1,500 dollars including the paperwork processes [104].

Solar energy investment should be considered as a long-term investment. The converter inverter that is used, is standardly guaranteed for 5 years. With a small difference, a warranty extension can be applied up to 10 years or even more is possible. On the other hand, solar panel warranties have an average of 10-15 years, and they guarantee 80% output at the end of 25 years. In other words, a panel with 100 Wp is predicted to give 80 Wp after 25 years [105].

Solar energy systems generally do not require to be maintained. They need to be kept relatively clean. Therefore, it is necessary to have it cleaned several times a year. The most reliable solar panel manufacturers guarantee their products for 20-25 years. In addition, since there are no moving parts, corrosion and abrasion are not seen very often. The Inverter used in Solar Energy Projects is generally the single piece that needs to be replaced after 5-10 year of usage. Because it constantly works to convert solar energy into electricity and heat. Apart from the inverter, the cables also need maintenance to ensure that your solar energy system works with maximum efficiency. Therefore, after the initial cost of the solar system is covered, there is no need to spend much on maintenance and repair [106].

10.4.14 Camera System Maintenance

Camera systems may be activated if alarm systems do not provide much benefit. The area is always scanned by high resolution camera recordings. In addition, thanks to the advanced technology, the camera recordings can also be viewed on mobile phones. Instead of controlling the solar panels constantly, in this way, everything can be controlled remotely from any place. The security system in the SPP, which is 7-24 active, enables the plant to be under protection. In case of an adverse condition, a notification warning is sent to the phone of the responsible. With the continuous camera recordings, it is possible to watch the recordings of the desired day, hour and minute can be watched.

In structures such as Solar Energy Systems, cameras are of great importance. Since it is a large investment, its control and protection become even more significant. In addition, it is almost impossible to stay at the power plant constantly.

Again, camera systems are the best way to obtain efficiency. A staff member may be required for control. Nevertheless, these processes are easier with cameras [107].

10.4.15 Field Control

The term SCADA is formed by gathering the first letters of the words "Supervisory Control and Data Acquisition". With SCADA systems, which are widely used in industry, are comprehensive and integrated data-based control and monitoring systems that provide the automatic control, monitoring, and reporting of results of all units from the control of all equipment of a facility or enterprise to production planning, from environmental control units to auxiliary enterprises.

The headquarters of Solar Energy SCADA systems are within the body of DISCOMs. The Distribution Company can monitor and control from its headquarters, all power plants connected to the distribution system in its own region. The connection between the headquarters and the power plant is made via the internet provided by the "GSM / GPRS modems" located in the SCADA panels placed in the switchboard. The data received and sent via this internet connection between the headquarters and the switchboard are under the protection of the IEC 60870-5-104 protocol, which is a licensed private communication protocol [108].

Solar monitoring systems, not only provide many tools to help you understand the solar energy system you installed, but also help you view the energy consumption and production data. Solar monitoring software can often help identify problems and defects with panels and recommend the ideal repair type to your installation. Also, historical data may be tracked in your monitoring system. Solar panels have a minimum performance guarantee of 20-25 years. Nevertheless, solar monitoring systems should be used to determine whether their performance falls below the guaranteed value, or not. For example, monitoring systems provide data on past weather-based performance, thus, the way how weather has affected solar production in the past, and what is expected in the future can be predicted.

The efficiency of the solar inverter is directly proportional to the power output. If the performance of the inverters decreases, loss of electrical power generation can be expected. The most important feature of the solar monitoring system is to detect system failures, or the possible solar panel failures in similar cases. On the other hand, solar energy monitoring software saves solar energy data to memory and creates an archive. A person or institution who wants to check the status of the solar energy system can see and compare all the information. Thus, the repair process of the problem identification in the solar power plant will initiate.

Another benefit of solar energy monitoring systems is to easily control the amount of solar energy the system produces. Most monitoring software give an opportunity to check how each inverter and panel shows performance. In that way, whether any of them need maintenance or whether it is possible to increase their solar efficiency amount can be identified. The solar monitoring system also updates data quickly, simultaneously allowing you to always know how your system operates [109].

Due to both the size of the field and the high number of equipment used, it is very difficult to control the field in SPPs. Mostly, the problems that occur in the field can be seen and resolved when they reach very dramatic levels. This situation causes the power plant owner to lose production/money.

Some power plants are penalized by EMRA (Energy Market Regulatory Authority) since their production goes beyond the allowed upper limit from time to time.

For all these reasons, nowadays, monitoring/controlling the power plants from the power plant management room locally or from the remote central management unit prevents all these problems and increases the investor's money/time gain.

Since SPPs have a lot of equipment in the field, it will be a great advantage to monitor and control the following data via the SCADA system in addition to the data received from the EDC (Electricity Distribution Corporation) data monitoring system in terms of their monitoring-control.

- Panel temperatures monitoring
- Further radiation measurement via pyranometer
- Measuring wind speed
- Receiving current, voltage, power, and capacity information from panel strings, and measuring the total DC power entering the inverter
- Monitoring the status information of fuse-residual current switches in field collection panels
- Monitoring inverter operating parameters and controlling the production by measuring it.
- If there are secondary transformer centers, monitoring and controlling the LV switch, analyzer, protection relay, transformer, MV cell, relay operating status information and the measured parameters.

When the SCADA system is installed locally at the SPP management center or the central management center, according to investor’s wish, the system also allows relevant person/people to monitor the system via a web browser (internet) with a computer or mobile phone [110].

Cleaning the grass in a solar power plant is as important as cleaning panels. Grass growing on these panels can cast a shadow, which, then will cause hot spots on them. Every year, the area should be regularly cleaned from grass [111].

It is necessary to cover the entire area with wire fences, and if the power transmission line passes over the plant, these wire fences should be properly grounded. All grounding must be done as specified in the certified electrical project. All cables that are not buried in the ground must be mechanically protected with galvanized pipes or metal cable ducts.

Underground cables in the field must be steel armored, and these cables must be drawn at a depth of 1m through PVC pipes. The carrier stands, which are part of the metal construction, should be brought to equipotential bonding under the ground, and are required to be connected to each other from above. Labeling in the field needs to be checked [112].

11. MEASUREMENTS AND CALCULATIONS TO BE TAKEN FOR MAINTENANCE AND REPAIR

Reading Isc and Voc values in an SPP is not a suitable method because it prevents the system from working. However, the system, while working at maximum power, measuring the output voltage and current (these values are equal to Vmp and Impp values) with the voltmeter and current meter connected to the system as shown in Figure 66, does not create any obstacle to the operation of the system.

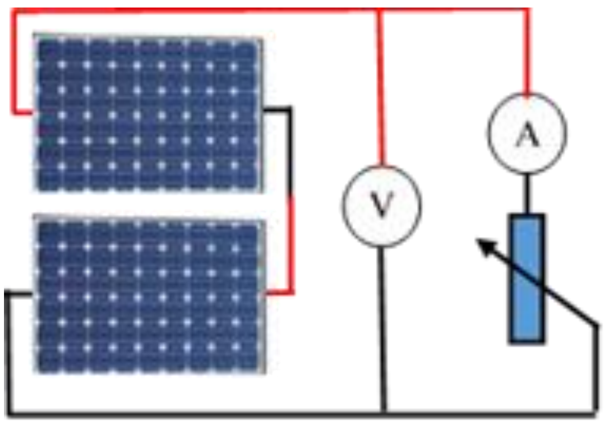


Figure 66. Measurement Wiring Diagram

Thus, by measuring the Impp value continuously, intensity (E (Impp)) falling can be calculated the light on the panels from the graphs, which has done experimentally before. When we compare this value simultaneously with the light intensity (E) measured by an external solar meter placed in the same way as the positions of the panels, the difference will be an indication of the panel's contamination. Thus, it indicates that the panels should be cleaned when the difference in the calculated light intensity (ΔE) reaches a level that will affect the efficiency. (When determining the required (ΔE) value for cleaning the panels, it is necessary to make sure it economical)

It is not enough to consider the change in Vmpp value with only the changes in light intensity. There are two main reasons which change the Vmpp value, apart from the light intensity. These are the temperature of the panels and any shading that will occur on the panels.

Since the panels are under the sun during the day, the surface temperature will change depending on the ambient temperature and light radiation coming to the panel surface. If we assume that the change of the surface temperature under the constant sun radiation, Vmpp and Voc values will decrease (in terms of exp) with increasing surface temperature, while Impp and Isc values will increase slightly. This increase in current is negligible in addition to the decrease in voltage in most panels.

While the panel surface temperature and the light intensity falling on the panel are constant, when a shadow falls on panel or a cell in the panel, the panel/cell terminates the current generation and starts spending power over itself. This issue causes a significant power decrease at the panel output. As seen in Figure 200, let's have a panel which consisting of 36 cells connected in series with each other. If there is no bypass diode, when any of the cells in the panel shading, the current (Isc and Impp) value of the panel decreases towards to zero and stops generating power. However, if we connect the cells in groups of 18 with two bypass diodes. In this case, when one or more cells in the group are shaded, these 18 cells are deactivated by bypass diode and voltage drop only 0.6 V occurs above these 18 cells. The output voltage (Vmpp) of the panel is found by Kirchhoff's law and is slightly (as much as the voltage falling on the bypass diode) lower than half the value in the unshaded state.

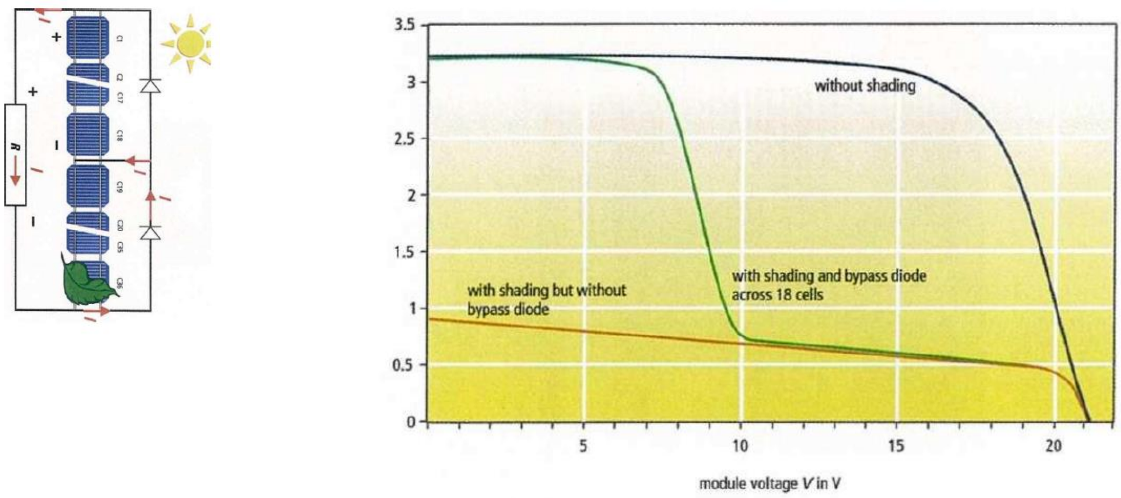


Figure 67. Module I / V Graph Change with and without Bypass Diode When Shadow Falls on the Module

As a result, considering that the shading effect and there are two or three bypass diodes in each panel, in addition to Impp and light intensity measurements, we must be simultaneously measured, Vmpp, ambient temperature and the surface temperature of the panels.

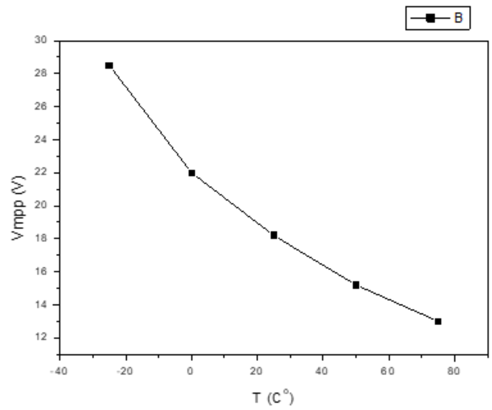


Figure 68. Variation of Vmpp Value with Temperature Under Constant Light Intensity

As shown in Figure 68, if Vmpp is calculated as a function of light intensity, ambient temperature, and surface temperature (Vmpp (T, E)) and plotted, then these values can be compared with the value of Vmpp measured instantaneously from the output. As a result of the comparison, the value of ΔVmpp is found. If there is no fault in the system, then this value must be zero. However, due to the change in light intensity, the difference becomes a value close to zero.

But, if there is shading or a panel failure in the system, there must be a certain difference of ΔVmpp value depending on the number of bypass diodes and the number of panels connected in series in the system. In this difference value, the size of the shadow or the number of defective panels can be found.

As seen in Figure 69, if at least one of the cells connected in series to a bypass diode is shaded or broken, the bypass diode connected to the cells is activated and the output voltage of the panel decreases by approximately 1/3.

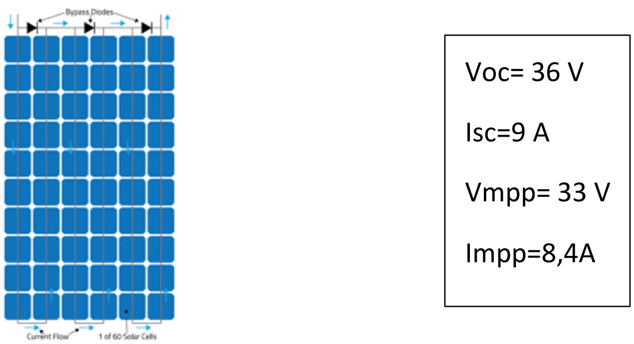


Figure 69. A Panel Composed of 60 Cells

As shown in Figure 62, Let the assume that there is a panel consisting of 60 cells. Assuming the number of cells in the panel be nh, and the number of bypass diodes is nbp. Assuming create a series-connected array using n panels with these properties.

Then, the number of cells connected on a bypass diode will be:

$n_{h\text{-}bp} = n_h / n_{bp} = 60/3 = 20$ Pieces

1. V_{mpp} Value of the Cell = $V_{h(mpp)} = V_{mpp} / n_h = 33 / 60 = 0{,}55$ V

When a by-pass diode is activated, as many cells as nh-bp will not be able to produce

$V_d = n_{h\text{-}bp} \times V_{h(mpp)} = 20 \times 0{,}55 = 11$ V

The Voltage decrease when a bypass diode is activated

$V_{g.d} = Vd + 0{,}6 = 11 + 0{,}6 = 11{,}06$ V

If there is "n" number of panels in line, then the Voltage output will be:

$V_ç = n \times V_{mpp} = 10 \times 33 = 330$ V

If the "Y" number bypass diodes are activated, then the new Voltage output will be:

$V_ç = V_ç – y \times V_{gd}$

As seen from the example, if the voltage decreases of Vmmp value is proportional with multiples of Vg.d then, it means that there is a panel error.

