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DESIGN AND SIMULATION OF A ROOFTOP PHOTOVOLTAIC SYSTEM IN TURKISH STANDARDS INSTITUTION

M. Sc. Thesis by

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ANKARA

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April, 2022 **Tuğba ARDIÇ ÇAKMAK**

DESIGN AND SIMULATION OF A ROOFTOP PHOTOVOLTAIC SYSTEM IN TURKISH STANDARDS INSTITUTION

ABSTRACT

In this study, by using the PV*SOL software, an off-grid rooftop PV system was designed for the Turkish Standards Institution building and it was analyzed how much of the energy that the system would produce could meet the real annual electricity consumption of TSE. The location of the institute was marked on the map in the software, and the temperature and radiation values of the region were taken. 3D design of the institute building was made and determined the areas where the PV modules will be placed. Domestic PV modules certified according to TS EN IEC 61215-2, TS EN IEC 61730-1 and TS EN IEC 61730-2 standards were selected. After calculating the minimum distances required so that these selected PV modules do not shade each other, the modules are placed on the roof. Inverters and batteries are selected according to the configuration automatically created by the software. After completing the design, the maximum possible PV energy of the system was calculated by subtracting losses such as configuration, inverter and radiation losses from the total global PV radiation. Finally, it has been calculated how much of the electricity consumption can be met from this system.

According to the simulation results, designed system can produce 70283 kWh of electrical energy annually. The performance ratio of the system was calculated as 73.1 percent and the specific annual efficiency was calculated as 1112 kWp/kWh. The electrical energy produced by the designed system can meet approximately 30 percent of the annual real electricity consumption of the institute.

Keywords: Photovoltaic, solar energy, renewable energy, off-grid photovoltaic systems

TÜRK STANDARDLARI ENSTİTÜSÜ BİNASINDA BİR ÇATIÜSTÜ FOTOVOLTAİK SİSTEM TASARIMI VE SİMÜLASYONU

ÖZ

Bu çalışmada PV*SOL yazılımı kullanılarak Türk Standartları Enstitüsü binasına şebekeden bağımsız bir çatı üstü FV sistem tasarlanarak sistemin üreteceği enerjinin enstitünün gerçek yıllık elektrik tüketiminin ne kadarını karşılayabileceği analiz edilmiştir. Enstitünün bulunuğu konum yazılımdaki harita üzerine işaretlenerek bölgenin sıcaklık ve ışıma değerleri alınmıştır. Enstitü binasının 3 boyutlu tasarımı yapılarak fotovoltaik modüllerin yerleştirileceği alanlar belirlenmiştir. Daha sonra TS EN IEC 61730-1, TS EN IEC 61730-2 ve TS EN IEC 61215-2 standartlarına göre belgelendirilmiş olan yerli FV modüller seçilmiştir. Seçilen bu FV modüllerin birbirini gölgelememesi için gerekli minimum mesafeler hesaplandıktan sonra modüller çatıya yerleştirilmiştir. Yazılımın otomatik oluşturduğu konfigürasyona göre eviriciler ve bataryalar seçilmiştir. Tasarımı bitirdikten sonra sistemin mümkün olan maksimum FV enerjisi, toplam küresel FV radyasyonundan konfigürasyon, evirici ve ışınım kayıpları gibi kayıplar çıkarılarak hesaplanmıştır. Son olarak elektrik tüketiminin ne kadarının bu sistemden karşılanabileceği hesaplanmıştır.

Analiz sonucuna göre tasarlanan sistem yıllık 70283 kWh elektrik enerjisi üretebilecektir. Sistemin performans oranı yüzde 73.1, spesifik yıllık verimi 1112 kWp/kWh olarak hesaplanmıştır. Tasarlanan sistemin ürettiği elektrik enerjisi, enstitünün yıllık gerçek elektrik tüketiminin yaklaşık yüzde 30'unu karşılayabilmektedir.

Anahtar Kelimeler: Fotovoltaik, güneş enerjisi, yenilenebilir enerji, şebekeden bağımsız fotovoltaik sistemler

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NOMENCLATURE

Roman Letter Symbols

b	Module mount width
d	Row spacing
d_1	Mounting support clearance
E_{PVuse}	Solar energy generated (AC side) - inverter power consumption
E_{in}	Energy irradiated to the PV array surface
h	Mount height
FF	Fill factor
G	Total solar irradiation
I_{mp}	Current at the maximum power point
I_{sc}	Short circuit current
$I_{SC}(Lab)$	Measured maximum I_{SC} of each module in the stabilized state
$I_{SC}(NP)$	Maximum rated nameplate I_{SC} of each module
m_1	Measurement uncertainty in % of laboratory for P_{max}
m_2	Measurement uncertainty in % of laboratory for V_{OC}
m_3	Measurement uncertainty in % of laboratory for I_{SC}
P_{max}	Maximum power
$P_{max}(Lab)$	Measured maximum STC power of each module in the stabilized state
$P_{max}(NP)$	Maximum rated nameplate power of each module without tolerances
$P_{max}(Lab_Gate\#1)$	Module's initial measured output power
$P_{max}(Lab_Gate\#2)$	Maximum power output drop of each module
P_{nom}	Installed PV array output
t_1	Manufacturer's rated lower production tolerance in % for P_{max}
t_2	Manufacturer's rated upper production tolerance in % for V_{OC}
t_3	Manufacturer's rated upper production tolerance in % for I_{SC}
V_{MP}	Voltage at the maximum power point
V_{OC}	Open circuit voltage
$V_{OC}(Lab)$	Measured maximum V_{OC} of each module in the stabilized state
$V_{OC}(NP)$	Maximum rated nameplate V_{OC} of each module

Greek Letter Symbols

η	Efficiency
r	Reproducibility
γ_m	Safety factor
Ω	Ohm
β	Module inclination
β1	Roof angle
ɣ	Solar elevation angle

Subscripts

stc	Standard test conditions
d	Diode
max	Maximum
out	Output
oc	Open circuit
sc	Short circuit
ph	Photovoltaic

Acronyms

AC	Alternating current
AM	Air mass
AR	Anti reflective
c-si	Crystalline silicon
DC	Direct current
GW	Gigawatt
GWh	Gigawatt-hours
EIA	Energy Information Administration
IEA	International Energy Agency
IEC	International Electrotechnical Commission
kWp	Kilowatt-peak
LCOE	Levelized cost of energy
MENR	Republic of Turkey Ministry of Energy and Natural Resources
MPPT	Maximum power point tracking
MQT	Module quality test
MST	Module safety test
MW	Megawatt

MWh	Megawatt-hours
NMOT	Nominal module operating temperature
p-si	Polycrystalline silicon
PERC	Passivated emitter rear cell
PR	Performance ratio
PV	Photovoltaic
SAY	Specific annual yield
SEM	Solar energy map
SPP	Solar power plant
STC	Standard test conditions
TEIAS	Turkish Electricity Transmission Company
TSE	Turkish Standards Institution
TSKB	Industrial Development Bank of Turkey
TWh	Terawatt-hours
YEKDEM	Turkish Renewable Energy Resources Support Mechanism

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CHAPTER 1

INTRODUCTION

1.1 Installed Capacity Analysis

The total installed power of Turkey is increasing depending on the population, needs, economic and technological developments. With the increase in incentives given to power plants that generate electricity from renewable energy sources and domestic sources in recent years, a significant increase in Turkey's total installed power continues. Turkey's installed power by years is given in Figure 1.1. As seen on Figure 1.1 Turkey's total installed power, which was around 39 GW in 2005, reached 99.8 GW and the total number of power plants reached 10457 at the end of 2021 [1].

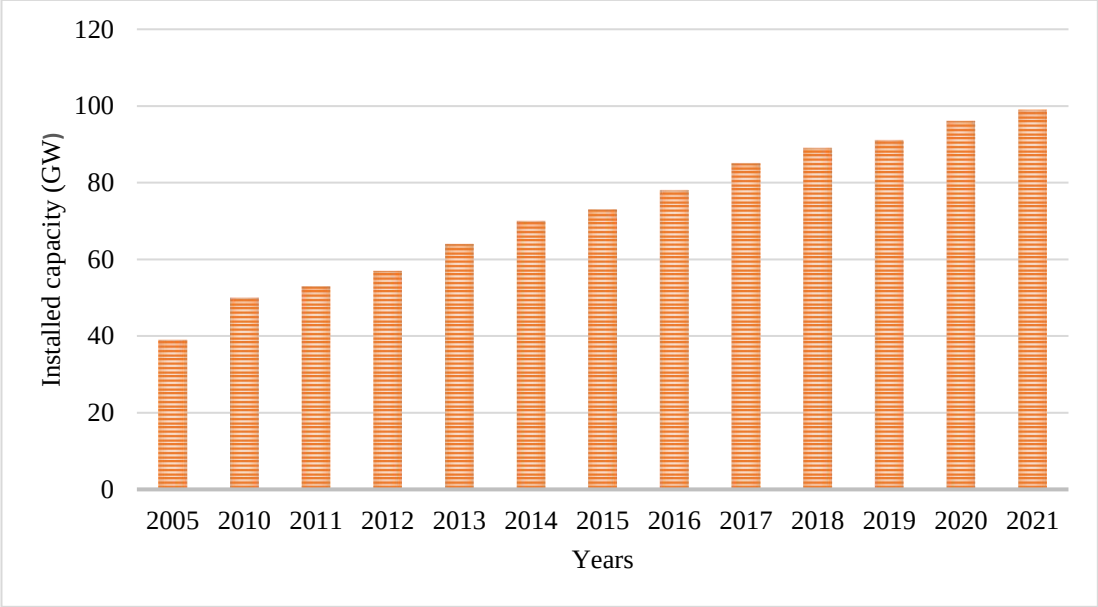


Figure 1.1 Turkey installed power by years

When we analyze the data of 2021 the largest share in the installed power was natural gas power plants with 25.5 GW, followed hydro with a dam with 23.2 GW. Wind power plants with an installed power of 10.6 GW were followed by lignite power plants with 10.1 GW and imported coal power plants with 8.9 MW. These are followed by solar power plants with 7.8 GW [1]. Compared to the previous year 3.9 GW

installed power increased. The installed power increased by 1.7 GW in wind power plants, 1.1 GW in solar power plants and 0.5 GW in hydroelectric power plants. In this period, the total installed power of the power plants that generate electricity using natural gas and fuel oil decreased. Turkey's installed capacity by source at the end of the 2021 is given in Figure 1.2.

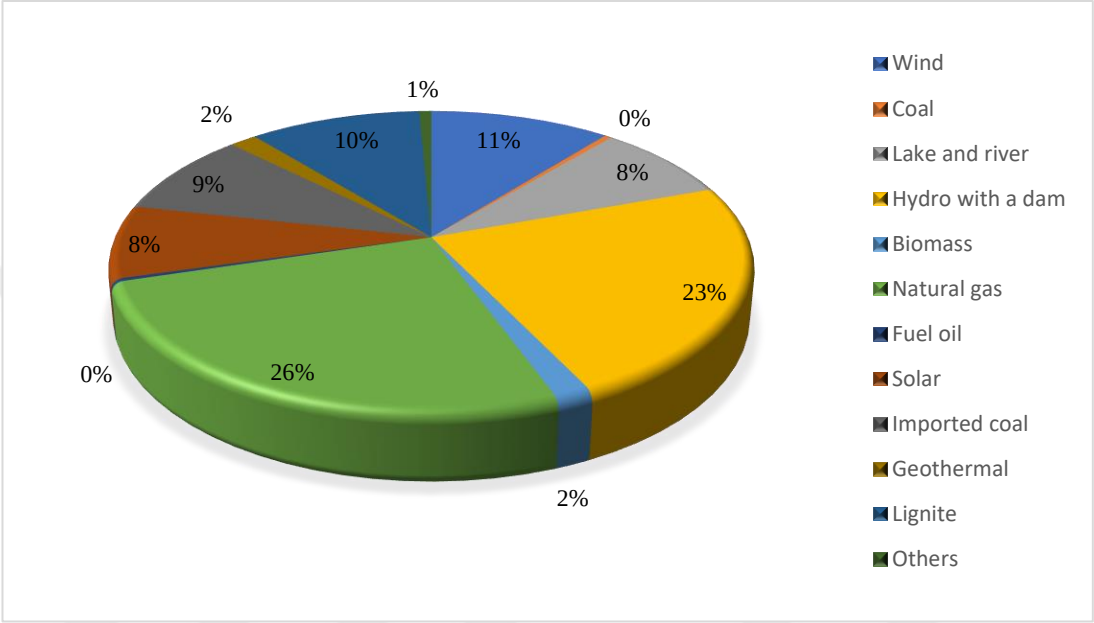


Figure 1.2 Installed capacity shares in Turkey by source (2021)

Since 2005, the share of renewable energy sources in the total installed power has increased. The share of power plants generating electricity from renewable energy sources, which was 33% in 2005, increased to 53.7% in 2021. It is considered that Turkish Renewable Energy Resources Support Mechanism (YEKDEM), a support mechanism that emerged to support renewable energy production in order to reduce fossil fuel energy production in our country in the short term and to finish it in the long term, played a decisive role in this rise. Turkey's installed capacity growth and share of renewables are given in Figure 1.3. As can be seen in the figure, especially the wind and solar power plants gained great momentum. But considering the gross potential, the existing installed power is insufficient.