As a result,

The parameters which are required to measure are:

- Impp (A),
- Vmpp (V),
- T (Surface Temperature (C°)
- E (radiation that falling on panels (W/m2)

The parameters which are required to known are:

- Changes of Impp with the light intensity
- Changes of Vmpp and T within the different radiation

The parameters which are required to calculate are:

- The pollution density on Panels
- The radiation that falling on Panels daily
- The daily efficiency of Panels and Power production
- The shadowed area / number of failed Panels

12. ARTIFICIAL INTELLIGENCE AND SOLAR SYSTEMS

12.1. Artificial intelligence

Artificial intelligence is the general name of the technology for the development of machines that can exhibit human-like behaviors and movements, created entirely with artificial tools, without the use of any living organism. It is a set of techniques that enable computers to imitate human behavior. Although this concept has been used since the 1950s, it continues to be used every day to develop newer and more complex technologies. The concept of artificial intelligence is one of the most exciting concepts for the future. Especially in recent years, artificial intelligence studies, which have been a factor in pushing the limits of imagination, demonstrate innovations every day.

Many different techniques are already used to understand and use artificial intelligence, and new techniques are produced and studies are carried out over time. The key to training machines depends on these factors [113]:

- *Meaning* : Identifying and recognizing meaningful objects or concepts in the midst of big data. For example, a vehicle taillight or distinguishing a tumor/normal tissue.
- *Reason* : Understanding the wider context and making a plan to achieve a goal. For example, if the goal is to prevent a collision; The vehicle must calculate the probability of collision based on vehicle behavior, proximity, speed and road conditions.
- *Action* : Suggesting or directly initiating the best course of action. Based on vehicle and traffic analysis, for example, it can brake, accelerate or prepare safety mechanisms.
- *Adaptation* : Finally, at each stage, algorithms should be able to be adapted and improved based on experience. For example, recognizing more blind spots, incorporating new variables into context and adjusting actions based on previous events, etc.

The fields (applications?) of artificial intelligence are increasing day by day, and the universe of artificial intelligence is expanding over time. Successful artificial intelligence applications are being developed in many fields from education to health, from industry to agriculture, from automotive technologies to economics and finance applications . Especially in the last 20 years, the world's leading IT sector organizations such as Microsoft, Google, Apple, Facebook have been implementing artificial intelligence-based applications. These studies also show that the techniques that will guide the course of the world are artificial intelligence techniques.

12.2. Machine Learning

Machine Learning is the general name of computer algorithms that model a given problem according to the data obtained from the problem environment. There are many approaches and algorithms proposed for solving problems such as estimation, forecasting, classification.

In order for any problem to be solved by the computer, it is necessary to know its algorithm. An algorithm is a set of commands to be executed to convert input to output. For example, for spam extraction, in its simplest form, a text file is input, while the output is a yes or no sign indicating whether this email is requested or not. The aim is to determine the output based on the input. There is no single algorithm used for this process, and at the same time, the concept of desired and unwanted may vary from person to person. If the amount of information available (tens of thousands or hundreds of thousands) of emails could be examined, could it be inferred which email would be wanted and which would not? What kind of algorithm is needed if this problem is to be solved with a computer?

Thanks to the developments in information technologies, a large amount of data emerges in every field and this data must be stored. For example, in a banking sector, millions of customer information and credit card expenditures of these customers can be recorded in instant systems. Bytes of information are stored in systems from electronic devices at every moment of human life. The gigabytes of information collected in the systems will only be valuable when it is analyzed and turned into information that will help to make predictions about the future. Data belonging to a credit card user is not random. Although the behavior of the credit card user cannot be defined exactly, a pattern and pattern can be observed and this falls within the field of machine learning. Thus, by looking at the collected digital data, predictions can be made about the future. It helps to find solutions in many areas such as machine learning, computer vision, speech recognition, face recognition and robotics [114].

By using machine learning methods, it is possible to have computers do the work and operations, calculations and studies that people aim to perform. Machine learning can be used for operations such as forecasting, forecasting, attribution, basket analysis, and classification.

Estimation: The values produced by the methods used when the system output is quantitative in models that learn from data.

Forecasting: The process of predicting and calculating the future situation based on past and present data.

Association: The ability of programs to find patterns among the data presented to them as input. When people see someone they know, they immediately remember it, but they can't explain how they did it or write their algorithm. The facial image does not consist of random dots. It has a definite structure. For example, the places of the eyes, mouth and nose are clear. Programs, on the other hand, can identify the pattern specific to that person by examining the face images of a person. It can then infer how similar a given picture is to this pattern. This process is called pattern recognition.

Basket analysis: If a customer buys product X, he also buys product Y, then the customer who buys product X is said to be a candidate to buy product Y. While finding the association rule, the probability of $P(Y|X)$ for the product Y is calculated conditionally to the set X from the previous purchases of the customer.

Classification: In cases where the outputs of the input data are qualitative, the methods used determine which class each data sample belongs to. The purpose here is to divide the entire space of the problem into a certain number of classes. In classification tasks, the machine learning program must draw a conclusion from the observed values and determine which category the new observations belong to.

Machine learning; there are various types such as supervised learning, unsupervised learning, semi-supervised learning and reinforcement learning. Many algorithms are used under these types when solutions to real world problems are sought.

In supervised learning, a computer program with labeled data is provided. For example, when defining the task of separating images of different animals using an algorithm to classify images, each animal will have a label. This is considered a “training” dataset, and the labels remain in place until the program successfully classifies the images at an acceptable rate. At the end of the process, the function that best describes the input data is selected and makes the best guess of “y” (output) for the given “X” (input). Supervised learning algorithms attempt to model the relationships and dependencies between the target prediction output and the input features in such a way that it can predict output values for new data based on relationships learned from previous datasets. Among the algorithms used for supervised learning, there are main algorithms such as nearest neighbor, naive bayes, decision trees, linear regression, support vector machines, artificial neural networks [115].

In unsupervised learning, there is no labeled data, instead the program divides the data into groups based on features. It can be used in clustering operations. In clustering operations, for the example of grouping animals mentioned in the previous paragraph, this includes leg length, body length, eyes, etc. Similar animals are grouped together based on characteristics.

Unsupervised learning is also used in association processes. Here, rules are created based on the similarities that the program has discovered. In other words, a common pattern is determined among the images and the images are ordered accordingly. It is a family of machine learning algorithms mainly used in pattern detection and descriptive modeling. The main unsupervised learning algorithms can be counted as k-means clustering and association rules algorithms [115].

Semi-supervised learning is a type of learning that deals with the study of how natural systems such as humans learn in the presence of both labeled and unlabeled data. In semi-supervised learning, only a few pictures are labeled. The computer program then uses an algorithm to make the best guess about the unlabeled images, and then the data is fed back to the program as training data. A new set of images is then presented with just a few tags. It is an iterative process until the program is able to distinguish animals within the data (such as animal classification) among themselves at an acceptable rate. Semi-supervised learning falls between the previous two. Labeling is very costly, as in many cases it requires specialists. Thus, semi-supervised algorithms are the best candidates for model construction, although most of the observations have no tags, a few are present. These methods take advantage of the idea that although the group membership of unlabeled data is unknown, these data carry important information about group parameters. Many machine-learning researchers have found that unlabeled data combined with a small amount of labeled data can significantly improve learning accuracy [115]. Various algorithms such as self-training, generative mixing models, semi-supervised support vector machine, and graph-based algorithms are examples of semi-supervised learning algorithms.

In reinforcement learning, an answer is sought to the question of how an autonomous agent that perceives its own environment and acts in its environment can learn to make the most appropriate movements to achieve its purpose. It is widely used in systems such as robotics, game programming, disease diagnosis and diagnosis, automation. In the reinforcement learning environment, in response to an action in the agent, the trainer or the software reinforces the agent with a reward or punishment to indicate the demand status of the new situation. Thus, in this system, it tries to choose the best action that can be taken to achieve the goal.

There are two main methods for solving problems with reinforcement learning: the first is to search the training space to find the one that improves the environment, and the second is to use statistical and dynamic programming methods to predict the useful action. The purpose of reinforcement learning is to find the optimal policy. The optimal policy ensures that the agent solves the problem optimally and achieves the result. Thus, the agent reaches its target, which is the highest reward value. In reinforcement learning, the objectives and rewards determined by the trainer or the software are of great importance for the factor to achieve its purpose. In a reinforcement learning system, there are four elements, one of which is optional, apart from the agent and the environment.

- Policy
- Reward (reward signal)
- Value/Status Value (value function)
- Environmental model (model)

Policy; determines the action that the agent can take in the situation it is in.

Award; the score that the agent receives from the environment in response to an action performed.

Status value; the sum of the rewards that the agent can expect from the situation it is in and other situations that follow it.

Model; an optional element included in the system.

Various algorithms such as temporal difference learning and Q learning are used in reinforcement learning problems.

12.2.1. Limitations of Machine Learning

Along with the opportunities and benefits that machine learning systems provide, there are also limitations and challenges. Determining the appropriate algorithm for the learning problem is one of the most important problems for machine learning. Researchers need to be able to determine the algorithm for the problem and test many different algorithms for this purpose. Along with the algorithm, the model parameters must also be determined. Some algorithms may perform well for text processing, while other algorithms may perform better for image processing.

Noise in the available data is another limitation of machine learning. The simultaneous presence of structured and/or unstructured data among data piles, especially with the concept of big data, is another problem that needs to be dealt with in machine learning. Noise in data; Differences in the characteristics of an image such as size, color, resolution, misspellings, punctuation marks, special symbols and abbreviations used in a text data can be encountered in different ways.

Feature extraction is one of the most important steps of the machine learning system, as the correct operation of the system depends on the selection of the correct features and the number of features. The feature extraction process depends on the problem for which the operation is performed and is specific. To be more precise, the features determined in a health problem will be different from the features that will be used for an autonomous vehicle. A common feature extraction produced for different problem solutions in different disciplines will be beneficial for very large problem solutions in the future.

Over-fitting is another machine learning limitation. While the model created may perform well during training, it may underperform on test data or perform less than expected. In this case, it is thought that the training data is memorized by the model, in other words, the model is overlearned. In order to prevent this, the complexity of the model is increased during training and various methods are tried.

In supervised machine learning methods, detection and diagnosis are performed by training the model on labeled data. In order to construct this model, a considerable amount of large data must be available. For such a data labeling job, experts and intensive work are required. It is also possible to cause human-induced errors. In solving special problems, there may also be a lack of specialized personnel. All of this combined, reveals the limitation of data labeling.

12.3. Deep Learning

In recent years, techniques developed in deep learning research are affecting a wide range of information processing studies, both in traditional and new forms, within expanded scopes, including the most effective and important aspects of machine learning and artificial intelligence. Although deep learning is a sub-field of machine learning, it is an increasingly common application area of deep neural networks. In this field, it is aimed to cover a larger data set of solutions based on learning data, rather than customized algorithms for each study. Deep learning is a promising approach to solving artificial intelligence problems in machine learning.

There are several definitions of deep learning:

Definition 1: A class of machine learning techniques that uses many layers of nonlinear computing for supervised or unsupervised feature extraction and transformation, model analysis, and classification.

Definition 2: A subfield within machine learning that relies on algorithms to learn multiple levels of representation to model complex relationships between data. Thus, high-level features and concepts are defined as low-level features, and such a hierarchy of features is called a deep architecture. Most of these models are based on learning unsupervised representations.

Definition 3: A sub-domain of machine learning based on learning several levels of representation corresponding to a hierarchy of features or factors or concepts in which higher level concepts are defined from lower level ones. The same low-level concepts can help define many high-level concepts. Deep learning is part of a larger family of machine learning methods based on learning representations. An observation (eg, an image) can be represented in many ways (eg, a pixel vector), but some representations make it easy to learn interesting tasks (eg, is this an image of a human face?) From examples and research in the field, deep learning tries to determine what can be represented and how to learn.

Definition 4: Deep learning is a set of algorithms that attempt to learn at multiple levels corresponding to different levels of abstraction in machine learning. Usually artificial neural networks are used. In these learned statistical models, the levels correspond to different levels of concepts, where higher-level concepts are defined from lower-level concepts, and the same low-level concepts can help define higher-level concepts.

Definition 5: Deep Learning is a new field of machine learning research introduced with the aim of bringing machine learning closer to one of its original goals (artificial intelligence). Deep learning is about learning multiple levels of representation and abstraction that help in understanding data such as images, sounds and texts.

In conclusion, deep learning is a machine learning technique that uses a deep neural network. Deep neural networks are multilayer neural networks that contain two or more hidden layers.

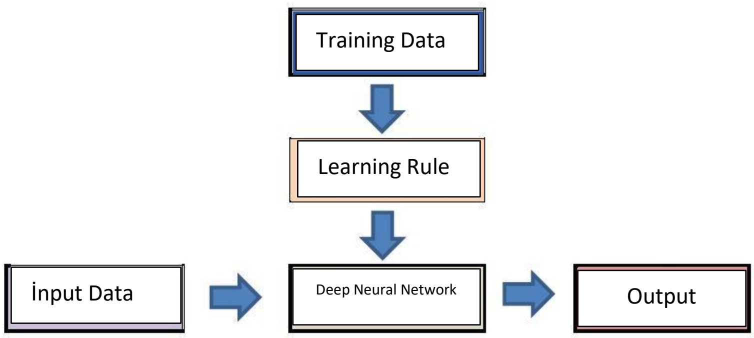


Figure 70. Deep Learning Structure

In deep learning, there is a structure based on learning more than one feature level or representation of data. Top-level properties derive from lower-level properties, creating a hierarchical representation. The representation for an image can be a vector of per-pixel intensity values or features such as edge sets, custom shapes. Some of these features better represent the data. In deep learning methods, efficient algorithms are used for hierarchical feature extraction that best represents the data instead of manually extracted features.

There are two key aspects in common among the various high-level definitions of deep learning:

- Models consisting of multiple layers or nonlinear computing stages,
- Methods for supervised or unsupervised learning of feature representation in successively higher, more abstract layers.

In order to run deep learning algorithms and solve problems, machines with high capacity (especially GPU) and large amounts of data are needed. Unlike standard machine learning algorithms that break down problems into parts and solve them individually, deep learning solves the problem from start to finish. More importantly, the more data a deep learning algorithm is fed, the better the task will be accomplished. The time factor is also important. Studies that are not time-constrained can produce better results when fed with big data.

Three major reasons for the popularity of deep learning today are the greatly increased processor capabilities (e.g. , graphics processors (GPU), the massive increase in data used for education, and recent advances in machine learning and signal/information processing research. These developments have enabled deep learning methods to effectively take advantage of complex, combinatorial nonlinear functions, learn distributed and hierarchical feature representations, and use both labeled and unlabeled data effectively.

Deep neural networks have two or more layers of hidden neural networks. In deep neural networks, more comprehensive relationships are established within the data from simple to complex. Each layer tries to establish a relationship between itself and the previous layer. Thus, a more detailed examination of the inputs is made and a more accurate decision is made.

Different activation functions can be used when creating a deep neural network structure. These functions may vary depending on the type, structure, size of the data and the person who created the model. The activation function determines the output that this cell will produce in response to the input to the cell. Usually a nonlinear function is chosen. Major activation functions are Sigmoid, TanH and ReLU.

While creating deep learning architectures, the algorithm to be used is of great importance. These algorithms may differ according to the type, size, volume and structure of the data and the parameters to be used. Convolutional Neural Networks (CNN), Recurrent Neural Network (RNN), Restricted Boltzmann Machines (RBM) and Deep Belief Networks (Deep belief Nets -DBN) are the main ones.

12.4. Artificial Intelligence Usage Areas

Thanks to artificial intelligence and studies in its sub-fields, as many innovations will be included in human life in the future as there are today. Thanks to the high-performance results obtained from artificial intelligence-based studies, almost every discipline today carries out parallel studies with artificial intelligence, uses the algorithms, methods and techniques used here, and produces solutions. Energy, medicine, education, cyber security, entertainment, social life, agriculture, transportation, tourism, customer service, smart cities, e-commerce, events, banking and finance, etc. Successful solutions are produced in many areas [118-119].

In the medical field, artificial intelligence algorithms enable doctors and hospitals to better analyze data and customize healthcare services based on each patient's genes, environment and lifestyle. Thanks to artificial intelligence, there will be a personalized medicine revolution and groundbreaking innovations in the field of health.

Thanks to the use of artificial intelligence in educational technologies, it will be possible to analyze the missing areas of the students and to design the program that will be created in accordance with the individual. With the personalized education program, it is foreseen that the students will be more productive and will provide addedvalue to their environment as individuals who love their job in the future. Artificial intelligence, which personalizes educational software according to student needs, can better understand students' deficiencies and create a personalized support advantage for development. Intelligent data collection, supported by intelligent computer systems, is a process actively practiced by many schools today. Today, schools use artificial intelligence technology to follow the development process of the students and to increase the performance of the students with this analysis [116].

One of the most important elements in the cyber world is to be able to resist cyber threats by taking precautions against malicious people and software. Individuals and institutions struggle with these elements. Different studies have also been successfully carried out in the field of cybersecurity, which stated that the self-learning and automation capabilities provided by artificial intelligence can protect data in a more systematic and affordable way and keep people safer from terrorism or smaller-scale identity theft.

Entertainment has been one of the areas where artificial intelligence technologies are used extensively. Especially recently, the game industry has made great progress thanks to the developments in artificial intelligence techniques [117]. Similarly, developments are being experienced in the film industry, cinema industry and music industry thanks to forecasting and suggestion systems.

Intelligence techniques are also used in social life, for example, assistants help people who need someone's help due to their age to stay independent and live longer in their own homes. In the future, AI tools will keep nutritious food available, safely reach objects on high shelves, and monitor people's movements around their home.

Artificial intelligence technologies in the field of agriculture have become increasingly widely used, especially in recent years. A wide range of artificial intelligence applications are carried out in agriculture, from smart spraying systems to efficient production analysis, from farming with autonomous vehicles to drone -assisted agriculture technologies.

Artificial intelligence can have the greatest impact on transportation in the near future on automobiles. Thanks to smart technologies, safe driving technologies will be provided with autonomous vehicles that will process data from many sensors and central computer systems. There are companies that have made great progress in this regard. Airports are among the places that use artificial intelligence technologies most intensively in transportation.

Artificial intelligence and tourism virtual assistants, specially developed for tourism and cultural protection zones, meet the expectations of tourists by increasing visitor satisfaction from the beginning to the end of visits, entertainment, journeys, events and similar holiday actions. Thus, people can get up-to-date information about visiting points such as artifacts, restaurants, services and events belonging to the relevant touristic region, or they can watch relevant promotional videos and reach every point they want to go within the scope of touristic areas with navigation guidance.

Thanks to artificial intelligence and customer service experience, users can get information about available products, online technical assistance and even make a technical service appointment. Artificial intelligence smart customer assistants can be activated by voice or text, imitating human intelligence and natural speech. When they communicate with individuals with the voice command system, they interpret human voices and provide appropriate consultancy service to the questions.

Thanks to artificial intelligence and smart cities technologies, municipal services are provided more efficiently with less cost and it is possible to provide more effective service to the citizens. While smart cities add value to human life, they also improve the quality of life. Smart city applications have begun to be used in many municipalities. They focus mostly on the fields of environment, transportation, governance, security, health and geographic information systems.

(Something is missing here) are personalized thanks to artificial intelligence algorithms. More improvements are being made in this regard every day. Artificial intelligence brings together information such as customers' shopping habits and interests, making it possible to make personalized product recommendations to consumers. Artificial intelligence is also used extensively in the e-commerce sector for purposes such as offering different discounts to different customers or showing different products to different customers.

Event assistants enable users to get up-to-date information about the event, movies and more, or to watch promotional videos about the subject, allowing them to examine weather and traffic conditions, check promotions in cafes and stores, and be informed about current campaigns thanks to artificial intelligence technologies.

Banking and financial services are among the leading areas in which artificial intelligence technologies are most widely used. Artificial intelligence and banking and financial services experience increase the work efficiency of users, helping investors in many matters from account transactions to stock recommendations. In order to use the time allocated for stocks tracking, trading process, fund tracking and similar processes more effectively, artificial intelligence technology oversees this process for investors by getting information about user account information, credit information, updates, investment reports and more. Today, almost every bank provides services to its customers using smart assistants [118-119].

Artificial intelligence studies are also frequently used in the renewable energy sector. Artificial intelligence in this field in solar, wind, geothermal, hydro, ocean, bio, hydrogen and hybrid renewable energy types; It is used for the purposes of design, optimization , forecasting, management, deployment and policy formulation [120]. Solar energy systems have an important share in this sector. For this reason, the use of artificial intelligence in solar energy systems has been opened as a separate topic.

12.5. Artificial Intelligence and Usage in Solar Energy Systems

Today, due to the large number of data that energy companies have to manage, there are serious problems in many issues such as the cost of energy, production and distribution. Chief among these problems is the inconsistency in carbon footprint and energy efficiency. Thanks to artificial intelligence technologies, it is possible to store, process and manage this data with less time and cost [121]. The benefits that can arise from the use of these technologies can be explained as follows.

Predictive Analysis: There is an increasing need for energy in the world for the continuity of modern industries and due to global population growth. It is thought that the analytical and predictive ability of artificial intelligence will play an important role in meeting this need. Energy companies have problems that require complex data systems to reduce costs, conserve power, be prepared for changing conditions and provide better customer service. The solution to these problems can only be achieved with high accuracy prediction and analysis, and artificial intelligence technologies today have this ability. With the help of artificial intelligence machine learning, it can solve all these problems by maximizing the use of predictive data in the energy industry. Energy companies need to predict demand changes, system overloads and potential failures as precisely as possible. The cost of error for any deviation from these estimates is quite high for the energy sector. For this reason, the predictions that artificial intelligence will reach as a result of the data it processes will be able to produce solutions to overcome these problems [121].

Resource Management: The next step in the predictions that AI achieves is resource management. Through the analysis of these forecasts, energy companies will be able to better allocate their resources, prepare for energy demands in advance, anticipate problems and save resources. For end consumers, it will be possible to achieve results in the form of power savings, lower bills and customized services with artificial intelligence [121].

Storage of Energy: Efficient storage of energy is a very difficult and complex issue. As the amount of power to be stored increases, additional capacity and new management systems are needed. Artificial intelligence can optimize the industry's energy storage. In addition, the storage of clean and renewable energies is quite problematic. Combining renewable energy with AI-powered storage can simplify storage management and minimize power losses [121].

Prevention Services: Energy is a powerful resource that can be very dangerous if misused. Thanks to artificial intelligence supported systems, system overloads can be predicted and operators can be informed about potential transformer failures [121].

Today, research has been carried out on the adaptation of artificial intelligence technologies to solar energy systems in different studies. Some of these studies can be summarized as follows.

In the thesis study carried out by İzmirli Ayan in 2018, it is aimed to estimate the power that the Photovoltaic (PV) system will produce, taking into account the changing environmental factors. As environmental factors, radiation, panel temperature, ambient temperature, wind speed, wind chill and humidity data were measured and recorded at different times. In the light of these data, the power to be produced by the photovoltaic panel has been estimated with the artificial neural network algorithm, one of the artificial intelligence methods. Eight different neural network training algorithms were created, tested and their success results were compared. The lowest mean absolute percent error

(MAPE) was 6.6% and the success rate (R2) was 98.9%. In addition, the performance of the artificial neural network was compared with Multiple Regression Analysis, one of the statistical techniques, in the power estimation of the PV panel. These results show that artificial neural networks can accurately predict the power produced by PV panels. In the study, the effect of environmental factors on the power in the PV system was examined and also the power that the PV panel would produce according to changing environmental factors was successfully predicted [122].

Similarly, in the study carried out by Geçmez and Gençer (2020), the 24-month production data of a solar power plant installed in Şahinkaya, Elazığ province, in the Eastern Anatolia Region, between January 2018 and December 2019, were calculated to Meteorological data (Daily Average Relative Humidity (%), Daily Estimated based on Average Temperature (°C), Daily Total Global Solar Radiation (kWh /m^2)). Production information of SES is taken from SES. Meteorological data were taken from MEVBIS. The ANN model to be applied in the study was carried out by training with MATLAB (R2018 Version) software. In the study, it was observed that the regression values for all data were close to 1. It has been determined that the ANN model output values are very close to the real data. The performance of the proposed model, namely the Mean Squared Error (MSE) value, was found to be 0.00908 [123].

In the study carried out by Kayabaşı, Yıldız and Balcı (2018), it was aimed to examine the output power efficiency of the solar panel depending on the weather conditions. With the established air measurement station, data such as humidity and temperature, sun and light level, wind intensity were obtained. While taking these values, the current and voltage values of the solar panel were measured and all data were analyzed with the Artificial Neural Networks (ANN) artificial intelligence method. In the ANN model, wind speed, humidity, temperature and luminous intensity are taken as inputs and solar panel power is taken as output. The effects of these environmental factors were measured and evaluated with the use of ANN, one of the artificial intelligence techniques. The total error rate between the actual output power of the system and the test output power was determined as 1.57%. As a result of these analyzes, the effects of weather conditions on efficiency were evaluated and more efficient solar energy systems were installed and operated [124].

In Güzel, Okatan and Kırbaş (2021), in order to predict energy production, solar radiation values were tried to be estimated one day in advance, using previous meteorological data. For this purpose, time series analysis was performed with Artificial Neural Networks (ANN), which is one of the widely used machine learning techniques today. NAR and NARX methods were used for time series analysis. As the data set, meteorological data covering the years 2016 – 2020 belonging to the province of Isparta, obtained from the

General Directorate of Meteorology, were used. Performance was compared between different time delay values, and the results obtained with different combinations were analyzed by selecting features among meteorological data. It is thought that the evaluations will contribute to the installation and operation of solar power plants [125].

Turgut et al. (2019), a system was designed for air temperature estimation. In the study, analog information such as temperature, humidity, wind strength and wind direction connected to the microcontroller were obtained by the sensors and recorded in the database. Recording of data by Ethernet, which can transfer the measured data connected to the microcontroller in real time to the database quickly without any loss, was realized with the module. Artificial neural network models (ANN), which is a sub-title of artificial intelligence, created the database, K- Nearest. Neighbors (K-NN) and Random. It was processed by Forest (RF) algorithms, and network models were created. Thus, the prediction rate of the air temperature, which is the system output parameter, was carried out with 87% based on the system input parameters humidity, wind direction and intensity [126].

Similarly, in different studies, estimation of PV panel power outputs using ANN and comparison with heuristic algorithms [127], new real-time forecasting models for output power and energy efficiency of PV systems [128], the effect of radiation for power estimation obtained from a PV system [129].] and electrical energy demand forecasting [130].

As can be seen from the researches summarized, there has not been enough work yet on the smart maintenance and repair of solar energy systems, which is the subject of our project named Innovative and Smart Maintenance in Solar Energy Systems. Studies have focused especially on energy estimation. One of the artificial intelligence application areas for photovoltaic systems is photovoltaic fault diagnosis. The application of artificial intelligence in photovoltaic fault diagnosis and maintenance has been gaining ground in discussions in recent years, as have studies such as [131], [132], [133], [134] and [135].

12.6. Artificial Intelligence Software Infrastructure for Solar Energy System

Sensors placed on the panels were used to process the data to be used in artificial intelligence algorithms. Kafka, Elasticsearch and Kibana open source software tools were used for the analysis of these data. These tools are described in this section.

12.6.1. Kafka

Apache Kafka is an open source distributed streaming system used for stream processing, real-time data pipelines, and data integration at scale. First created in 2011 to handle real-time data streams on LinkedIn, Kafka has rapidly evolved from the messaging queue into a full-fledged event streaming platform capable of processing more than 1 million messages per second or trillions of messages per day [136].

Kafka has several advantages. Today Kafka is used by more than 80% of the Fortune 100 in nearly every industry, for myriad uses in cases large and small. They are de facto technology developers and architects used to build the latest generation of scalable, real-time data flow applications. While these can be achieved with a number of technologies available in the market, here are the main reasons why Kafka is so popular.

- **High Throughput** : Kafka, which can handle high speed and high volume data, can process millions of messages per second.
- **High Scalability** : Kafka clusters can scale up to a thousand agents, trillions of messages per day, petabytes of data, hundreds of thousands of partitions. Storage and processing can be flexibly expanded and collapsed.
- **Low Latency** : It can transmit high volume messages using a cluster of machines with latency times as low as 2ms.
- **Persistent Storage** : It can securely store data streams in a distributed, durable, reliable, fault-tolerant cluster.
- **High Availability** : You can efficiently extend clusters over availability zones or connect clusters across geographic regions, making Kafka highly available and fault-tolerant without risk of data loss.