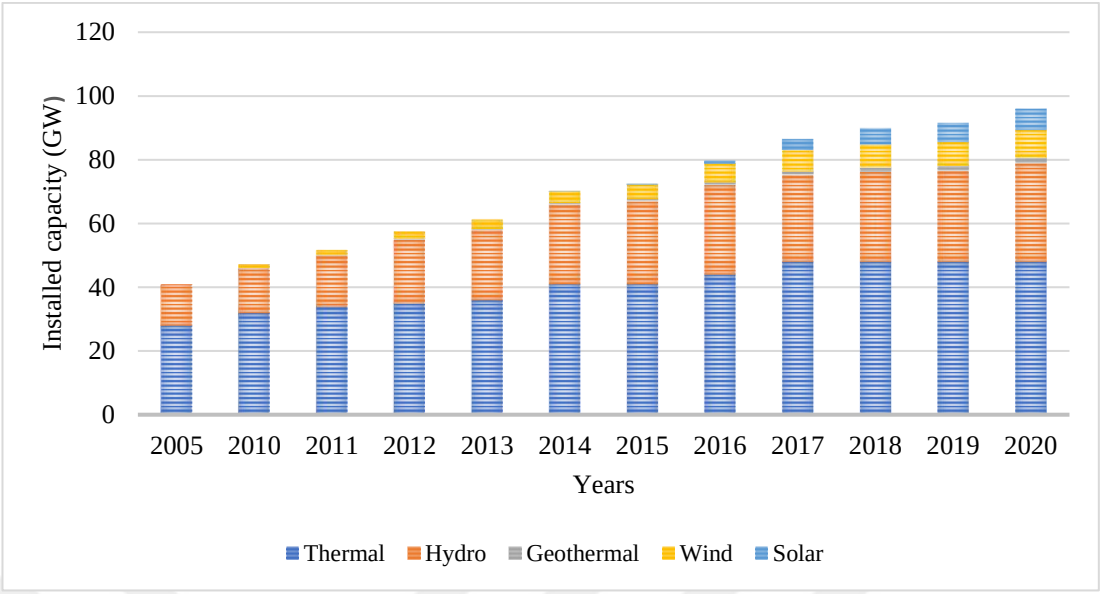


Figure 1.3 Installed capacity growth in Turkey and share of renewables

1.2 Electricity Production Analysis

Although our country is not a very rich country in terms of fossil fuels and is in a very good geographical location in terms of renewable energy potential, the level of renewable energy production is low. When the data for 2021 is analysed approximately 51% of electricity production is obtained from natural gas and coal. This difference can be reduced by eliminating deficiencies in legal regulations and reducing costs. Turkey's energy demand is increasing steadily. Demand for electricity and natural gas has nearly tripled in the last 20 years. Turkey's energy demand has increased due to both the increasing population and the factors brought about by economic growth. Although it changes according to years, Turkey is a country dependent on foreign sources for primary energy by 70%. Considering these two issues, on the one hand, sustainable solutions should be produced in order to meet the increasing demand permanently, and on the other hand, this foreign dependency should be reduced.

Figure 1.4 shows Turkey's gross electricity production by years. Various investments have been made in order to meet the electricity demand and electricity production has increased (Increased except for 2001, 2009 and 2019. It decreased 1.8% in 2001, 0.2% in 2009 and 2019).

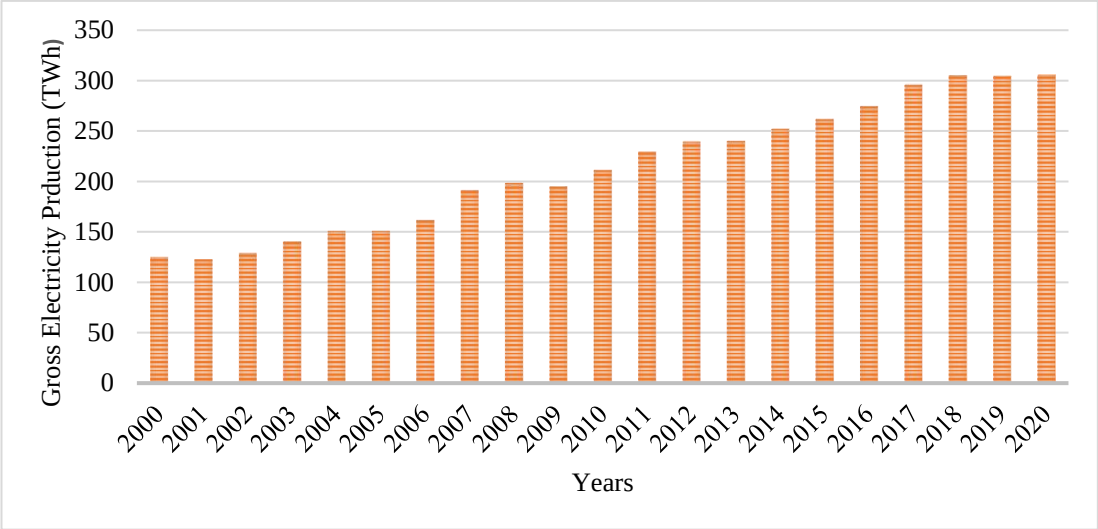


Figure 1.4 Gross electricity production in Turkey according to years

With the COVID-19 virus turning into a global epidemic in the world at the beginning of 2020, global measures have been taken, due to partial or full-time curfews, electrical energy consumption has shifted from places such as industry, business and educational institutions to homes, supermarkets and hospitals [2]. Electricity demand decreased in the March-June period, however, there was also a decrease in Turkey's gross electricity production. Gross electricity generation, which decreased by 0.6% in March compared to the same period of the previous year, decreased by 14.6% in April and 16.5% in May annually. Electricity production and consumption, which fell in March, April and May, started to rise as of July. At the end of 2020, it reached the level of 305 TWh [3]. Figure 1.5 shows monthly electricity generation of Turkey compared with previous year.

While the gross electricity production in our country decreased due to the Covid-19 pandemic, it is seen that the share of electricity produced from renewable energy sources increased to 41.8% in total, according to the end of 2020 data [4]. For this reason, it can be said that the power plants that produce electricity from renewable energy sources maintain their status and even strengthen it during the Covid-19 pandemic. According to electrical energy generation by sources in 2020, Turkey’s electricity production was sourced 25.5% by hydro, 22.6 % by natural gas and 20.3% by imported coal and 20.3% by imported coal [4].

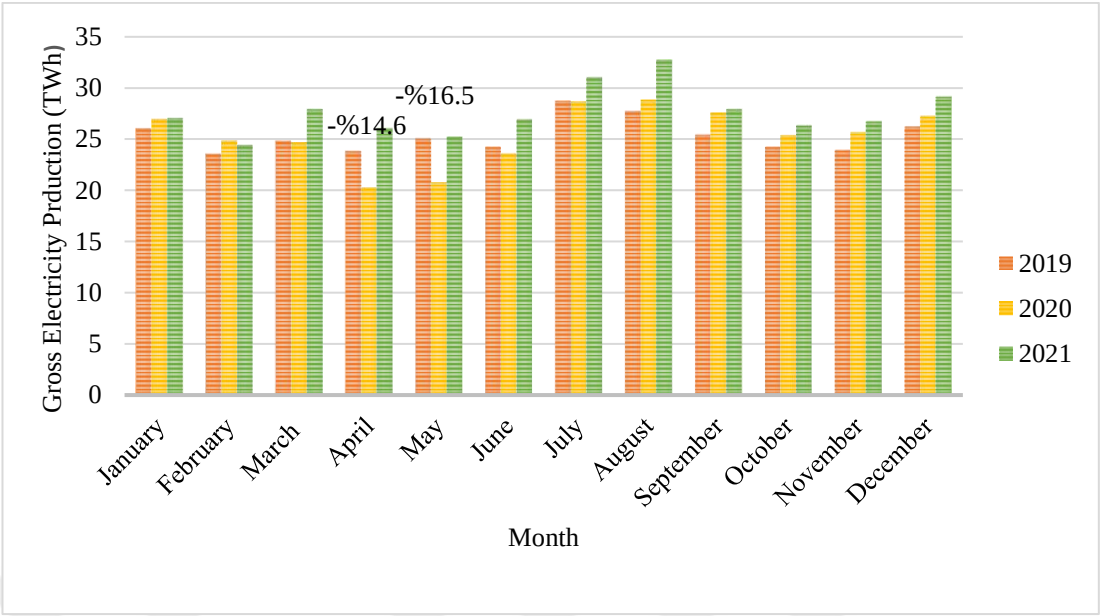


Figure 1.5 Monthly electricity generation of Turkey compared with previous years

After the Covid-19 pandemic, which also affected Turkey in 2020, 2021 has come to the fore as the year of growth. Considering the data for 2021, there was an increase of 7.5% compared to 2020 and 329.6 TWh in production was reached [5]. While 31% of the total gross electricity production during the year was provided by imported and domestic coal power plants, 33% was obtained from natural gas power plants. Figure 1.6 shows Gross electricity generation in Turkey by primary energy source in 2021.

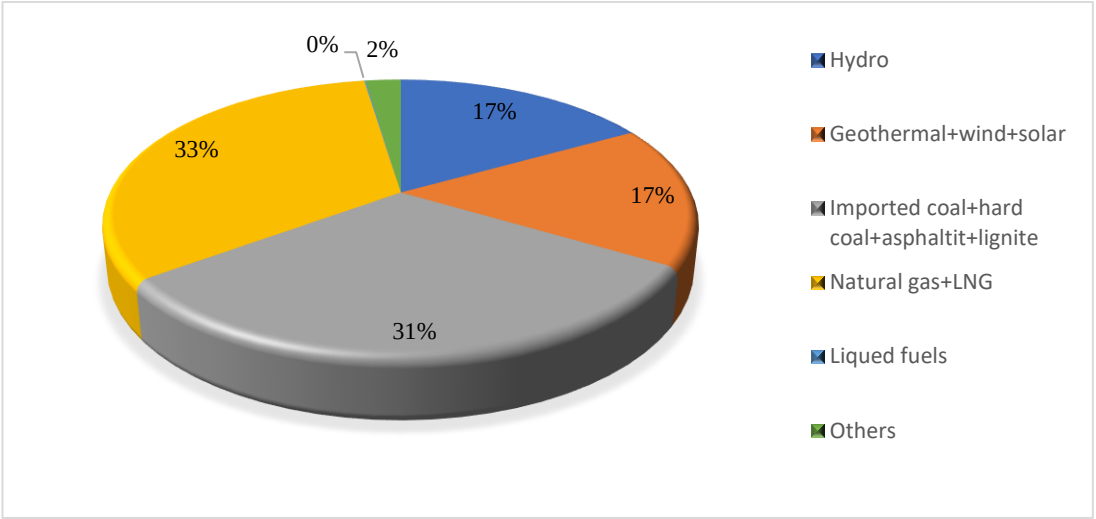


Figure 1.6 Gross electricity generation in Turkey by primary energy source in 2021(%)

1.3 Growth of Photovoltaic

Today, as people become more aware of the importance of the environment and turn to more environmentally friendly energy sources, the demand for renewable energy sources has increased significantly. When current data is analyzed, it is predicted that renewable energy will have a share of 62% in total electricity generation by 2050 [6]. Figure 1.7 shows the electricity demand and the share of different sources in the near and far future. The circle represents the total electrical energy demand, the shares represent the ratio of different energy sources, and the orange colored part represents solar energy. It is predicted that solar energy will gradually increase its share in 2025, 2050 and 2075 and in 2100, more than half of the electricity demand will be met from solar energy.