Apache Kafka consists of a storage layer and a compute layer that combines efficient, real-time data retrieval, streaming data pipelines, and storage across distributed systems. In summary, this provides simplified data flow between Kafka and external systems, so it can easily manage real-time data and scale across any infrastructure.

- **Real-Time Processing at Scale** : A data flow platform wouldn't be complete without the ability to process and analyze data as it's created. Kafka Streams API is a powerful, lightweight library that allows for on-the-fly processing, aggregation, creating windowing parameters, merging data in a stream, and more. It's important that Kafka is built on top of it as a Java applet and keeps your workflow intact without any extra clusters to maintain.
- **Stable, Persistent Storage :** Apache Kafka, an abstraction of a distributed commit log commonly found in distributed databases, provides durable storage. Kafka can

act as a 'source of truth' by distributing data across multiple nodes for a highly available deployment in a single datacenter or multiple availability zones.

- **Publish + Subscribe** : There is an immutable commit log in the center, from which it can be subscribed and data can be published to any number of systems or real-time applications. Unlike messaging queues, Kafka is a highly scalable, fault-tolerant distributed platform that allows it to be deployed for applications such as managing passenger and driver matching on Uber, providing real-time analytics and predictive maintenance for British Gas 's smart home, and performing multiple real transactions. is the system. This performance makes it possible to scale from a single application to enterprise-wide use.

There are many Kafka use cases today that are widely used to build realtime streaming data pipelines and realtime streaming applications. It provides many benefits for any application that relies on or works with data.

- **Data Pipelines** : In the context of Apache Kafka, a streaming data pipeline means getting data from sources into Kafka as they were generated, and then streaming that data from Kafka to one or more destinations.
- **Stream Processing** : Includes operations such as filters, joins, maps, aggregations, and other transformations that organizations use to support many use cases. Kafka Streams is a stream processing library for Apache Kafka that enables organizations to process data in real time .
- **Stream Analysis** : Kafka provides highly efficient event delivery and when combined with open source technologies like Druid can create a powerful Stream Analysis Manager (SAM). Druid uses streaming data from Kafka to enable analytical queries. Events are first loaded into Kafka, where they are buffered on Kafka agents before being consumed by Druid real-time workers.
- **Extract, Transform, Load (ETL) : Real-time ETL with** Kafka combines different components and features such as Kafka Connect source and repository connectors to consume and produce data from / to any other database, application or API .
- **Event Driven Microservices** : Apache Kafka is a popular tool for microservices because it solves most microservice orchestration issues while enabling attributes like scalability, efficiency, and speed that microservices aim to achieve. It also facilitates inter-service communication while maintaining ultra-low latency and fault tolerance.

12.6.2. Elasticsearch

Elasticsearch is a distributed, free and open search and analysis engine for all types of data, including textual , numerical, geographic, structured and unstructured . Elasticsearch , Apache It is built on Lucene and was first released in 2010 by Elasticsearch NV (known as Elastic). Known for its simple REST APIs , distributed nature, speed, and scalability, Elasticsearch is a set of free and open tools for data retrieval, enrichment, storage, analysis, and visualization . It is the central component of Stack . Elastic , commonly referred to as the ELK Stack (after Elasticsearch , Logstash , and Kibana) Stack now includes a rich collection of lightweight transport agents known as Beats for sending data to Elasticsearch [137].

Elasticsearch's speed and scalability, and its ability to index many types of content, mean it can be used for different uses:

- Application search
- website search
- Corporate search
- Logging and log analysis
- Infrastructure metrics and container tracking
- Application performance monitoring
- Geospatial data analysis and visualization
- Security analytics
- business analytics

Raw data can be imported into Elasticsearch from a variety of sources, including logs, system metrics, and web applications. Data retrieval is the process by which this raw data is parsed, normalized, and enriched before indexing in Elasticsearch. Once indexed in Elasticsearch, users can run complex queries against their data and use aggregations to get complex summaries of their data. From Kibana, users can create powerful visualizations of their data, share dashboards, and manage Elastic Stack.

An Elasticsearch directory is a collection of interrelated documents. Elasticsearch stores data as JSON documents. Each document associates a set of keys (names of fields or properties) with their corresponding values (strings, numbers, Booleans, dates, value arrays, geolocations, or other data types). Elasticsearch uses a data structure called an inverted index, which is designed to allow very fast full-text searches. A reversed index lists every unique word that appears in any document and identifies all documents in which each word occurs. During the indexing process, Elasticsearch stores documents and creates an inverted index to make document data searchable in near real time. Indexing is initiated with the index API , where you can add or update a JSON document to a given index.

Elasticsearch is fast at full-text search as it is built on top of Lucene. Elasticsearch is also a near real-time search platform, meaning the latency from indexing a document to becoming searchable is very short - typically one second. As a result, Elasticsearch is well suited for time-sensitive use cases such as security analytics and infrastructure monitoring.

Elasticsearch is distributed by nature. Documents stored in Elasticsearch are distributed among different containers known as shards, which are replicated to provide backup copies of the data in case of hardware failure. The distributed nature of Elasticsearch allows it to scale to hundreds (or even thousands) of servers and process petabytes of data.

Elasticsearch comes with a wide variety of features. In addition to its speed, scalability, and flexibility, Elasticsearch has a number of powerful built-in features that make storing and searching data more efficient, such as data aggregations and directory lifecycle management.

Elastic Stack simplifies data retrieval, visualization and reporting. Integration with Beats and Logstash makes it easy to process data before indexing it into Elasticsearch. Kibana provides real-time visualization of Elasticsearch data as well as user interfaces for application performance monitoring (APM), logs, and quick access to infrastructure metrics data.

12.6.3. Kibana

Kibana provides search and data visualization capabilities for data indexed in Elasticsearch. It is a free and open front-end application on Stack [138]. Typically as the graphical tool for the Elastic Stack, Kibana also functions as the user interface for monitoring, managing and securing an Elastic Stack. It is the hub for embedded solutions developed on the Stack . Developed in 2013 within the Elasticsearch community, Kibana offers a portal for users and companies. It has become the window to Stack itself. Kibana's Elasticsearch and tight integration with Stack makes it ideal for supporting the following elements:

1. Search, view, and visualize data indexed in Elasticsearch and analyze data by creating bar charts, pie charts, tables, histograms, and maps. The dashboard view

combines these visual elements for later sharing via the browser to provide real-time analytical views to large volumes of data to support use cases such as :

a. Logging and log analysis
b. Infrastructure metrics and container monitoring
c. Application performance monitoring (APM)
d. Geo data analysis and visualization
e. Security analytics
f. business analytics

2. Elastic via web interface Monitoring, managing and securing Stack instance.
3. Elastic for observability , security and enterprise search applications Centralizing access to embedded solutions developed on the Stack .

Kibana provides visual analysis of data from an Elasticsearch index or multiple indexes. Indices are created when Logstash (a large-scale receiver) or Beats (a collection of single-purpose data senders) takes unstructured data from log files and other sources and transforms it into a structured format for Elasticsearch storage and search functions. Kibana's interface allows users to query data in Elasticsearch indices and then visualize the results via standard chart options or built-in applications such as Lens, Canvas , and Maps. Users can choose between different chart types, change sums of numbers, and filter by specific data segments.

The Kibana dashboard is a collection of charts, graphs, metrics, searches, and maps brought together in a single pane. Dashboards provide at-a-glance insights into data from multiple perspectives and allow users to drill down.

To create a dashboard in Kibana, users must have data indexed in Elasticsearch and have already created a search, visualization or map. From within Kibana , click Dashboard in the side navigation panel. When opening the dashboard interface, you are presented with an overview of the available dashboards. If no dashboards are available, sample datasets containing previously created dashboards can be added.

To create a dashboard, users can follow these steps:

1. Dashboard in the side navigation.
2. Create new dashboard.

3. Add.
4. Add Panel to add visualizations and saved searches to the dashboard. Lists can be filtered if there are many visualizations.

If there is a read-only icon in the title, it indicates that the user does not have sufficient permissions to create, edit, or save the clipboard. Kibana administrators can change these permission settings on an individual or group basis.

Kibana Lens is a built-in tool designed to provide faster access to data insights for both experienced and inexperienced users. Lens has a drag and drop interface to simplify the process of exploring Elasticsearch data and creating images. Lens helps create charts with smart suggestions that provide alternative ways to visualize data based on data analytics best practice and common usage patterns.

With Kibana Lens, a user can:

- Elasticsearch directory with minimal program interaction
- Drag and drop data fields to create multiple data visualizations
- Multiple Elasticsearch indexes simultaneously for comparison in the same visualization,
- Customize data visualizations by changing chart types and changing aggregations in real time.
- interactive data visualizations without code or previous experience using Kibana .

Canvas is a data visualization and presentation application within Kibana. With Canvas, live data can be imported directly from Elasticsearch and combined with colors, images, text, and other customized options to create dynamic, multi-page images.

Canvas , a user can:

- Create and customize a workspace with backgrounds, borders, colors, fonts and more.
- Customize artboards with custom visualizations such as images and text
- Customize by pulling data directly from Elasticsearch ,
- View data with charts, graphs, progress trackers and more
- Focusing on the data that is desired to be displayed with filters.

Kibana is the official interface of Elasticsearch. Elasticsearch users can discover data insights and They will find Kibana as the most effective interface to perform active management of their stack's health .

Kibana covers many use cases. APM leverages Kibana's built-in features for use cases such as security analytics, business analytics, uptime monitoring, geospatial analytics, and more.

Kibana has a strong support community. As a free and open interface, Kibana has seen strong adoption and community input. The experience levels of Kibana users vary considerably - the documentation, instruction and community support reflect this broad range of expertise. Elastic also offers training and individual support to help users get started.

12.7. Possible Challenges of Artificial Intelligence Application in the Energy Sector

There are some factors that limit artificial intelligence applications in the energy sector. These elements can be explained as follows [121]:

Lack of Theoretical Knowledge: One of the reasons for the slow adoption of AI in the energy sector is the lack of knowledge of decision makers about AI. Many companies do not have the technical background to understand how to leverage AI applications. Some stakeholders prefer to stick with proven methods rather than risk trying something new.

Lack of Practical Expertise: Artificial intelligence is still a new technology and there are few professionals who specialize in it. Although there are many experts with in-depth theoretical knowledge, it is extremely difficult to find experts who can develop new artificial intelligence software with practical experience. Because the cost of error is high in the energy industry, many companies are reluctant to try new approaches.

Outdated Infrastructure Outdated Infrastructure: This structure is the biggest obstacle to the use of artificial intelligence in the energy sector. Companies that provide energy services to the public are immersed in the clumps of data they collect and have no idea how to deal with it. The energy sector suffers great losses due to the security vulnerabilities of outdated systems.

Financial Pressure: Implementing AI technology may be the smartest thing to do. But it's definitely not the cheapest. Finding an experienced software services provider, developing and customizing software, managing and monitoring takes a lot of time and resources. Businesses in the energy sector must be willing to allocate an impressive budget and accept the risks of replacing their legacy systems before reaping the benefits of incorporating artificial intelligence, machine learning, and deep learning into their strategies.

13. SMART ENERGY INDUSTRY TRANSFORMATION

13.1 Electrical Energy and Resource Efficiency

In physics, energy is referred to as the capacity for work. Numerous forms of energy are depicted in the diagram below.

The mobility of electrons is the source of electrical energy.

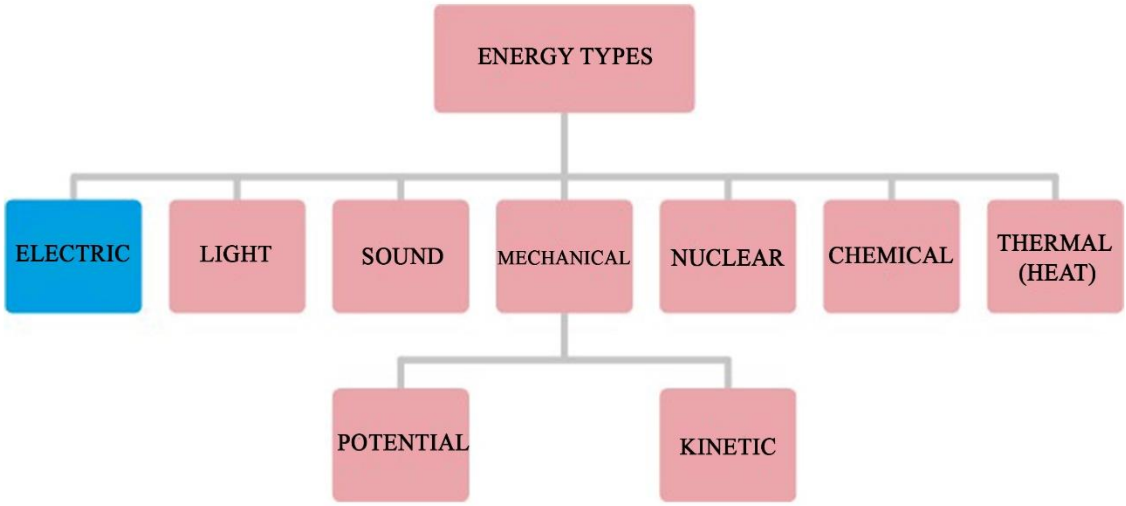


Figure 71. Types of Energy [139]

Renewable and non-renewable energy sources are separated into two categories to produce electrical energy. Renewable energy sources are non-toxic and ecologically favourable energy sources. The usage of non-renewable energy sources, which contribute to environmental harm like global warming, is being phased out in favour of renewable energy sources. One of the actions performed in this direction can be seen in the Kyoto Protocol. Turkey has endorsed and signed this protocol.

However, some countries have not yet ratified it. Since the development of fossil fuel engines has slowed down, the automobile industry is focusing all of its R&D efforts on the development of electric vehicles and hydrogen fuel.

Figure 72. Renewable Energy Sources [140]

Renewable energy sources show that energy can be produced without disturbing the balance of nature.