The share of renewable energy, especially electricity generated from wind and solar power plants, in the total energy supply is gradually increasing. The main factors in this situation are the environmental friendliness of these power plants, the decrease in production costs and the increase in the compatibility of these types of power plants with the electricity grid thanks to new technologies.

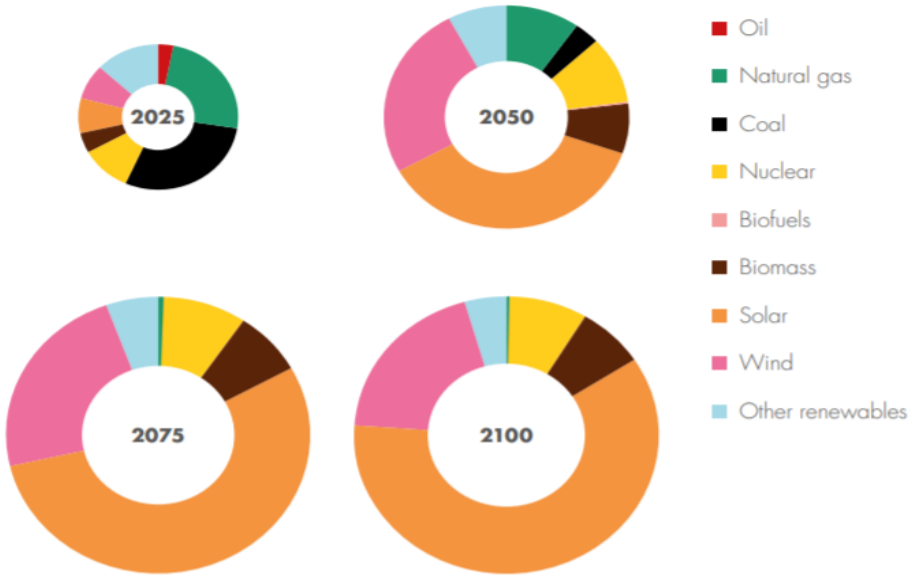


Figure 1.7 Electricity demand and share of different resources in the near and far future [7]

With the widespread use of solar and wind-based power plants, the levelized cost of energy (LCOE) of these technologies is decreasing. The levelized cost of energy (LCOE), a measurement used to evaluate and compare different methods of energy production, is calculated by dividing the average total cost of building and operating a system by the total amount of electricity produced. According to the latest Levelized Cost of Electricity (LCOE) calculations from US investment bank Lazard Capital, large-scale solar power plants (GES) cost less than new combined cycle gas turbines, coal and nuclear power plants. Figure 1.8 shows levelized cost of energy of solar PV. As seen in Figure 1.8, the LCOE of solar PV in 2021 has reached the range of 30-41 $/MWh. For comparison, the LCOE cost of natural gas, which is the cheapest fossil fuel resource, remains in the range of $45-74/MWh.

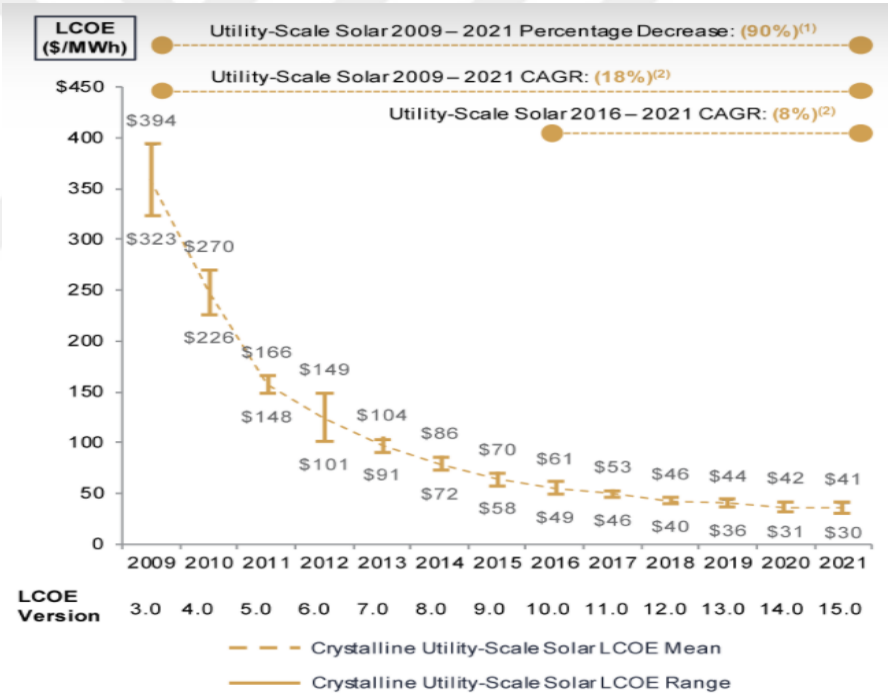


Figure 1.8 Levelized cost of energy of solar PV [8]

Although Turkey has a very good solar energy potential due to its geographical location, solar energy has been used mostly in solar thermal collector systems, which are used for the production of hot water from the sun. In terms of energy production, photovoltaic system technology had a negligible share in our country until the last ten

years. However, as in all countries of the world, electricity generation from the sun has been tried to be widespread with some government supports and incentives in our country. In this way, an increase in the installed photovoltaic power has been achieved in recent years. This increase is very promising in line with the country's targets. Figure 1.9 shows PV installed capacity and PV yearly production between 2014 and 2021 years. In our country, which started to produce electricity from solar PV in 2014, 13876.5 GWh of electricity was produced according to the data of December 2021, and the share of solar energy in the total electricity generated was 4.19%. The installed capacity of solar PV increased by 15% compared to the previous year and reached 7746 MW, its share in the total installed power was 7.8% [9]**.** This increase in our country, which started to benefit from the solar energy very late, has been very rapid compared to previous years and the solar energy has significantly increased both its share in electricity produced from renewable energy and its share in total electricity production.

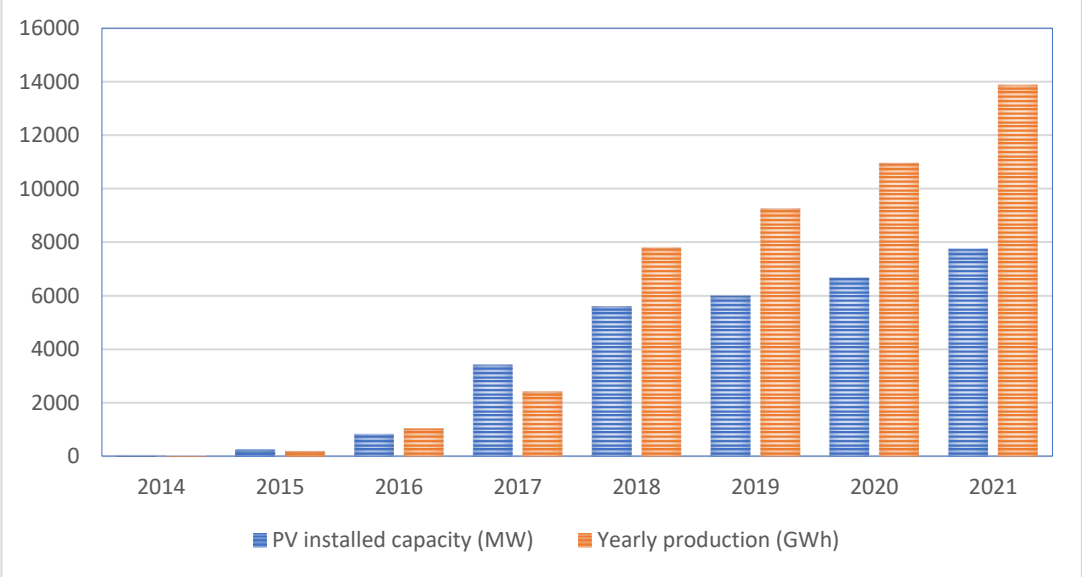


Figure 1.9 PV installed capacity and PV yearly production of Turkey

Turkey, which has a high solar energy potential, has a total annual insolation time of 2741.07 hours (corresponding to 7.5 hours per day) and a total ayearly solar energy of 1527.46 kWh/m² (corresponding to 4.18 kWh/m² per day) according to the solar

energy potential atlas prepared by the Ministry of Energy and Natural Resources [10]. Figure 1.10 shows Turkey's monthly average solar potential.

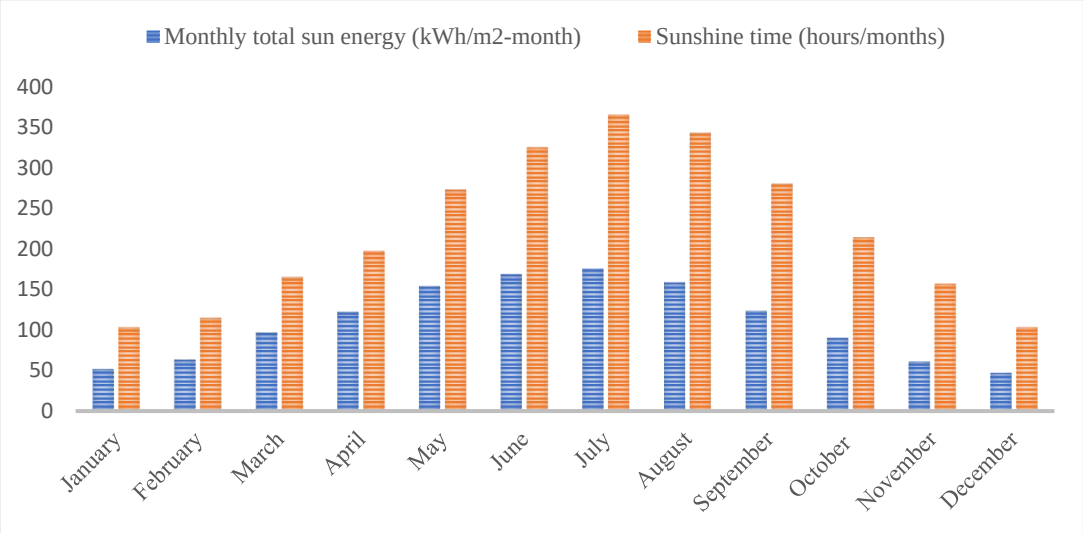


Figure 1.10 Turkey's monthly average solar potential

Figure 1.11 shows distribution of PV power potential in Turkey. The daily PV power potential varies between 3 kWh/kWp to 4.8 kWh/kWp in our country. If we look at the distribution of solar energy potential in geographical regions in Turkey, we see that they are listed as Southeastern Anatolia, Mediterranean, Eastern Anatolia and Central Anatolia in order. Investments in PV systems in these areas are more efficient and PV systems in these areas can repay their energy investment faster than other regions.

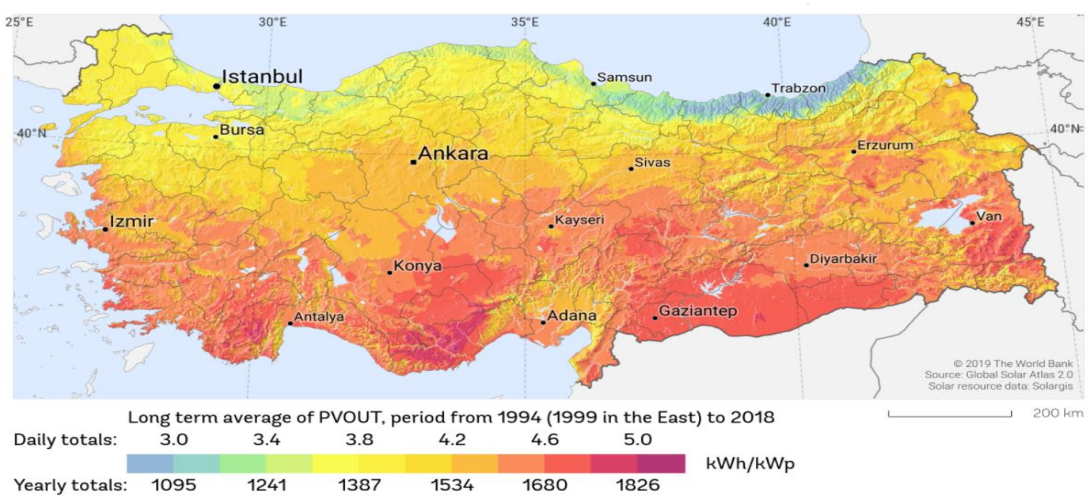


Figure 1.11 Distribution of PV power potential in Turkey [11]

CHAPTER 2

PV SYSTEM COMPONENTS

PV systems can be grouped into three general categories. These categories are off-grid PV systems, on grid/grid-connected PV systems, and hybrid PV systems. In off-grid PV systems or in other words stand-alone PV systems, the electrical energy produced by photovoltaic modules is stored in batteries and this stored energy can be used when needed (for example, at night). These systems are generally used where access to mains electricity is difficult/costly. Figure 2.1 shows schematic representation of an off-grid PV system.