13.2 Difficulties In The Generation And Distribution Of Electric Energy

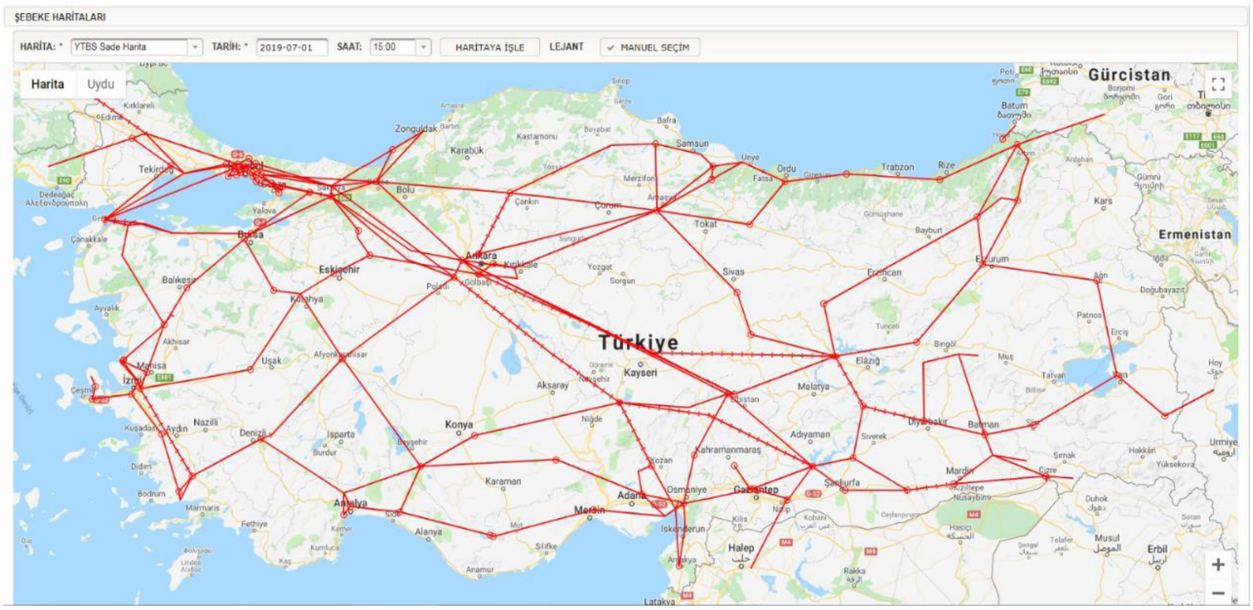


Figure 73. 400 KV transmission line network

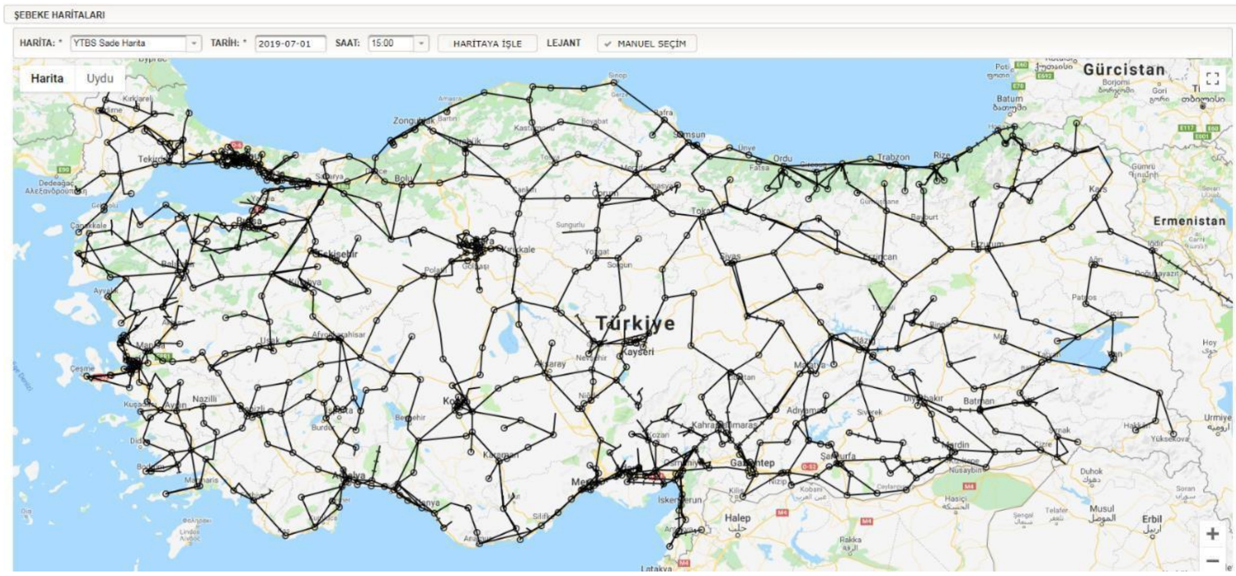


Figure 74. 154KV transmission line network

Early 1900s networks and infrastructure for generating electricity are no longer sufficient. There are times when the energy derived from a region is insufficient for that region, depending on how that region is used during the day. A different region might have a lower need for energy during the same period. Demand and supply will be equivalent if the unused energy is moved to the other area that needs it. A network that is connected is necessary as a result of this circumstance. All power plants in our country are connected by this network. The power plants are connected by a very high voltage line. Production and consumption must be in constant balance. Since AC (Alternating current) current cannot be stored, it must be transferred directly to the consumer. As a result of the rapid population growth and the increasing demand of people for electrical devices day by day, the existing electricity production lines are also insufficient. The biggest loss in the electricity produced is transmission lines, transformer losses and inefficient device usage. The use of an unbalanced load in consumption is also one of the negative factors of the system.

13.3 Smart Grids

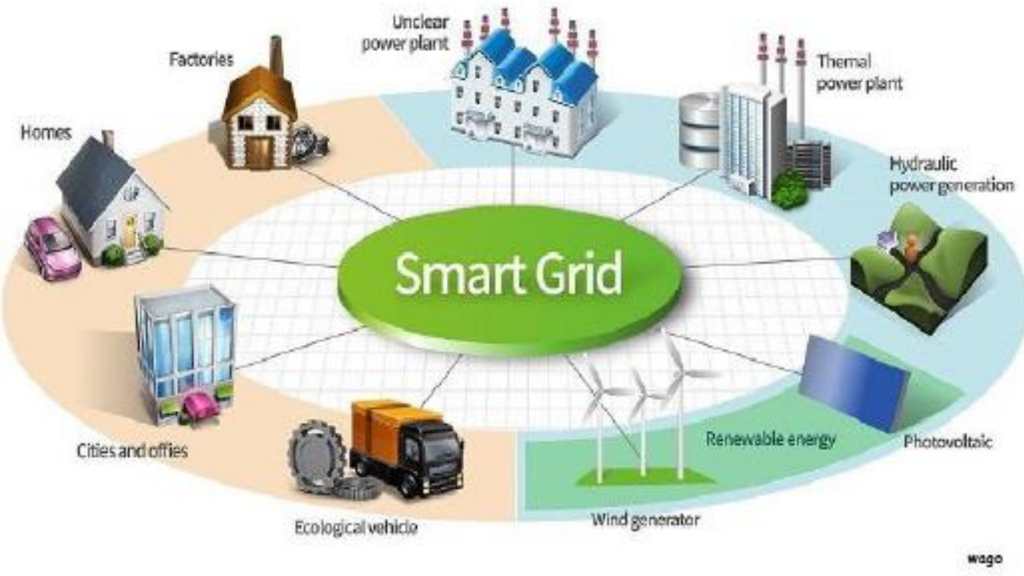


Figure 75. Smart Grids

Due to the issues and challenges associated with the generation and transmission of electrical energy, it is clear that the current electrical energy infrastructure requires modernization to become a smarter structure. By adjusting the communication and information processing technologies utilized for this to the current system, efficiency can be further boosted. This new structure is called smart grids. Energy efficiency and outages are estimated to have declined with the implementation of smart grids. If there is a backup system, it could be quite simple to find it and activate it in the event of an interruption or malfunction.

Figure 76. SCADA Controlled System [141]

Ensuring the power plant where the generation takes place is compatible with the system is one of the key operations of smart grids. Figure 76 displays the Karkamş Hydroelectric Power Plant. The power plant is operated using SCADA (Supervisory Control and Data Acquisition – Central Supervision Control and Data Acquisition) software. All of the switchboard's transmission cables and gear can be controlled by SCA software. Thus, both retrospective reporting and live monitoring of the control process are options. Resources for forthcoming investments and planning might be based primarily on the report information that has been received. The power plant will quickly adapt to the smart grid because its infrastructure has been prepared appropriately. [142]

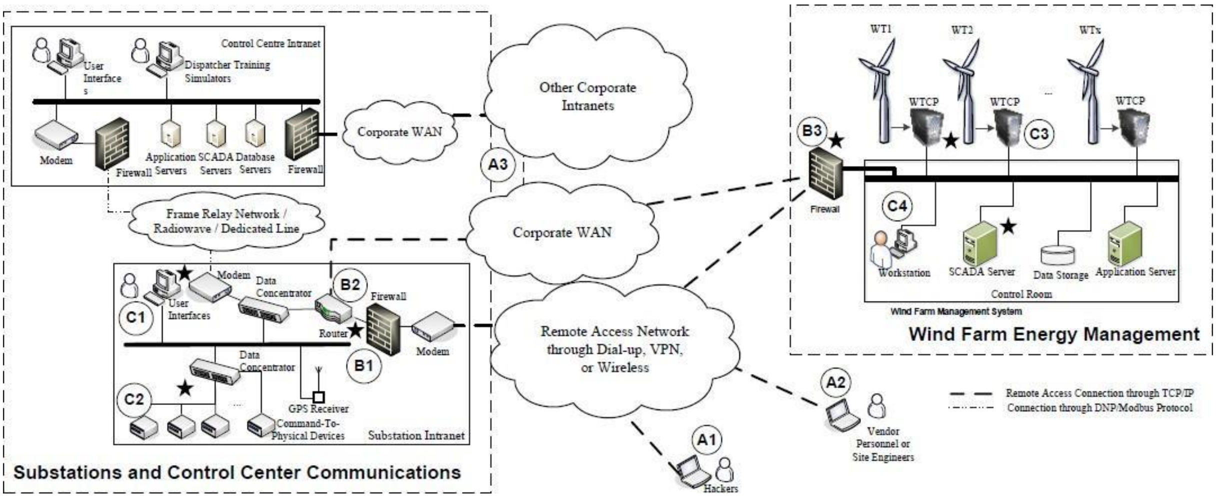


Figure 77. SCADA Infrastructure and Network Connectivity Between Substation-Level Network, Control Centers, and a Wind Farm Management System

To access smart power plants, data operation and control are essential. It is required to have the transmission system, which is employed in systems with interconnections. Interventions for business problems and precautions in this area are crucial for the systems to operate well. Data communication across the current electrical network is made possible by a technique called power line communication (EHT). Signals from Scada can also be used for voice communication. Having access to computer-based data transmission made it easier to implement immediate and adequate solutions.

Turkey experienced a severe power outage on March 31, 2015. This interruption is caused by the maintenance of tension wires that run from the country's east to west. The connecting system was broken in this fashion, which caused the output to split in two and be unable to meet demand. Numerous negative events and disruptions took place throughout the day as a consequence of the disruptions in Turkey's western province. [143]

Turkey's network of interconnected systems includes ties to its neighbours. Energy can also be obtained from neighbouring nations when there is a shortage in Turkey. The nation's entire energy needs are met by very big power plants, which might have negative effects during malfunctions, natural disasters, or scheduled maintenance and repairs. Alternative energy sources are becoming more and more essential. There may be a solution in the form of microgrids. Microgrids primarily use renewable energy sources. Voltage and frequency synchronization are needed for connecting microgrids to existing grids. If not, it will damage the network or cause harm to itself. The control units in the microgrid are in charge of providing synchronization.

Microgrid-based smart energy automation incorporates the internet of things, a networked control system, sensors, and electronics to interconnect sources of energy, the microgrid, and cloud-based real-time data storage. The software then makes use of the information to keep track of the energy sources, continuously analyzing energy requirements and environmental factors (weather conditions) to establish the ideal energy mix to accomplish the targets of the microgrid operator. For illustration, the software can be set to promptly complete its choice, turn off the energy it receives from the sun, and switch on the source from the batteries when the system that helps in monitoring the weather conditions receives weather forecasts of impending rainfall. [144]

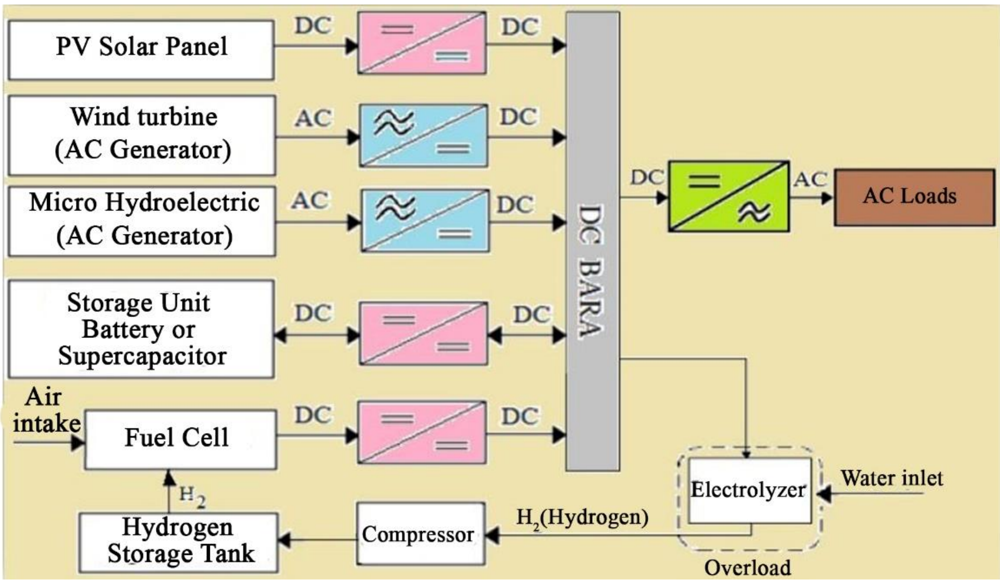


Figure 78. Components of microgrids

Microgrids are defined as small-scale energy networks that can operate separately or in collaboration with the grid and have their own energy sources, generation, and loads with certain constrictions. Microgrids provide energy supply in off-grid areas through on-site generation, and they provide benefits such as lowering transmission losses, improving service quality by detecting faults instantly, utilizing resources efficiently through management control, commissioning more domestic resources, and having a more durable and dynamic network.

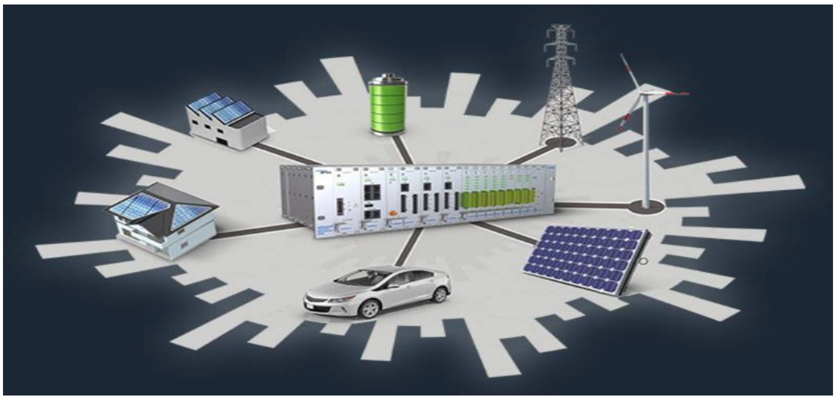


Figure 79. Microgrids

Microgrids System components related to microgrids are as follows:

- Renewable Energy Systems
- Energy Storage Systems
- Measurement and Control Systems
- Mains Connection Systems
- Power Converter Systems
- Battery Management Systems
- Intelligent Lighting Systems
- Electric Vehicle Charging Systems
- Smart Home/Building Systems
- SCADA/EMS/DMS
- Energy Management Systems
- Communication and Information Security Systems
- Generators [145]

13.4 Smart Meters And Mbus Technology

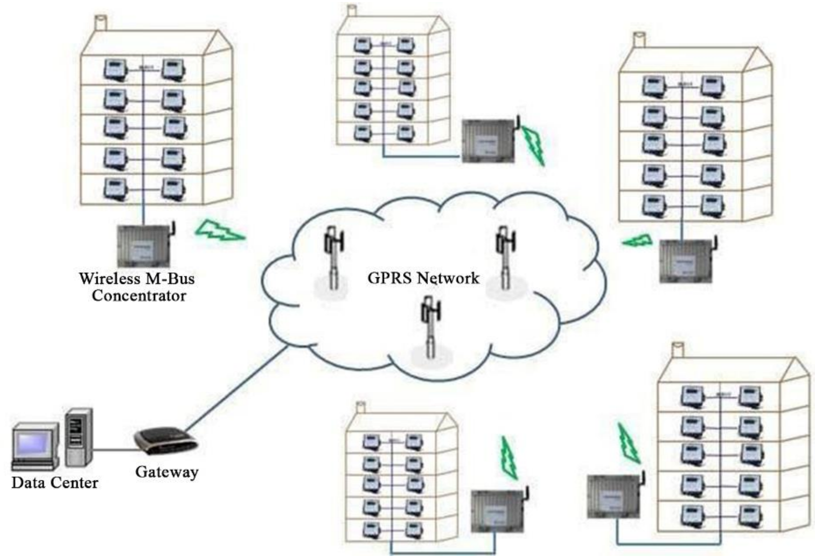


Figure 80. MBUS Meter Reading System

Meters that measure energy consumption should be read remotely to maximize the effectiveness of energy systems. Meters are not only read but also remotely managed in this technique.

Apart from the hydroelectric power stations that provide energy, irrigation operations are also conducted out on farmland. Technical decisions about irrigation, such as what the farmers should cultivate and how much water to use, should be made and organized by professional teams. MBUS meters with prepaid card readers could be used to charge the system. The farmer can perform the irrigation operation at the counter utilizing mobile phone applications. It is prevented from going over the limits that have been set for it by this system. As a result, farmers are treated with respect and energy resources are properly used. The automated system also saves on meter reading and budget needs.

In residential areas with central heating systems, MBUS meters are also utilized in the invoicing procedures. Each flat is required to respond more to the system the more usage it obtains.

Business advantages of Automatic Meter Reading (OSO) systems:

- Increased billing accuracy,
- Reduced revenue collection cycle,
- Better load management,
- Increased billing accuracy,
- On/off remote meter,
- Increased customer reliance,
- Increased customer reliance,
- It is defined as creating new revenue streams through additional services such as internet connection, home security, and automation. [146-147].

13.5 Remote Wireless Smart Management Lora

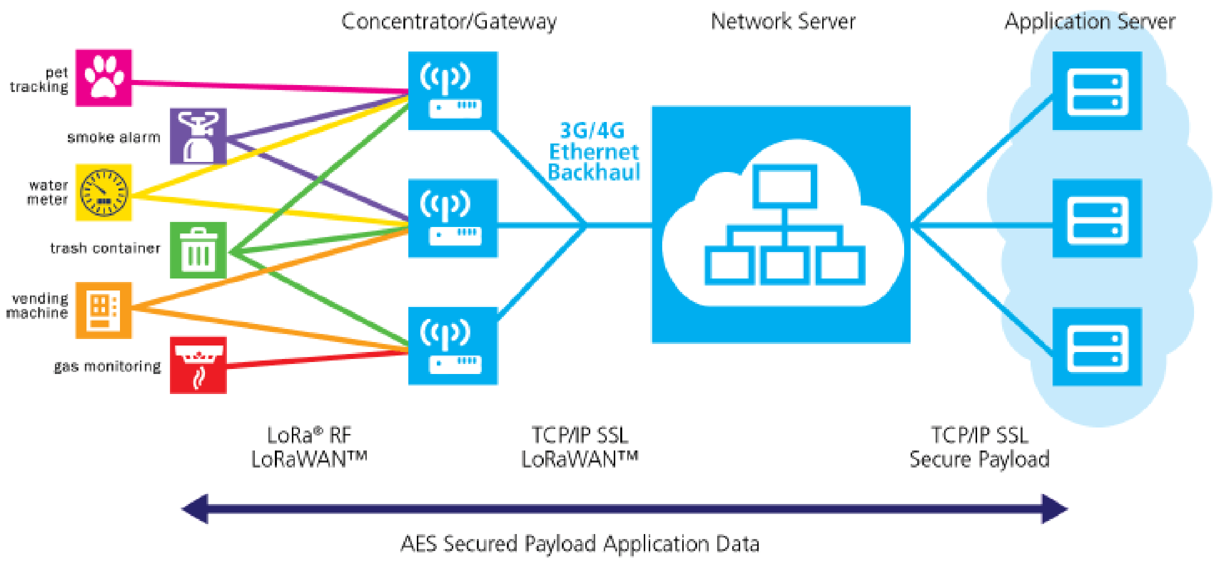


Figure 81. Wireless LoRa Network Management System

Devices in smart energy management must be remotely operated. With the aid of wires, communication with the devices is not always probable. When transportation is challenging or the infrastructure is unsuited for cable, wireless communication features are used. The LoRa wireless communication network is one of the techniques used to Access the machine by accessing the data on the device, particularly in the case where the distance is significant.

LoRa-WAN; It uses unlicensed radio frequency bands such as 433 MHz, 868 MHz (Europe), 915 MHz (Australia and North America), 865 MHz - 867 MHz (India) and 923 MHz (Asia). [148]

Communication may be given over vast distances since it employs extremely narrow band, little data packets. As an illustration, this distance, which is impacted by geographic factors, can be up to 10-15 kilometres. In our nation, the State Hydraulic Works maintains the infrastructure of irrigation systems using this system (DSI). It works well for managing and remotely monitoring meters.

13.6 Internet of Things IoT Technology

The number of devices that can connect to the web is constantly growing as a result of the rise of the internet and technology. There is still disagreement over the precise concept of the Internet of Things, as well as other definitions that have been presented. The Internet of Things, however, can be regarded as everything that can be connected to the Internet in its most basic form [149].

Kevin Ashton invented the term "Internet of Things" in 1999 to define the supply chain using RFID (Radio-Frequency Identification) [150].

Figure 82. Internet of Things

Many systems and gadgets in homes and offices can be handled through internet infrastructures using Internet of Things (IOT). An internet-based application can be used to immediately turn on and off a gadget that is plugged into a smart socket at home. This management approach has now been implemented by many white goods models. This provides an excellent degree of comfort and energy savings.

13.7 Energy Savings and Efficiency

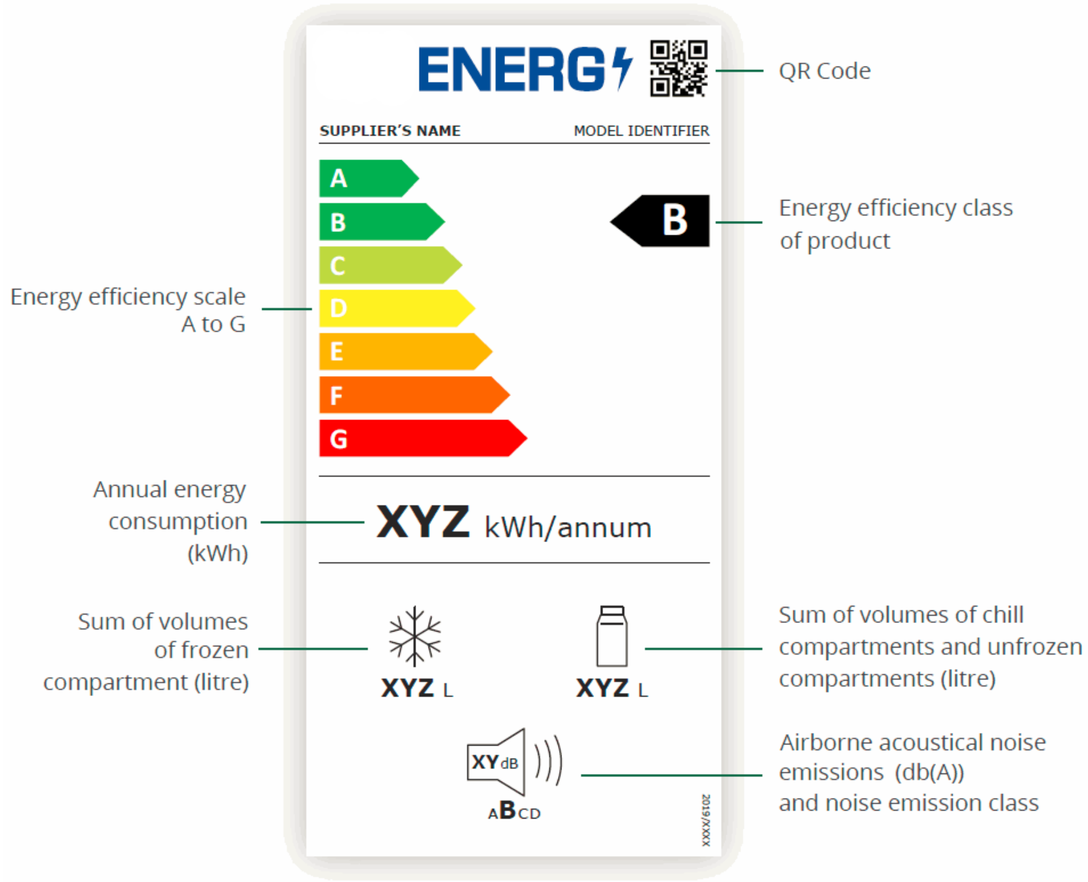


Figure 83. Efficiency Table

Effectiveness, which is crucial for energy generation, is vital for energy use as well. It is well recognized that when energy production costs rise, so do the requirements for energy-consuming equipment. While a product made with new technology costs more to buy than a product made with old technology, a product with low lengthy energy usage can pay for itself through lower long-term electricity costs. In this scenario, the ecosystem will sustain less harm while still earning a profit.

13.8 Industry 4.0

The Chinese government, which mostly relies on coal for its electrical energy needs, is no longer capable of supplying the need. Limited in its ability to adequately meet its energy needs, China needs to strive to serve as the global production hub. The supply-demand balance is upset as it can fulfil demand. Presently, Industry 4.0 is being used by other states that wish to build solutions to get over restrictions.

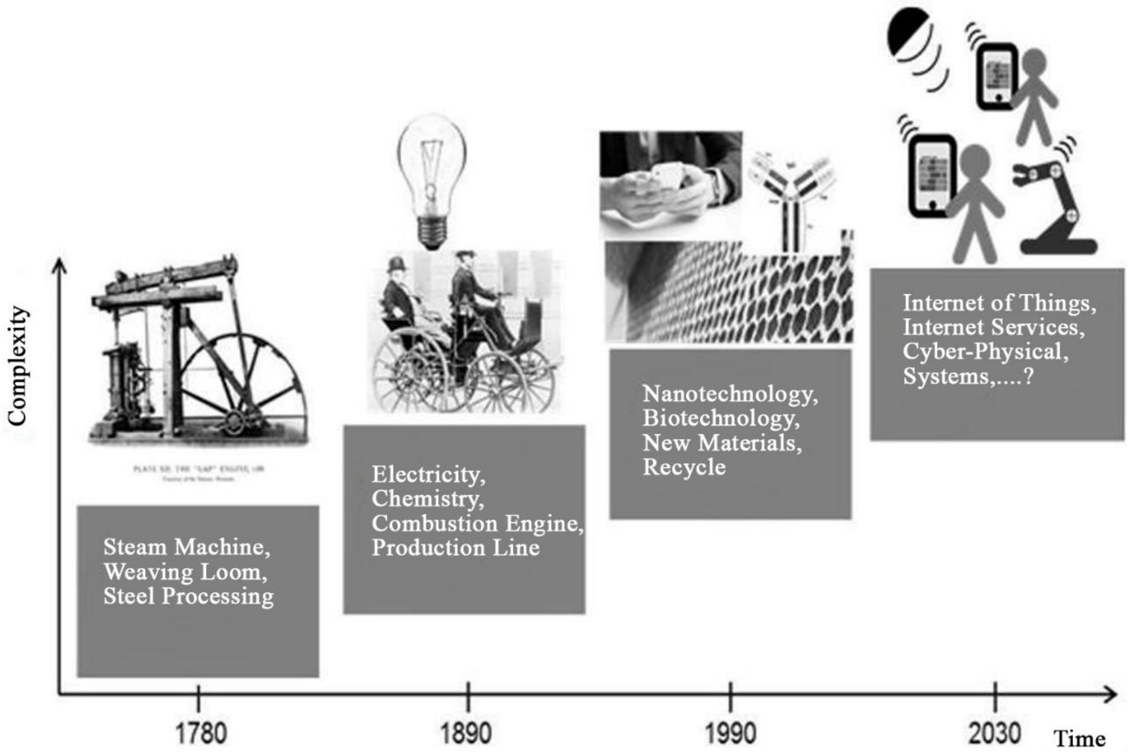


Figure 84. Chronology of Industrial Revolutions

The idea behind Industry 4.0, commonly referred to as the fourth industrial revolution, is to build intelligent factories employing virtual and physical technologies. Self-configuring, self-monitoring, and self-healing production environments are made possible by Industry 4.0 and are managed by dynamically controlled intelligent systems. Industry 4.0, therefore, enables previously unseen levels of operational efficiency and accelerates the speed of productivity growth. [151]

Industry 4.0 is anticipated to have an impact in a few areas. You could arrange them in this order:

- As machine control improves, human labor will take a backseat.
- The current workforce will decline.
- The repercussions of the change in position or the steady diminution of the human factor would be noticed in socioeconomic life.
- Businesses who upgrade their production in accordance with the new procedure will be in a stronger place than the competition and have the possibility to stand out in the industry.
- Some businesses that influence international trade do not yet display a resolve to

enter Industry 4.0.