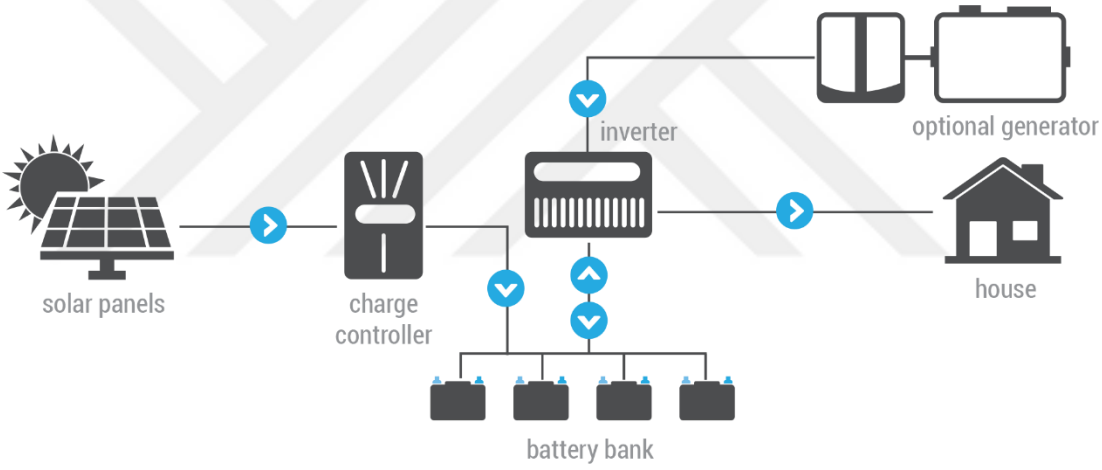


Figure 2.1 Schematic representation of an off-grid PV system

In grid-connected PV systems, also known as on-grid PV systems, the energy consumption of the user is met from the energy produced by the PV system. If the user's production is more than its consumption, the excess energy can be fed to the grid, if the user's consumption is more than its production, it takes the excess energy from the grid, and the amount of energy received and given is determined with the help of a bidirectional counter. Figure 2.2 shows schematic representation of a grid-connected PV system.

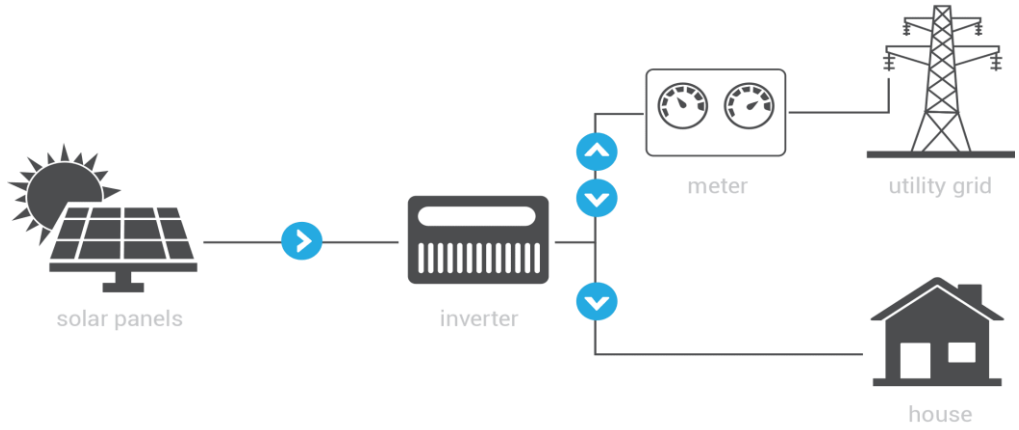


Figure 2.2 Schematic representation of a grid-connected PV system

The third type of system is hybrid PV systems. The term hybrid is used in two senses. The first one is that there is an additional source such as wind or biogas in addition to the PV system. The second one is the use of systems that are both connected to the electricity grid and include battery storage.

2.1 Photovoltaic Module

Photovoltaic modules, which are obtained by combining solar cells in a certain order (serial / parallel), are the most basic component of a solar power plant. These modules are named according to the cell type that creates them, for example, if a PV module is obtained using PERC monocrystalline silicon solar cells, the type of this module will be the PERC monocrystalline silicon PV module, if a PV module is obtained using thin-film solar cells, this module is called a thin-film PV module. It is placed in the field according to the manufacturer's recommendation in a series/parallel configuration. PV module components are detailed below.

2.1.1 PV Module Components

We can say that PV modules basically consist of 6 components. These components are solar cell, encapsulant, backing, junction box and frame. They are obtained by combining solar cells placed in a certain order and other materials, placing them in the lamination oven and heating them, and then mounting the junction box and frame. The

detailed production process is mentioned in clause 2.2.2 and the components of a typical c-Si PV module are shown in Figure 2.3.

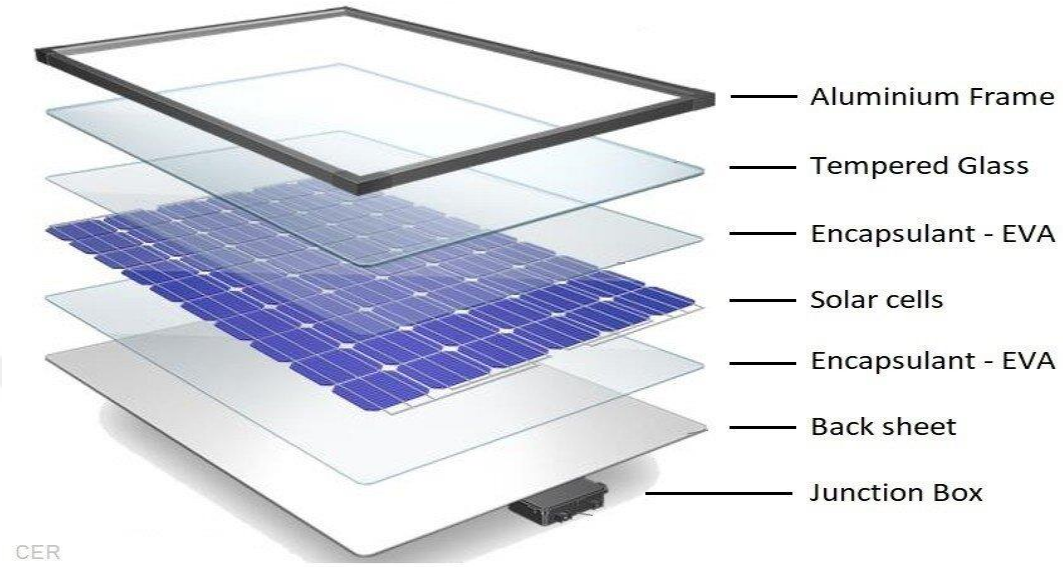


Figure 2.3 The components of a typical c-Si PV module

2.1.1.1 Solar Cell

The solar cell consists of the combination of two different doped silicon layers called n-type and p-type. P-type material wants to gain electrons and n-type material wants to donate electrons. The photovoltaic effect consists of 3 steps, first one is generation of charge carriers, second one is separation of the photo-generated charge carriers and third one is collection of the photo-generated charge carriers. Figure 2.4 shows these processes. When the photon from sunlight strikes on the PV cell, the photon is absorbed, resulting in an electron-hole pair. This event is shown as number 1 in 2.4. The energy of the photon is converted into the chemical energy of the electron-hole pair. Then the electron-hole pair will recombine and this event is shown as number 2 in Figure 2.4. E-field between the junction acts like semipermable membranes and separates this carriers, electrons move to the n-side and holes to the p-side (number 3 in Figure 2.4). By connecting two sides of the solar cell through a load seperated electrons occur an external electrical circuit (number 4 in Figure 2.4) After these processes electrones recombine with holes like shown in number 5 in Figure 2.4.

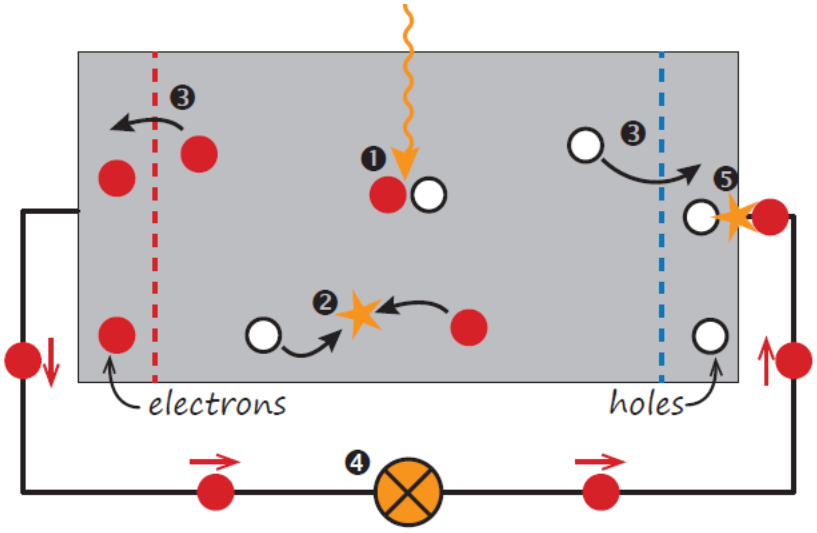


Figure 2.4 Simple solar cell model [12]

2.1.1.2 Backsheet

The backsheet placed under the PV module not only provides electrical isolation, but also prevents moisture from entering the module. It is available in various versions for higher protection and strength in different thickness, color and material combination. Different thickness backsheets should be selected according to the maximum system voltage value of the PV module. These thicknesses are specified in the TS EN IEC 61730-1 standard and are controlled by test teams. Table 2.1 shows the required thicknesses of backsheet.

Table 2.1 Backsheet thickness according to maximum system voltage

	< 35 V	**100 V**	**150 V**	**300 V**	**600 V**	**1000 V**	**1500 V**
Thickness of backsheet (mm)	0.01	0.01	0.01	0.01	0.06	0.15	0.3

2.1.1.3 Encapsulant

Encapsulant is the material that allows all layers to adhere to each other under a certain temperature and vacuum, by placing one layer above and below the solar cells in photovoltaic panels. This material, which is in solid form under normal conditions, melts and turns into a gel structure when it enters the lamination oven.

2.1.1.4 Frame

After the photovoltaic module is laminate in the form of a sandwich, the metallic frame is assembled. The frame both ensures the mechanical integrity of the module and takes part in the assembly of the module in the field through the holes on it. In addition, a special tape is placed between the frame and the laminated part to ensure sealing. Figure 2.6 shows a PV module frame.



Figure 2.5 PV module frame

2.1.1.5 Junction Box

The electrical terminations used in PV modules can be divided into 3 subcomponents as junction boxes, cables and connectors. There are bypass diodes inside the junction boxes that do not allow the power flow to go in one direction and prevent the panels from overheating in case of shadowing. In addition, the electrical connection of the PV modules is made through the cables connected to the junction boxes and the connectors at the ends of the cables. The standard used for certification of junction boxes is “IEC 62790: Junction boxes for photovoltaic modules - safety requirements and tests”. Figure 2.7 shows a PV module junction box.



Figure 2.6 Junction box

2.1.1.6 Solar Glass

One of the important components of PV modules is solar glass. It not only protects the cells in the PV module against external factors, but also directly affects the efficiency of the solar panels with its high light transmittance since the iron oxide ratio is low. Light reflections can be minimized with its patterned structure and special anti-reflective (AR) coating.

2.1.1.7 Ribbon

Ribbon is a tinned copper conductor used to make the electrical connections of the cells in the PV module. The ribbons used by soldering on the cells carry the current produced in the PV module to the junction box.