- Developing the personnel's skills and knowledge may require some time to transition to the last industrial revolution's revolutionary technologies quickly and accurately.

14. THE STATUS OF SOLAR ENERGY IN PARTNER COUNTRIES

14.1 Solar Potential Atlas of Türkiye

Turkish solar energy is capable of spreading more rapidly than other renewable energy sources due to its high capacity, practicality, renewability, and environmental friendliness. Nonetheless, some challenges in this regard must be addressed. Some of the technical and financial challenges include solar energy's high implementation costs as compared to other energy sources, as well as its relatively low efficiency and capacity factor. Solar power generation will soon become much more appealing once these issues are resolved. Turkey has a favourable geographic location for solar energy, however, it now falls short of maximizing its potential. This is a problem that impacts our nation seriously [152].

Studies on the utilization of solar energy picked up steam, notably after the 1970s. Solar energy systems have demonstrated a decline in technological advancement and cost, and they have established themselves as a clean energy source. The significance of solar energy is increased by the fact that it is a clean energy source and operates at a low cost once established.

- Due to its geographic location, our nation has tremendous potential for solar energy. The average annual total sunshine duration is 2741.07 hours, and the average annual total radiation value is computed as 1527.46 kWh/m2, per the Turkish Solar Energy Potential Atlas (GEPA) created by the Ministry of Energy.

Solar Model:

The "ESRI Solar Radiation Model" employed in the Geographic Information System and the following fundamental factors were used to create the Turkey Solar Model.

- A horizontally constructed 500m x 500m Digital Elevation Model (DEM) was produced from a 1/100,000 scale topographic map of Turkey for slope-aspect-shading calculations.
- Latitude values in Turkey between 36 and 42 degrees
- Zenith and azimuth angles in 32 directions; Sky Size Index;
- Methods for Calculating the Open and Closed Sky
- The 22-year hourly solar measurement values for the years 1985–2006 were measured at the EIE and DMI stations to compute the parameters to be utilized in the model and to calibrate the model.
- Sky Aperture and Sky Light Transmission Coefficient (Transmittivity) (Diffuse Proportion)
- Values of Earth's Sun Ray Reflection (Surface Albedo)

- The following data was obtained as a 500m x 500m grid map as a consequence of utilizing the model, and it includes monthly averages derived from daily values over 12 months.
- Solar Radiation overall (kwh/m2-day)
- Solar Radiation Direct (kWh/m2/day)
- Solar Radiation, diffuse (kwh/m2/day)

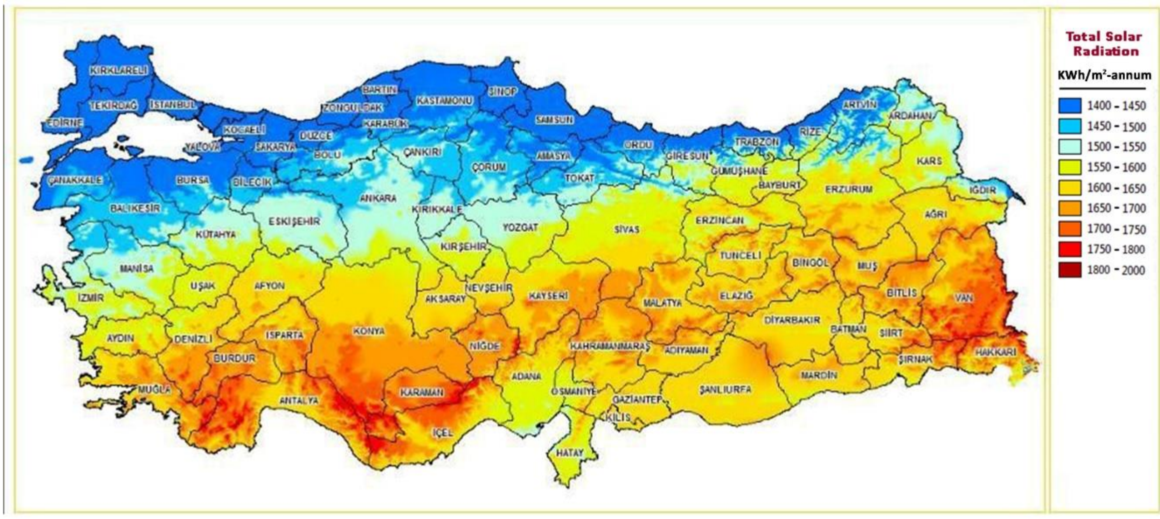


Figure 85. Total Solar Radiation of Turkey

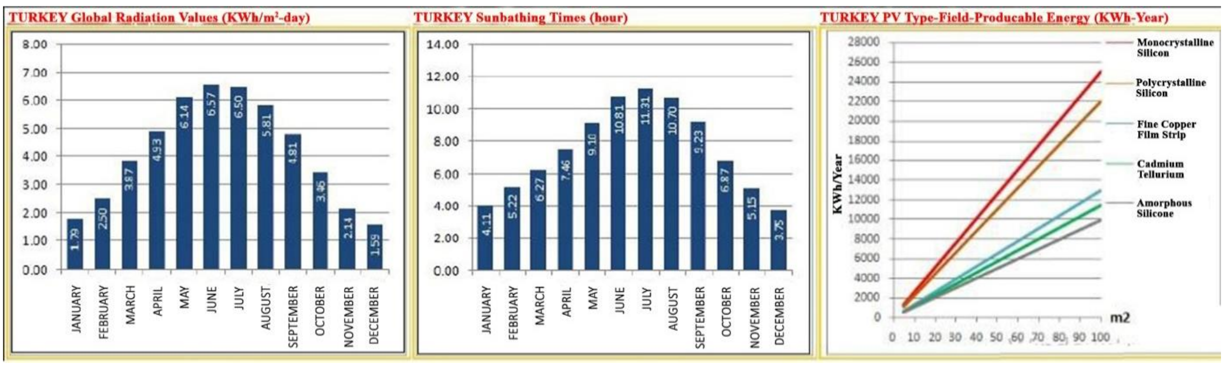


Figure 86. Turkey's Global Radiation Value - Sunbathing Times - Energy That Can Be Produced According to PV Type

The charts below show the change in installed power by year and its proportion to total electricity generation as of the end of December 2020. Turkey's installed power based on solar energy is 6,667 MW, and its share in total electricity production is 3.6 percent.

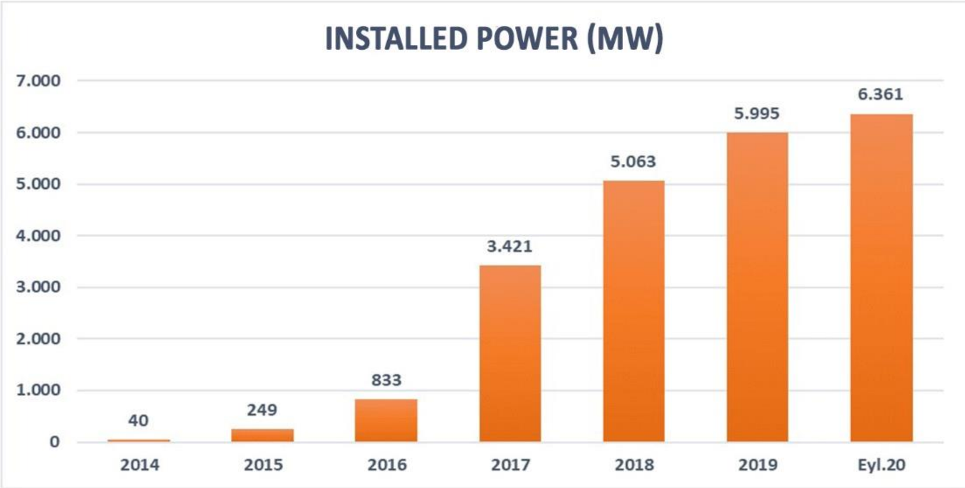


Figure 87. Total Installed Capacity of Turkey

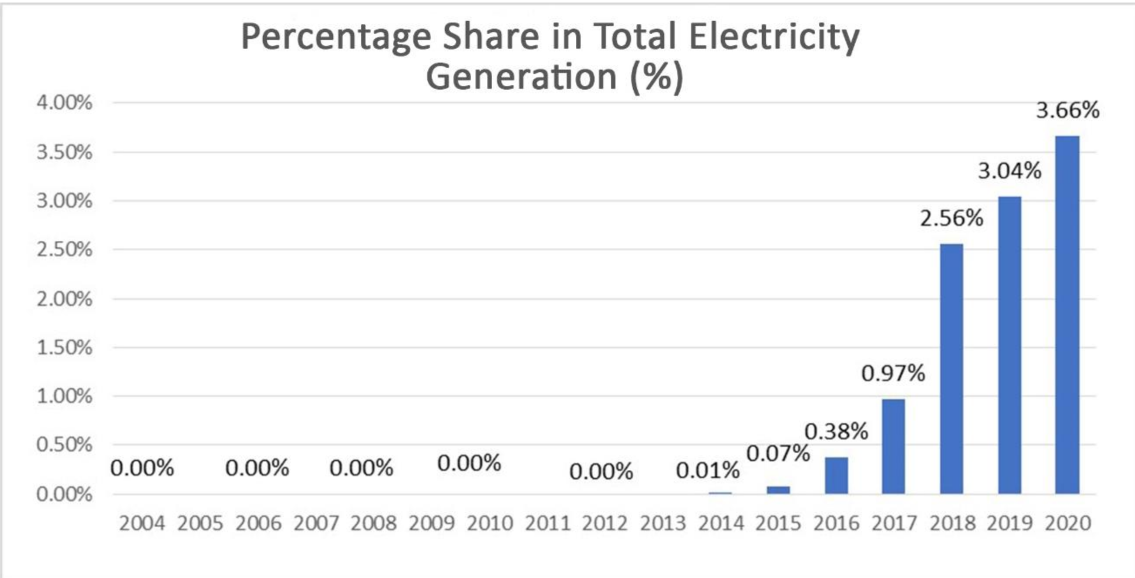


Figure 88. Percentage Share of Solar Energy in Total Electricity Production in Turkey

14.1.1 Roof and Facade Applied Solar Potential

The maximal installed power of generation facilities based on renewable energy sources that can run without a license was raised from 1 MW to 5 MW in May 2019 with the Presidential Decision. Within the boundaries of the decision, the idea that production and consumption are measured at the same location and that installed power is restricted to the power of the connecting agreement of the consumption facility is approved. The retail one-time active energy cost of its own subscriber group, as announced by EMRA, will be applied for the excess electricity produced in the electricity generation facilities based on renewable energy such as solar energy sources with roof and facade application, formed with the decision, for ten years from the date of operation of the facility [153].

The Turkish Statistical Institute (TUIK) states that there are 9.1 million buildings in Turkey, with residential structures making up roughly 87 percent of this total. Turkey's construction stock is enhanced by more than 100,000 building developments per year. In the next ten years, solar module systems with a cumulative capacity of 2,000–4,000 MW can be erected on the roofs and facades of these structures. The roof areas in our country that can be assessed can be categorized on the basis.

Figure 89. Roof Areas That Can Be Evaluated for Solar Power Plant Installation

It is not probable to meet the energy needs of industry, residences, or individuals directly from the sun, as plants do. As a direct consequence, solar energy can be converted in a range of methods. Countless technologies have been developed to exploit the sun's rays. While solar energy technologies diverge considerably in terms of method, material, and technological level, some of them straightforwardly use solar energy in the form of light or heat energy, while others use solar energy to generate electricity.

Direct or indirect electricity generation, hot water generation, space heating and cooling, process heat energy for industrial enterprises and greenhouse heating are just numerous small applications for solar energy. Below is information regarding roof submissions made to the Ministry of Energy as of January 1, 2021.

Table 16. Number of Roof Applied SPP Applications [154]

ROOF APPLIED SES APPLICATIONS			
SUBSCRIBER TYPE	PERIOD	INSTALLED PÖWER (MW)	QTY
INDUSTRY	10/05/2019 ÖNCESİ	670,52	2429
	10/05/2019 SONRASI	2868,90	4355
	TOPLAM	3539,42	6784
DOMICILE	10/05/2019 ÖNCESİ	10,07	1090
	10/05/2019 SONRASI	14,00	1410
	TOPLAM	24,07	2500
THE OVERALL TOTAL		3563,49	9284

With the publication of Law No. 6094 on the Amendment of the Law on the Use of Renewable Energy Resources for the Purpose of Electricity Generation, assigned 27809 in the Official Gazette on January 8, 2011, incentives were tightly controlled to give incentives to renewable energy resources based on the source type and locality rate. The specifications of the Renewable Energy Resources Support Mechanism have been ascertained in this framework by the regulation prepared by EPDK.

The "Regulation on Certification and Support of Renewable Energy Resources" became effective when it was published in the Official Gazette with the number 28782 and the date January 10, 2013. The principles governing the allotment of Renewable Energy Source Certificates to holders of generation licensing requirements as well as the creation and operation of the YEK Support Mechanism (YEKDEM) have been governed by the Regulation in an attempt to promote the output of electrical energy from renewable sources.

The table illustrates licensed YEKDEM participants by year, and both the installed energy and participation numbers are still expanding. Within the scope of YEKDEM in 2020, there are 821 licensed power stations with a combined installed power of 21,146.1 MW.

Table 17. Number of Licensed YEKDEM Power Plants by Years (Number)

Type	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Sun	-	-	-	-	-	-	2	3	9	17

Hydraulic	4	44	14	40	126	388	418	447	463	463
Wind	9	22	3	21	60	106	141	151	160	165
Biomass	3	8	15	23	34	42	57	70	100	126
Geothermal	4	4	6	9	14	20	29	37	45	50
The overall total	20	78	38	93	234	556	647	708	777	821

In dividing up YEKDEM's installed power by resource type, hydraulic power plants account for a large portion (12,434.7 MW), while wind power plants come in second (6,440 MW).