2.1.2 Production Process of Crystalline Silicon PV Module

Thanks to the developing technology, PV modules are now produced in automatic PV module production lines. Firstly solar cells are tested and grouped before entering the production line. If there is a defective solar cell, it is removed. Ribbons are soldered onto the busbars of the solar cells. Strings are formed by soldering the ribbons to the rear contact point of another solar cell. Different configurations can be created by connecting solar cells in series and/or parallel, and thus different output powers can be obtained. Solar cell matrixes are obtained by combining strings.

The pre-cleaned solar glass is sent to the production line and a layer of encapsulant and the formed solar cell matrices are laid on it. Another layer of encapsulant is laid on the cells. The backsheet layer, which is used to provide the electrical insulation of the PV module and to protect it against impacts, is laid on the encapsulant. This structure, which is brought into a sandwich form, is checked by making current, voltage and power measurements before entering the lamination oven. This check is important because if an error occurs after lamination it is irreversible. In the lamination oven, the encapsulant melts at a certain temperature and time and turns into a gel form. Thus, the materials used stick together. Silicone or double-sided tape is attached to the edge of the modules coming out of the oven and the frame is mounted. Then, the junction box containing the bypass diodes, cables and connectors is mounted behind the PV module with the frame. Finally, the current, voltage and power of the PV module are measured under standard test conditions, in addition, insulation and ground continuity tests are performed for electrical safety purposes. Labels with the obtained data are printed and pasted on the module. A PV module production line is shown in Figure 2.7.

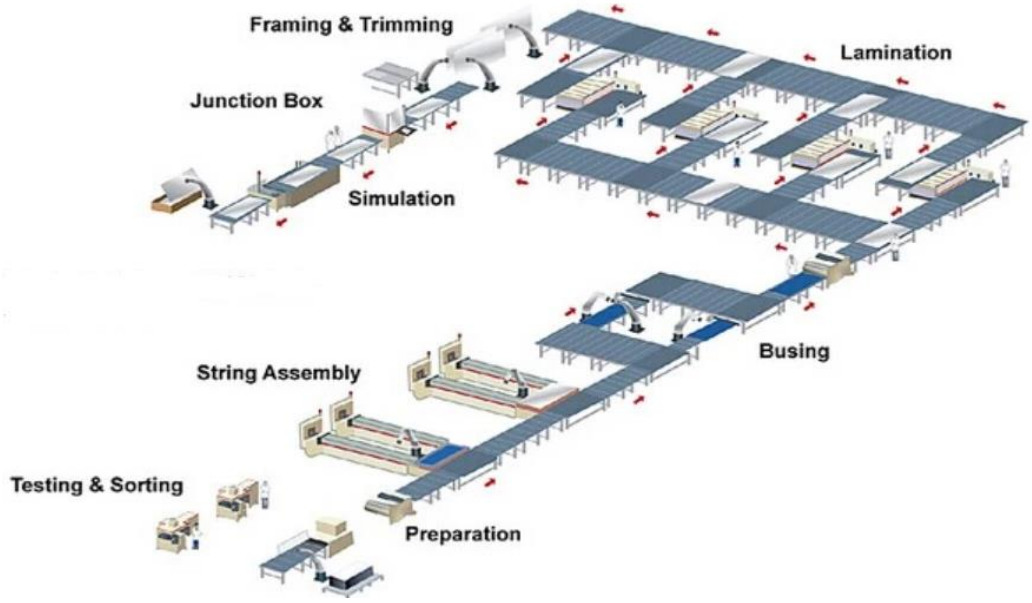


Figure 2.7 PV module production line

2.2 Mounting Rack

The structure of a solar power plant consists of many important components that help secure the PV modules and provide protection from the climatic conditions. One of them is mounting structure/ mounting rack. Solar power plants can be installed on many different grounds. Ground structure of the power plant area, ground water level, soil resistance and soil strength conditions are considered as important criteria in site selection. The structures used to place PV modules of different weights on these different floors are called mounting structures and appropriate mounting structures should be selected by making the necessary static calculations. After this selection, it should be determined how the structures will be assembled. Here, regardless of the type of construction of the solar power plant; it has to comply with "TS 498-Design Loads for Buildings" and "TS 500-Requirements for design and construction of reinforced concrete structures" standards. Figure 2.8 shows mounting racks.



Figure 2.8 Mounting racks

2.3 Inverter

Solar inverters, also known as power converters, are power electronics circuits that convert the DC current produced by photovoltaic modules into AC current. Inverters enable PV modules to operate at maximum power depending on radiation and temperature through MPPT (maximum power point tracking) [13]. With the

developing technology, new generation inverters can not only perform AC/DC conversion, but also perform tasks such as power optimization, monitoring and security, communication and temperature management. There are varieties such as string inverter, central inverter, micro inverter.

2.4 Battery

Batteries are systems that store electrical energy by converting it to chemical energy. If needed, they convert this stored chemical energy back into electrical energy. In photovoltaic systems where the electricity produced is not supplied to the grid, in other words, in off-grid PV systems the electricity produced is stored by means of batteries when it is not consumed. Thus, the energy stored in the batteries can be used in cloudy weather or in the evening. Batteries are the most costly equipment of a PV system, so battery selection should be done carefully.

2.5 Charge Controller

There are several components of a solar system that need to work together in order to make it all work effectively. One of these components is a controller. It is used to regulate the DC coming from the PV module. It is important in terms of preventing the battery from overloading or drying out completely.

2.6 DC and AC Disconnect

The main purpose of AC and DC disconnect switches is turn off the power flow from PV modules. DC breakers are placed between the PV module and inverter and are used to disconnect the PV module from the system. AC breakers are placed after inverter and are used to disconnect the inverter from the grid.

2.7 Meter

A meter measures how much electricity you use and how much you send back to grid. There are types such as consumption meter, PV meter and bi-directional meter.

CHAPTER 3

PV MODULE TESTS IN TURKEY

Turkish Standards Institution Photovoltaic Systems Test Laboratory tests PV modules for compliance with requirements of TS EN IEC 61215-1, TS EN 61215-2, TS EN IEC 61730-1 and TS EN IEC 61730-2 standards. In addition, salt mist corrosion test according to TS EN IEC 61701 and PID test according to IEC 62804-1 are also performed. Tests performed according to TS EN IEC 61215-2 and TS EN IEC 61730-2 standards are given in Table 3.1.

Table 3.1 PV module tests

TS EN 61215-2 Tests	**TS EN IEC 61730-2 Tests**
Visual inspection	
Performance at STC	
Insulation test	
Measurement of temperature coefficients	—
Measurement of nominal module operating temperature (NMOT)	—
Performance at NMOT	—
Performance at low irradiance	—
Outdoor exposure test	—
Hot-spot endurance test	
UV preconditioning test	
Thermal cycling test	
Humidity-freeze test	
Damp heat test	
Robustness of terminations	
Wet leakage current test	
Static mechanical load test	

Hail test	—
Bypass diode thermal test	
Bypass diode functionality test	
Stabilization	—
—	Insulation thickness test
—	Durability of markings
—	Sharp edge test
—	Accessibility test
—	Cut susceptibility test
—	Continuity test of equipotential bonding
—	Impulse voltage test
—	Temperature test
—	Reverse current overload test
—	Module breakage test
—	Screw connections test
—	Materials creep test
—	Cold conditioning
—	Dry heat conditioning

4.1 Visual Inspection

This test is done to decide if there is any visual imperfection in PV module. According to TS EN 61215-1 standard, no evidence of major visual defects like cracked/broken cells, broken/ cracked/ torn external surfaces, bubbles, delaminations, molten or burned encapsulant, backsheet, frontsheet, diode or active PV component, broken interconnections, burn marks.

4.2 Insulation Test

This test is done to determine whether there is any leakage current between live parts and accessible parts. Firstly maximum system voltage is applied for 2 minute. After 2000 V plus four times the maximum system voltage is applied for 1 minute. There

should be no dielectric breakdown. If the area of the module is less than $0.1m^2$, the insulation resistance shall not be less than 400 MΩ. If the area of the module is larger than $0.1m^2$, the measured insulation resistance times the area of the module shall not be less than 40 MΩ·m^2.

4.3 Performance at STC

This test is done to determine the electrical performance of the module and to verify the module's label values. In addition, after aging tests, the power drop in the module is determined by this test. We obtain modules current-voltage characteristic at 1000 W/m^2, 25 ºC and A.M. 1.5. Equaiton 3.1, 3.2 and 3.3 are expected to be fulfilled while label verificaiton.

$$P_{max}(\text{Lab}).(1+\frac{m_1[\%]}{100}) \geq P_{max}(\text{NP}).(1-\frac{t_1[\%]}{100}) \quad \textbf{(3.1)}$$

Where $P_{max}(\text{Lab})$ is the measured maximum STC power of each module in the stabilized state, $P_{max}(\text{NP})$ is the maximum rated nameplate power of each module without tolerances, m_1 is the measurement uncertainty in % of laboratory for Pmax, t_1 is the manufacturer's rated lower production tolerance in % for P_{max}.

$$V_{OC}(\text{Lab}).(1+\frac{m_2[\%]}{100}) \leq V_{OC}(\text{NP}).(1+\frac{t_2[\%]}{100}) \quad \textbf{(3.2)}$$

Where $V_{OC}(\text{Lab})$ is the measured maximum V_{OC} of each module in the stabilized state, $V_{OC}(\text{NP})$ is the maximum rated nameplate V_{OC} of each module without tolerances, m_2 is the measurement uncertainty in % of laboratory for V_{OC}, t_2 is the manufacturer's rated upper production tolerance in % for V_{OC}.

$$I_{SC}(\text{Lab}).(1+\frac{m_3[\%]}{100}) \leq I_{SC}(\text{NP}).(1+\frac{t_3[\%]}{100}) \quad \textbf{(3.3)}$$

Where $I_{SC}(\text{Lab})$ is the measured maximum I_{SC} of each module in the stabilized state, $I_{SC}(\text{NP})$ is the maximum rated nameplate I_{SC} of each module without tolerances, m_3 is the measurement uncertainty in % of laboratory for I_{SC}, t_3 is the manufacturer's rated

upper production tolerance in % for I_{SC}. At the end of each test sequence each test sample shall meet the requirements of Equation 3.4.

$$P_{max}(\text{Lab_Gate\#2}) \geq 0.95 \times P_{max}(\text{Lab_Gate\#1}) .(1-\frac{r[\%]}{100}) \quad \textbf{(3.4)}$$

4.4 Static Mechanical Load

In this test, the module is exposed to statical load and the withstand of the module is tested. Firstly, the minimum design load and safety factor is defined by the module manufacturer. The minimum design load should be 1600 Pa. Manufacturer should define the design load for positive (downward) and negative (upward). Safety factor(γm) should be at least 1.5. Test load is calculated according to the Equation 3.5 and 3 cycles are applied to the module (positive and negative). There should be no visual defects at the end of the test. The mechanical integrity of the frame should not be compromised and there should be no intermittent open-circuit fault during test.

$$\text{Test load} = \gamma m \times \text{design load} \quad \textbf{(3.5)}$$

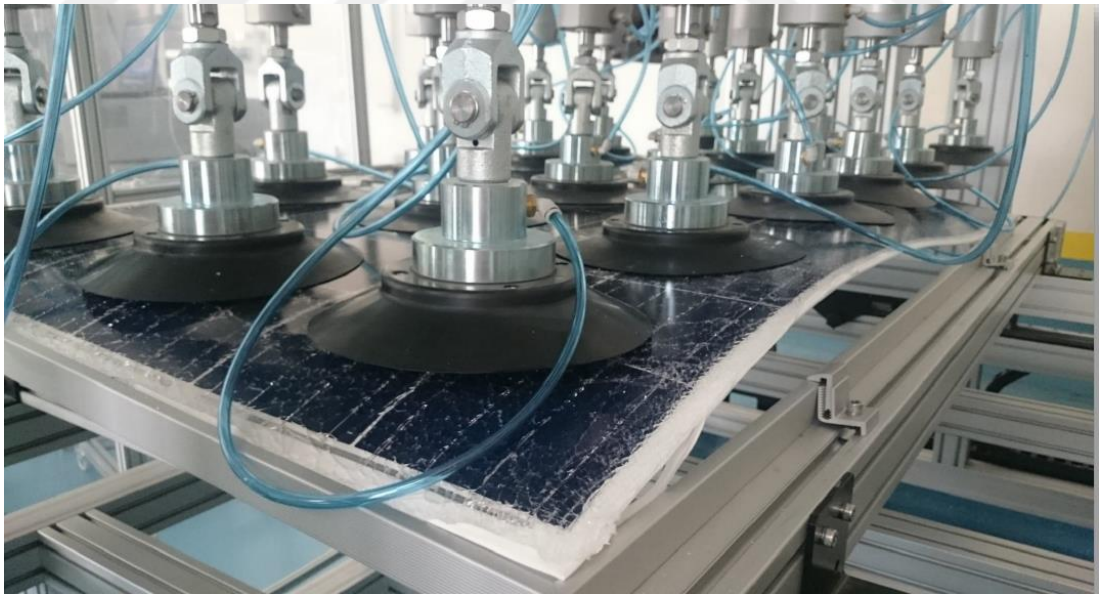


Figure 3.1 Mechanical load test

4.5 Electroluminescence Imaging

This examination is similar to taking an x-ray of the module. There may be broken and cracked cells in the module that are not visible to the eye. Electroluminescence imaging is performed to detect them. An EL image does not directly give us information about the output power of the PV module, but it provides detailed information about the damage status of the cells in the module, so that future problems can be detected early. An example of electroluminescence image is given in Figure 3.2.

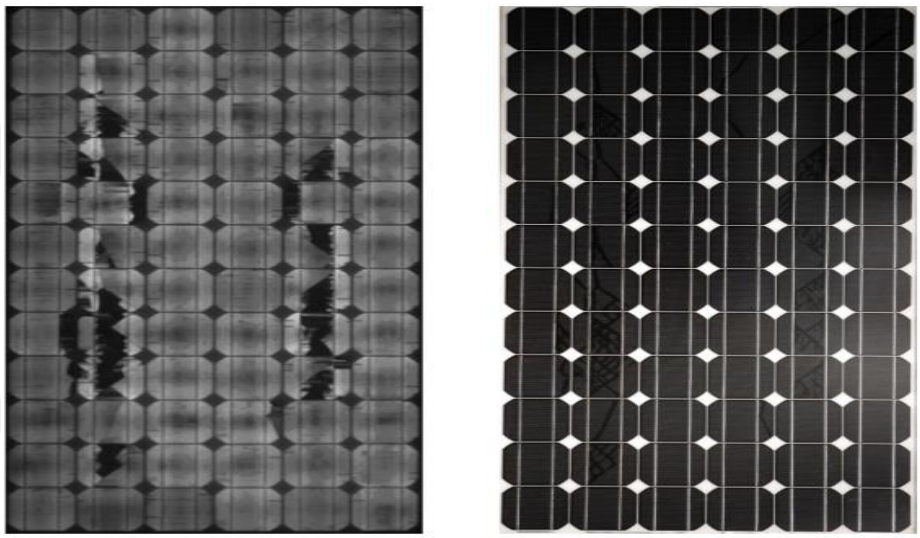


Figure 3.2 Electroluminescence image of a PV module [14]

4.6 Damp Heat Test

In this test, the module is exposed to humidity for a long time and the withstand of the module is tested. It performed by applying 85°C ± 2°C with a relative humidity of 85%. Test duration is 1000 hours. At the end of the test there should be no visual defect. Wet leakage current test requirements should be met.

4.7 Hot-Spot Endurance Test

Our aim in this test is to determine the ability to withstand hot-spot heating effects. We select 4 test cells. The first is the cell that has the lowest shunt resistance and is

adjacent to the edge. The second and third are the cells that have the lowest shunt resistance. The fourth is the cell that has highest shunt resistance. After cell selection we determine worst-case shading and shadow each cell in this condition. And then we expose the module to (1000±100) W/m^2 for 1 hour under the worst case shading condition. At the end of the test visual inspection, insulation, wet leakage current and maximum power determination tests are applied. Figure 3.3 shows photo of PVmodule after hot spot endurance test.

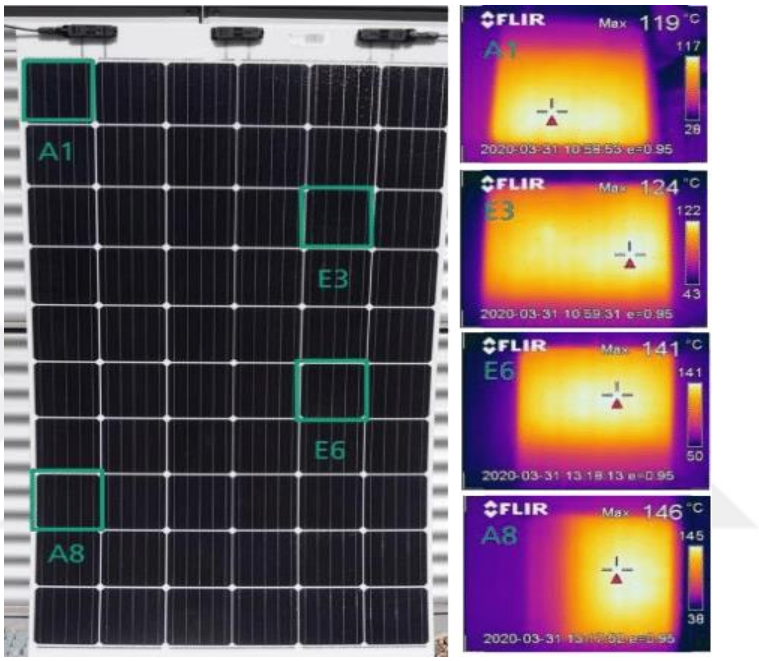


Figure 3.3 Photo of PV module after hot spot endurance test

4.8 Materials Creep Test

In this test, the PV module is kept at 105 °C ± 5 °C for 200 hours and it is checked whether there is any creep in polymeric materials and whether there is loss of adhesiveness. After material creep test visual inspection, insulation test, wet leakage current test and continuity test of equipotential bonding tests are repeated.

4.9 Wet Leakage Current Test

This test is similar to the insulation test but is carried out in wet conditions. The insulation of the module in wet conditions is tested. Module is sprayed with a solution

that has 3500 Ω/cm or less resistivity and (22 ± 2) °C temperature. If the area of the module is less than 0.1 m^2 the insulation resistance shall not be less than 400 MΩ. If the area of the module is larger than 0.1m^2, the measured insulation resistance times the area of the module shall not be less than 40 MΩ. m^2.

4.10 Thermal Cycling Test

Our aim in this test is to determine the ability of the module to withstand thermal stresses caused by repeated temperature changes. The module is placed in the climatic chamber. Appropriate current is applied. 50 or 200 cycles are applied between -40 and +85 degrees. Temperature and applied current profile is given in Figure 3.5. At the end of the test there should be no visual defect. Wet leakage current test requirements should be met. There should be no interruption of current flow during the test.

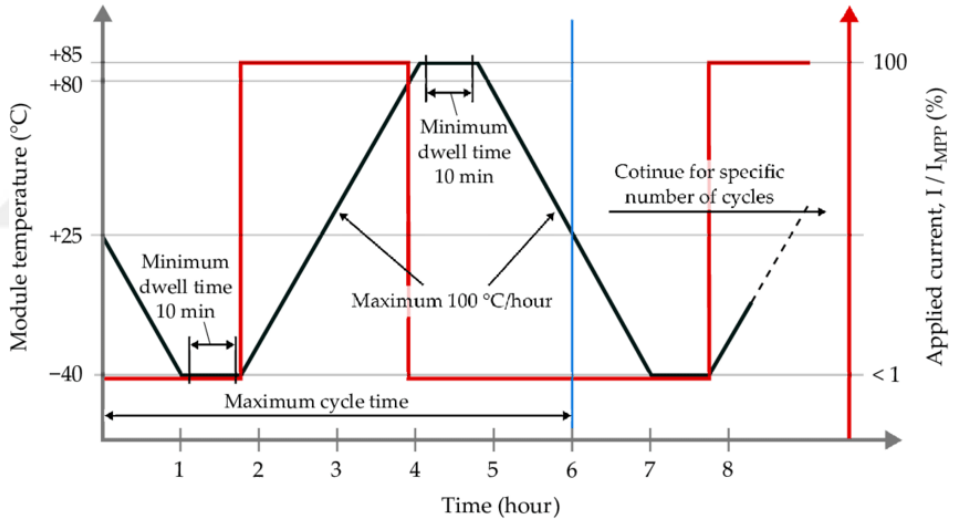


Figure 3.4 Temperature and applied current profile of thermal cycling test [15]

4.11 Humidity Freeze Test

In this test, firstly the module is exposed to high temperature and humidity, after that sub-zero temperatures. Figure 3.6 shows the temperature and humidity profile for 1 cycle. 10 cycles are performed and the test is completed. At the end of the test there should be no visual defect. Wet leakage current test requirements should be met. There should be no interruption of current flow and voltage during the test.

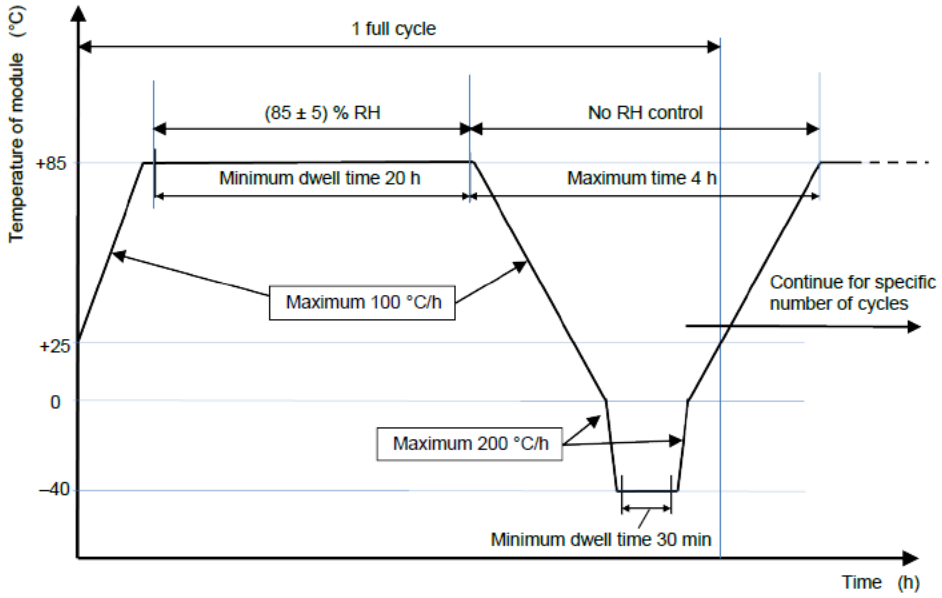


Figure 3.5 Temperature and humidity profile of humidity-freeze test [16]

4.12 Hail Test

The purpose of this test is to prove that the module is capable of withstanding the impact of hail. In this test, 11 ice balls are thrown at the points of the module given in standard. The velocity, mass and diameter values of iceballs are given in the Table 3.2. At the end of the test, visual inspection and wet leakage current tests are applied.

Table 3.2 Ice-ball masses and test velocities

Diameter (mm)	Mass (g)	Test velocity (m/s)	Diameter (mm)	Mass (g)	Test velocity (m/s)
25	7.53	23.0	55	80.2	33.9
35	20.7	27.2	65	132.0	36.7
45	43.9	30.7	75	203.0	39.5

4.13 Robustness of Terminations

The purpose of this test is to verify whether the terminations and cables are resistant to stresses that may be subjected during installation. This test has 2 stages. First one is Retention of junction box on mounting surface and second one is test of cord anchorage (pull test and torque test). Test of cord anchorage can be omitted if junction

box certified according to IEC 62790. At the end of the test visual inspection, insulation test and wet leakage current tests are repeated.

4.14 Reverse Current Overload Test

Our aim in this test is to determine the ignition or fire risk of the PV module under reverse current fault conditions. First of all, the FV module is placed on a special white tissue paper. Reverse current of 135% of the overcurrent protection rating is applied to the module for 2 hours. There should not be flaming of the PV module, nor flaming or charring of the tissue paper. There should be no visual defects. Insulation and wet leakage current test requirements should be met.

4.15 Performance at NMOT

This test is performed to determine the current-voltage characteristic of the module under nominal module operating temperature and 800 W/m^2 irradiance test conditions.

4.16 Performance at Low Irradiance

This test is performed to determine the current-voltage characteristic of the module under 25 °C temperature and 200 W/m^2 irradiance test conditions.