Furthermore, from now to the end of 2020, 6,420,80 MW of the installed power of 6,823.47 MW, with the exception of natural gas, is traded within the context of YEKDEM's unlicensed electricity generation.

While the installed power within the scope of YEKDEM, including non-licensed power plants, was 22.92 percent of the overall installed power in Turkey in 2019, it fell to 22.07 percent in 2020.

Figure 90 below shows the distribution of YEKDEM installed capacity in 2020 by resource.

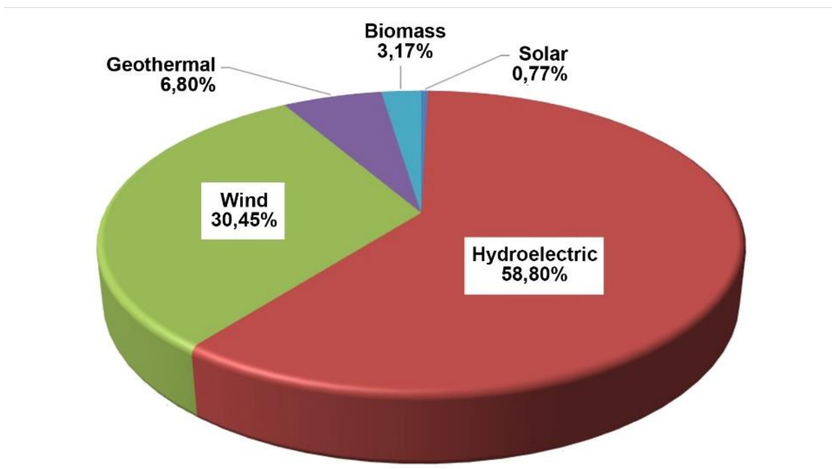


Figure 90. Distribution of 2020 YEKDEM Installed Capacity by Resources (%)

Table 18 illustrates the growth of YEKDEM participant production throughout time. YEKDEM production in 2020 dropped by almost 4.16 percent when unlicensed power plants were considered and reached to 73.48TWh.

Table 18 illustrates the evolution of YEKDEM participant production throughout time**.**

Type	2013	2014	2015	2016	2017	2018	2019	2020
Sun	-	-	-	-	24.269	39.140	159.961	375.476
Non-licensed	884	29.316	223.537	1.134.023	2.997.551	8.078.418	9.830.849	11.229.723
Hydraulic	528.427	1.072.832	5.651.215	16.212.717	17.213.394	27.369.727	36.961.886	29.671.021
Wind	223.243	2.378.819	8.275.992	14.163.402	16.765.418	19.002.863	19.900.973	20.658.797
Geothermal	857.527	1.436.579	2.710.856	3.706.764	4.503.345	5.968.202	6.997.209	7.816.509
Biomass	750.715	957.223	1.082.913	10.613.594	8.992.792	2.047.082	2.817.209	3.730.699
The overall total	2.360.795	5.874.769	17.944.514	45.830.502	50.496.769	62.505.431	76.668.087	73.482.227

Figure 91 illustrates the production distribution by resource type within the YEKDEM area of influence in 2020. Wind and hydraulic power generated the most output, correspondingly.

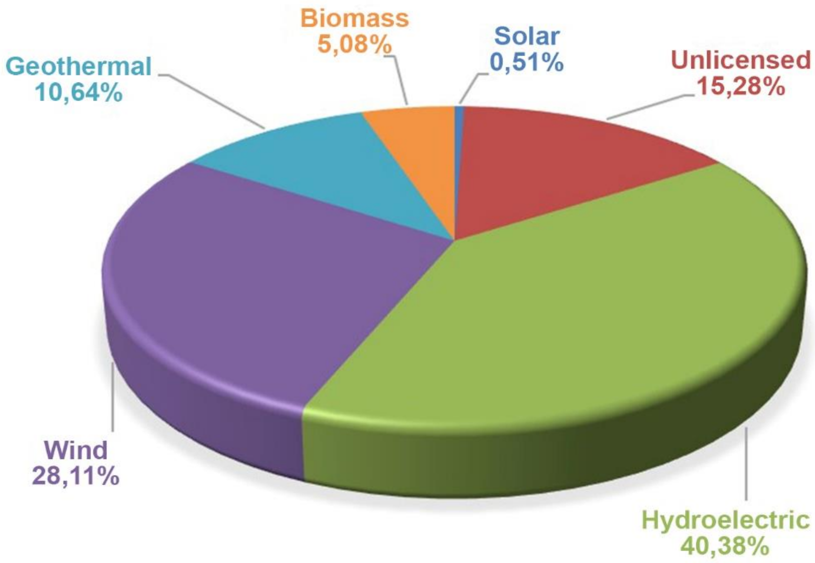


Figure 91. Distribution of YEKDEM Production in 2020 by Resources (%)

While the percentage of electricity produced by power plants operating under the YEKDEM to the nation's overall electricity generation was 25.21 percent in 2019, it was 24.07 percent in 2020.

When we look at the monthly progression of YEKDEM production in 2020, we can see that there is a correlation between the quantity of rainfall in the spring months and an increase in hydraulic production, which in turn leads to higher YEKDEM production. On the one hand, throughout the year, production from other sources was more constant [155].

14.2 Solar Energy Systems in Greece

The installation of solar thermal collectors has started in the early 1980's while in the decade 2010 – 2020 the development of newly installed thermal SES capacity followed a slightly increasing trend. In 2020, Greece ranked 5th in the world and 2nd in Europe, with an installed capacity in operation of approximately 3493 MWth, corresponding to 4.989.550 m^2 area of collectors [156].

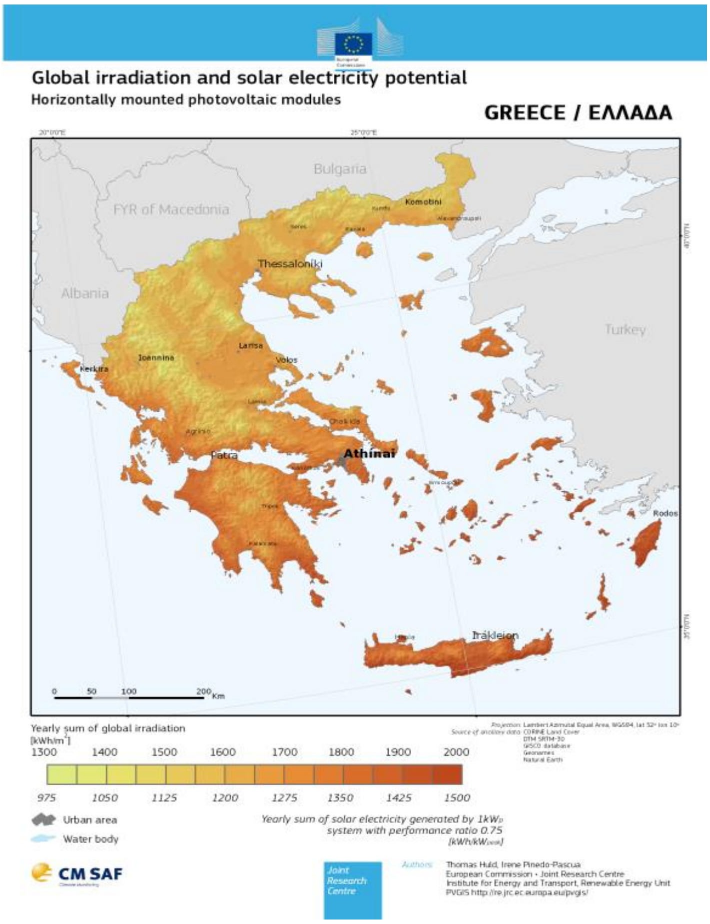


Figure 92. Global Solar Energy Potential of Greece

Since 2019 a significant increase in PV investements has been observed regarding PV SES, due to the Greek Energy Market transformation that is paving towards higher RES shares in electricity production until 2030 and due to regulative support through e.g. less strict environmental licensing procedures. As a result, in 2021 there was an over 4000 MWp photovoltaic installed capacity, with an average energy yield around 1500 kWh/kW and around 1300 kWh/kW for PV on Roofs . In the same year, PV installations were linked to approximately 8850 jobs whereas PVs contributed 9,6% to the total annual electricity production of the country slightly more as compared to the contribution in the year 2020 [157].

14.3 Potential Use of Solar Energy Systems in the UK

April 2020 and May 2020 are specified as the dates when the sun has proven to be a valuable source of energy in the UK. April 2020 solar power produced a new all-time high of 9.68 GW, while May 2020 solar provided 11% of all electricity in the UK [158]. The United Kingdom is geographically not considered one of the sunniest countries in Europe. It also has many natural sources of energy such as wind, hydro and geothermal, but solar continues to grow, playing an important role in the UK's power generation.

Solar energy use in the UK is divided into 3 markets:

• Large-Scale - Ground Mounted "solar power plants" (>5000 K/W system),

• Commercial Rooftop (12.5 KW - 250 kW),

• Residential Roof (3 kW – 12,5).

Large-scale solar farms have seen an increase of 75% in the last 3 years, reaching 345 solar farms with a total of >5000KW. A good example of large-scale solar power is the 310-acre Chapel Lane Solar Farm, which costs 55 million euros. It has an energy production of 51.3 MW and provides electricity to 60,000 households. This demonstrates the potential of solar farms to power towns and small cities. The UK government has recently reported that there are 269 current applications for new large-scale developments [159]. This shows that existing solar farms are financially stable.

Commercial Rooftop Solar (12 KW – 250KW) installations are spread over 250,000 hectares. This ratio is quite a small amount compared to the other two markets. Arguments suggest that commercial businesses are interested in making a 20 – 25-year commitment and that the initial payment might be better spent on other business resources.

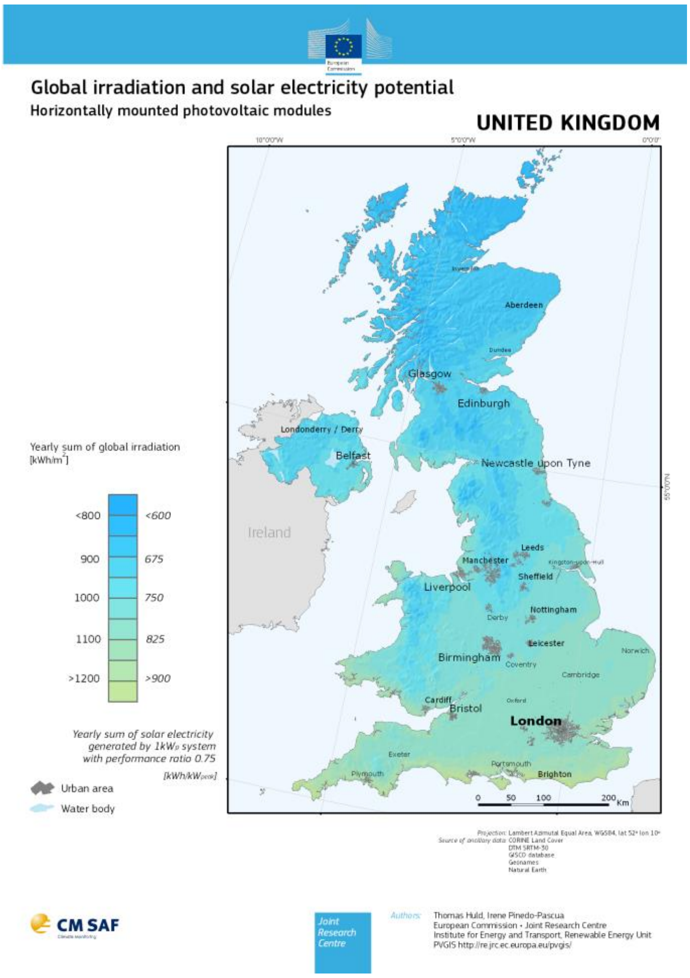


Figure 93. Solar Potential in the UK

In the UK, Domestic Solar Energy generates over 14,000 MW, supplying electricity to more than 1 million households. This is equivalent to almost 12% [160] of domestic use in the UK. It ranks third among all European countries. In fact, this area has good potential for growth. Previously the UK governments' Renewable Energy Liability Certificates scheme helped drive the solar market, but residential solar saw a setback when it was withdrawn in 2018. This has been identified by the government and a plan has recently been developed with the Smart Export Guarantee [161]. This was accompanied by a reduction in the cost of solar panels, and new buyers flooded the market, bringing the local solar rate to 17%.

The growth forecast for solar in the UK is quite large, with panel costs predicted to fall in the future and new technologies such as solar tiles and windows.

14.4 Status of Solar Energy Systems in France

France has recently reached a new peak of over 10.7 GW of solar-generated electricity. This ratio is equivalent to the amount that 10 nuclear power plants can produce on average. It is stated that 26% of France's electricity is obtained from solar energy. France has greatly increased its solar capacity, especially in the past year. By the end of the third quarter of 2021, France's electricity grid operator Enedis had connected more than 40,000 solar panels to the grid, more than in all of 2020.

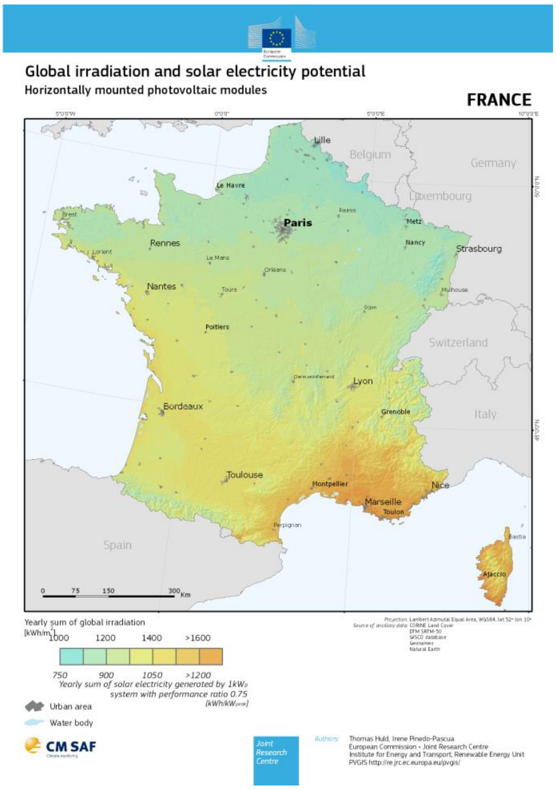


Figure 94. Solar Energy Potential in France

It has increased the number of solar panels connected in France to over 500,000, providing a total potential output of 11GW. This amount is sufficient to supply electricity to 2.9 million households. Installations include ground-mounted or floating solar power plants.

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Funded by
the European Union