CHAPTER 4

ROOFTOP PV SYSTEM MODELLING IN TSE

In this thesis, TSE Ostim service building was chosen to design the rooftop PV system. TSE Ostim campus is located at 39.98N 32.73E coordinates and has 2 floors. The first floor is 746 m^2, the second floor is 374 m^2, and the total roof area is approximately 1120 m^2. The roofs of the institute building are flat roof type and are very suitable for PV system installation because they are empty. Calculations were made through the PV*SOL program, taking into account the institute's electricity consumption values, building layout and roof areas. The feasibility of the designed system was analyzed by making an economic analysis.

5.1 Software Used For Modelling

In this study, the trial version of PV*SOL Premium software was used for PV system design. The software is produced by Valentine Software company in Germany. The software, which was first launched in 1993 as T*SOL, then made great progress and in 1998 it was published as PV*SOL, the first version of the design and simulation software for photovoltaic systems [17].

The characteristics of the modules in the database are used in the PV*SOL software to calculate the power output and performance of the PV system. The measured data of these modules under standard test conditions; their behavior against other variable parameters such as temperature and solar radiation form characteristic curves. The software uses these curves by obtaining the required data directly or by interpolation . There are basically 11 pages in the software. These pages are explained in detail below.

5.1.1 Welcome Page

This is the start page of the program. There are tutorials and webinars for those who are just starting to use the program. In addition to news about the PV*SOL software, creating new projects and opening previously saved projects are also done through this page. Figure 4.1 shows welcome page.

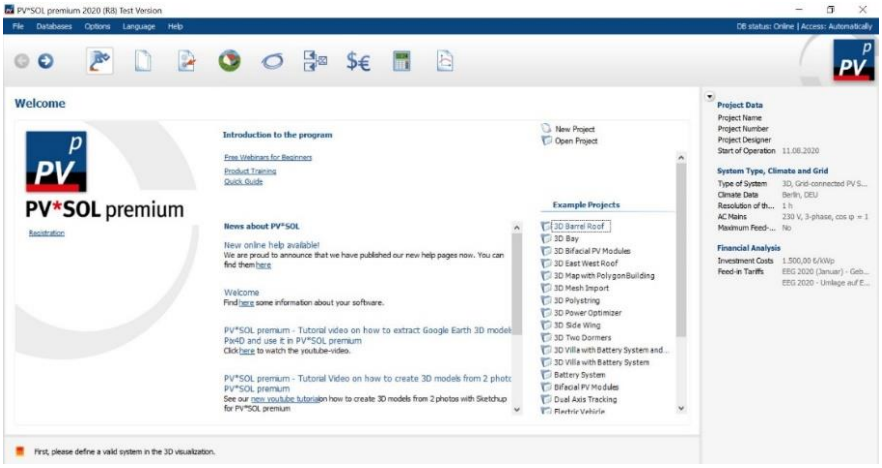


Figure 4.1 Welcome page

5.1.2 Project Data Page

This page is the page where general project information is entered. Data such as project number, project start date, project description, address where the site will be established, picture of the project, designer and customer information are entered on this page. Figure 4.2 shows project data page.

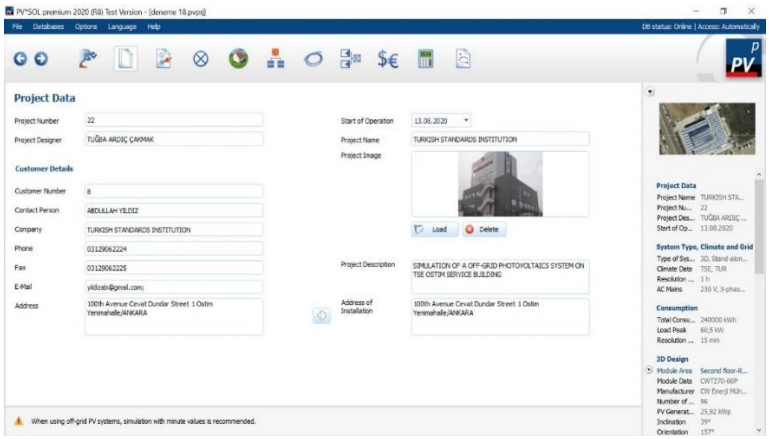


Figure 4.2 Project data page

5.1.3 System Type, Climate and Grid Page

This page is the section where the type of the system to be installed, the location to be installed, the climate information and the grid properties of this location are entered. As the system type; There are 7 different options. Whether the 3D design section will

be used for the project can also be selected in this window. While selecting the climate features, locations can be selected from the software's own data, or a new location can be selected on the map and added to the data system. The addition of these new locations is done through the MeteoSyn application integrated into the software. Figure 4.3 shows system type, climate and grid page.

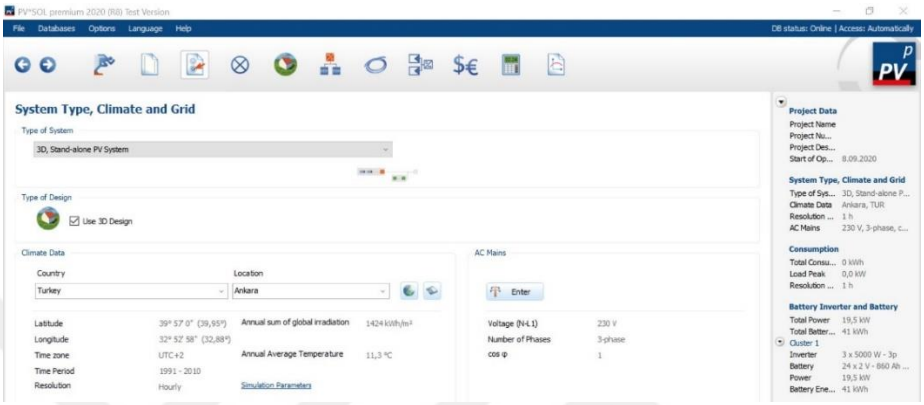


Figure 4.3 System type, climate and grid page

5.1.4 Consumption Page

The consumption window is the section where a consumption profile for the PV system is created. In this window, electricity consumption data is entered and the load type is selected, so the system makes the consumption distribution according to months. Figure 4.4 shows consumption page.

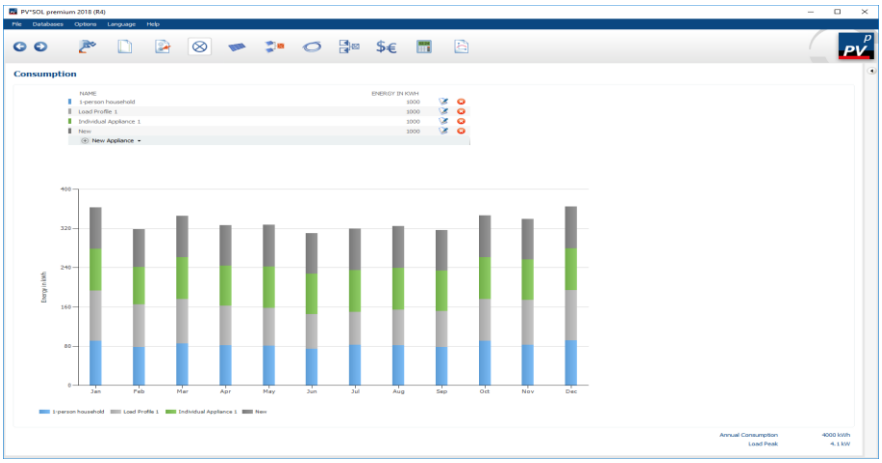


Figure 4.4 Consumption page

5.1.5 3D Desing Page

The PV system is designed with the 3D design page. On this page, the building or open area where the power plant will be established is drawn. Then the PV module type to be used in the field is selected. How many of these modules will be, how much slope and how they will be mounted on the site are determined. In addition, inverter selection and wiring arrangements are performed on this page. In addition, shading calculations are performed on this page. For this reason, we can say that the most important page of the design is 3d design page. Figure 4.5 shows 3D design page.

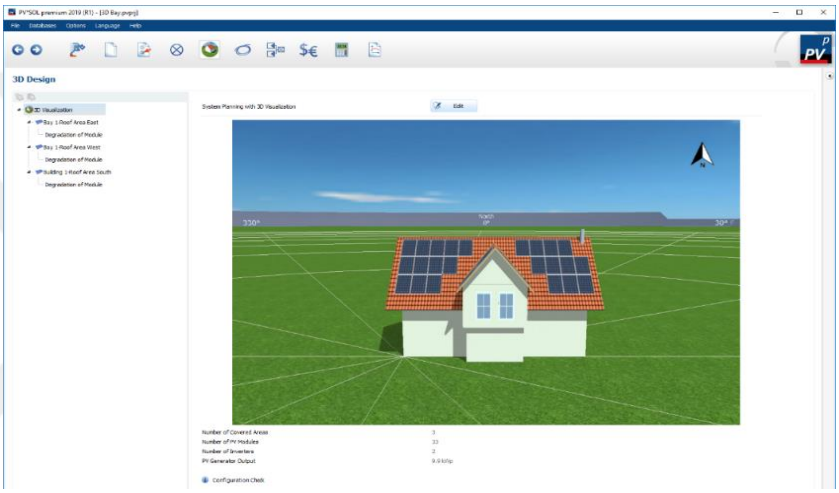


Figure 4.5 3D design page

5.1.6 Battery Inverter and Battery Page

This is the section in which battery and battery inverter data are entered. Batteries and battery inverters suitable for the features of the designed system are listed by the software. The designer chooses one of these options.

5.1.7 Plans and Parts Page

This page presents the circuit diagram, scaling plan and parts lists of the designed system to the designer in PDF format. Data entry cannot be made to this window.

5.1.8 Cables Page

This is the section in which cable data are entered.

5.1.9 Financial Analysis Page

The financial analysis page is the part where the cost analysis of the system is made. On this page, the components used in the design, their models, unit prices and quantities are entered by the user. In addition, data such as cable, work, fuel costs and annual fuel price increase rate are entered.

5.1.10 Results Page

When this window is reached, the simulation is started by the software. System efficiency, total investment cost, pv generator energy and profitability calculations are displayed as a chart. Figure 4.6 shows results page.

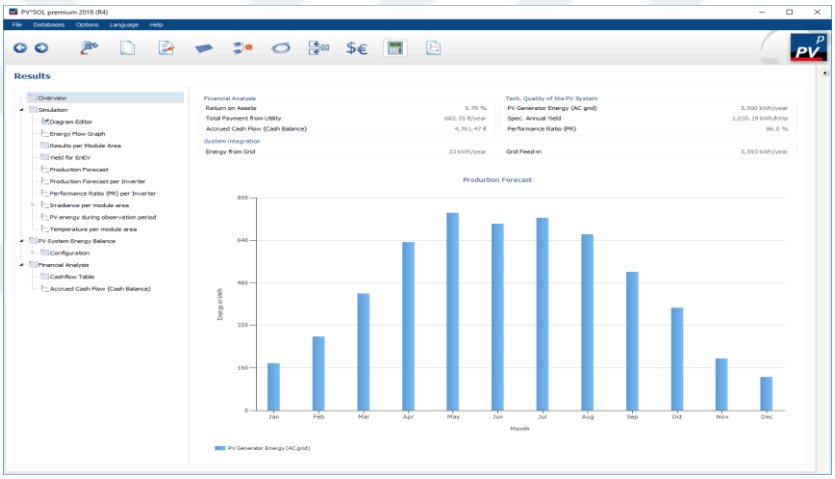


Figure 4.6 Results page

5.1.11 Presentation Page

In this page analysis results of the designed system can be exported in *.docx or *.pdf format.

5.2 PV System Modelling

In the PV*SOL software, first, the project address, number, designer and customer information were entered on the project data page. Then, stand alone PV system was selected as the system type on the system type, climate and grid page. Then, the

location where the PV power plant will be installed was selected from the map to the system. Figure 4.7 shows selection of TSE's location on MeteoSyn.

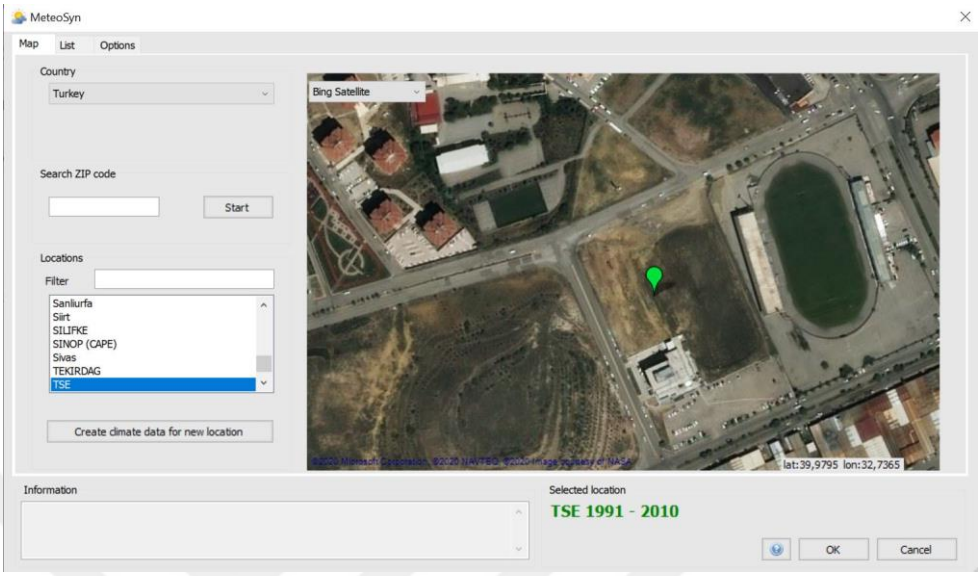


Figure 4.7 Selection of TSE's location on MeteoSyn.

On the MeteoSyn database, there are data between the years 1991-2010 at the measurement centers close to the selected location, and the institute data is created by interpolating these data. The annual sum of global irradiation for the selected location is 1423 kWh/m^2 and the annual average temperature is 11.8 °C. Figure 4.8 shows selection of system type, climate and grid for Ankara.

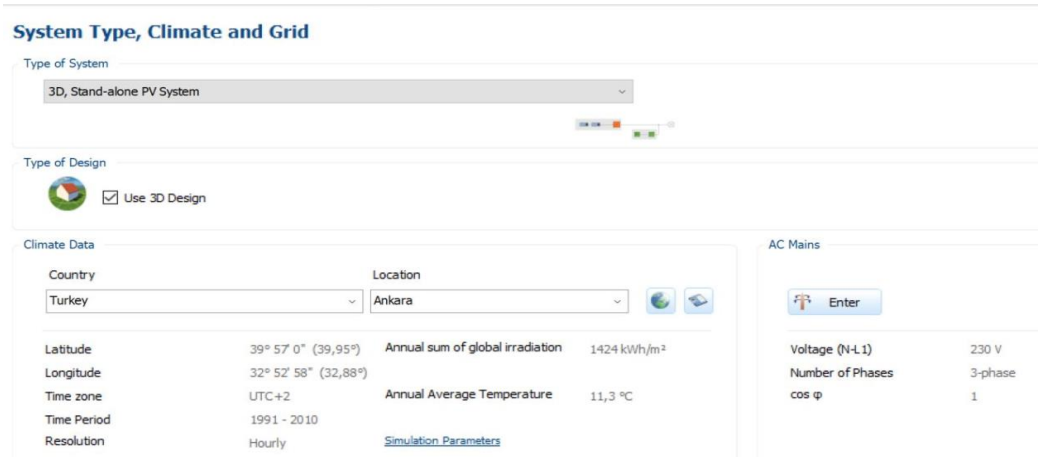


Figure 4.8 Selection of system type, climate and grid for Ankara

After the location was determined, it was time to select the profile type from the consumption page. PV*SOL software distributes the annual total electricity consumption by months, according to the selected profile type. These profile types are; houses, buildings that are active at night such as nightclubs, buildings with heating systems, offices that are active during working hours on weekdays can be counted. In the consumption window, where the electricity consumption data is entered, the annual consumption value is entered into the program and the commercial load profile is selected. Then, the system design was started by pressing the edit button in the 3D design page. First of all, the two-storey TSE Ostim building was modeled here. For the 3D design, a 3D rough design of the building was drawn on the satellite photo of the institute. In Figure 4.9, the real and the designed model of the building are given.



Figure 4.9 Real image and 3D model of the institute

After the building modeling, it was time to choose the PV module. There are many PV modules registered in the software's database. CWT270-60P model polycrystalline silicon PV modules, which are certified according to TS EN 61215-2, TS EN IEC 61730-1 and TS EN IEC 61730-2 standards, belonging to a domestic manufacturer, CW Enerji, were selected. The characteristic features of this module are given in Table 4.1 [18].

Table 4.1 Characteristics of selected PV module

Module type	CWT270-60P
Peak power (Pmax)	270 Wp
Maximum power voltage (Vmp)	31.81 V
Maximum power circuit (Imp)	8.50 A
Open circuit voltage (Voc)	38.84 V
Short circuit current (Isc)	9.10 A
Power tolerance	0 ~+5W
Maximum system voltage	1000V DC
Panel dimensions	1648x995x35mm

After the PV module selection, it should be determined how the modules will be placed on the field. To get the maximum benefit from solar radiation, the PV module should be placed with optimum azimuth and tilt angle. The angle of inclination should be equal to the angle of latitude in order to maximize the energy produced annually. Accordingly, the modules should be placed in the direction of the south and at an angle of inclination equal to the latitude angle. The tilt angle value for Ankara is 39°. One of the most important issues in module placement is to place the modules at the required intervals so as not to cause shadowing. The design that needs to be done so that the modules do not shade each other is shown in Figure 4.10.

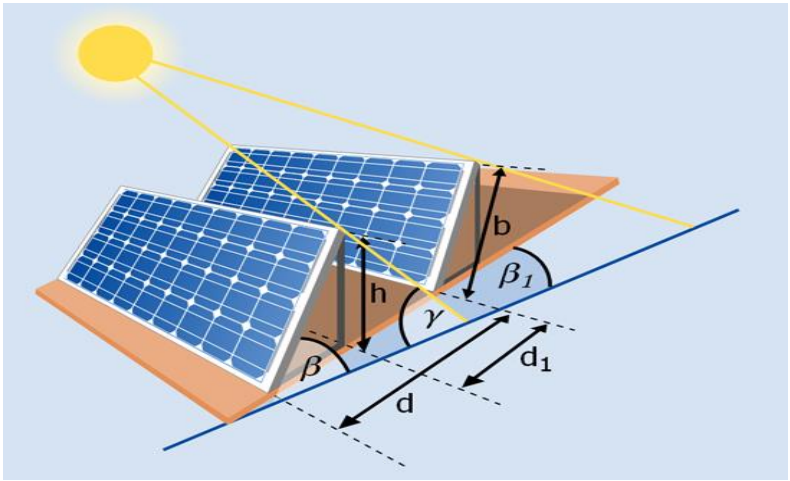


Figure 4.10 Minimum distances between PV modules

The ideal inter row spacing obtained with data such as module length, width, roof angle, solar elevation angle is calculated and given below. In addition, a module-sized free space has been left for operators to access the power plant easily. The distances of the modules in the roof areas are shown below.

Module mount width (b)	:	0,995 m
Mount height (h)	:	0,627 m
Module inclination (β)	:	39 ˚
Roof angle (β1)	:	0 ˚
Solar elevation angle (Ɣ)	:	26,58 ˚
Solar elevation angle applies to TSE	:	21/12 12:00
Row spacing (d)	:	2,025 m
Mounting support clearance (d1)	:	1,252 m
Depth of row (d-d1)	:	0,773 m

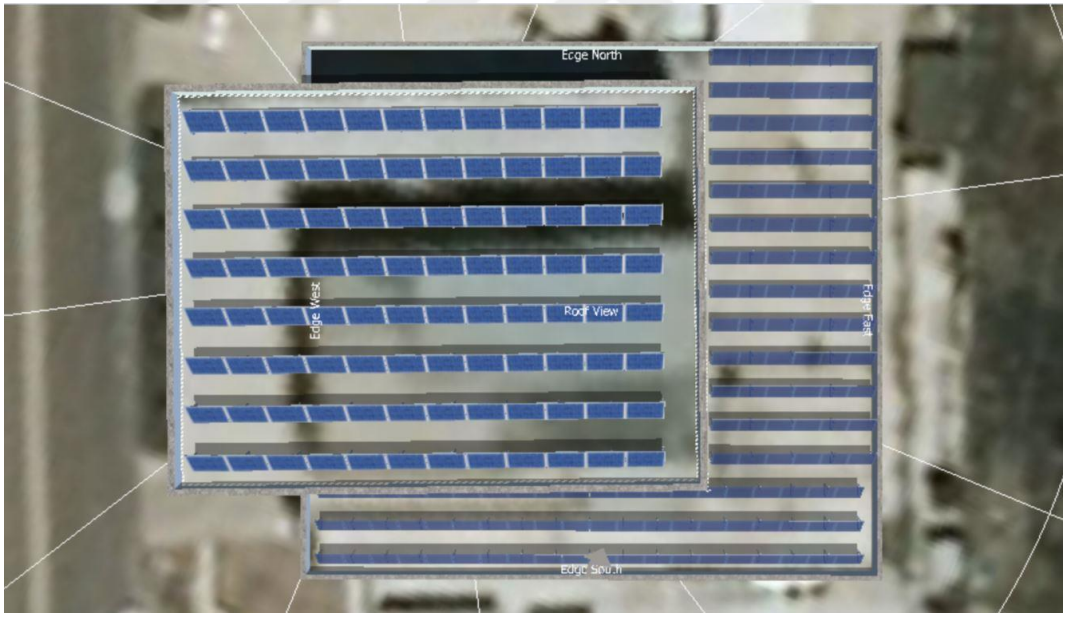


Figure 4.11 Layout of PV modules

After the PV module layout was completed, the dimensioning plan of the PV system to be installed on the first and second floor roofs were created by going to the plans

and parts page. The dimensioning plan of the first floor is given in Figure 4.12 and dimensioning plan of the second floor is given in Figure 4.13.



Figure 4.12 Dimensioning plan of first floor

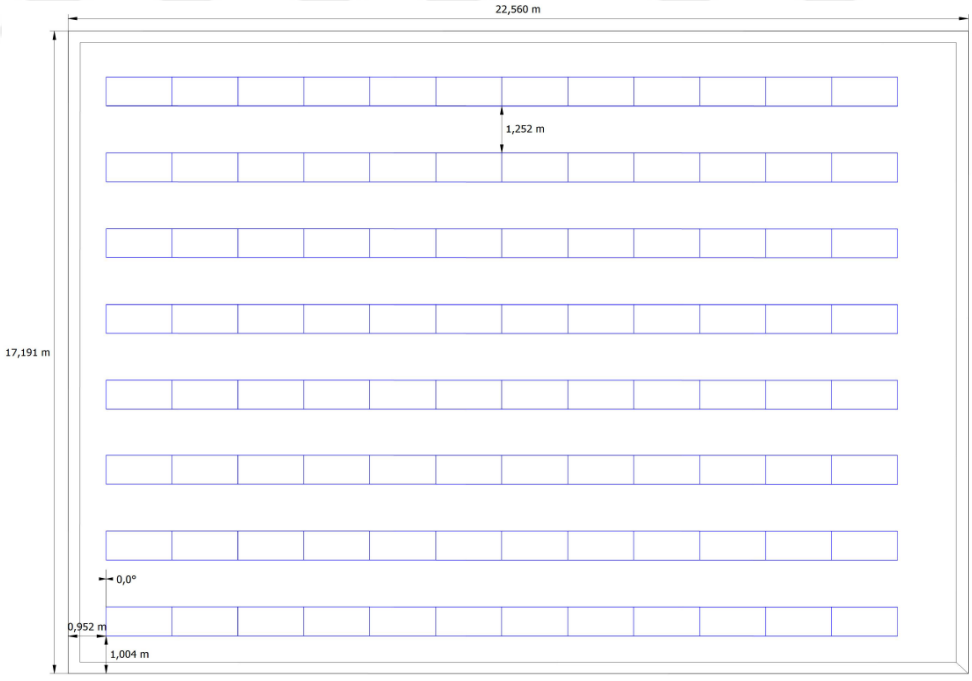


Figure 4.13 Dimensioning plan of second floor

The PV*SOL software can configure the appropriate inverter for the designed system after the module is selected and placed. The software has chosen ABB's inverters for the designed system.

A total of 3 inverters were selected, 1 on the first floor and 2 on the second floor. The inverters on the first floor are PRO-33.0-TL-OUTD and those on the second floor are PVI-12.5-TL-OUTD model inverters. 6 groups (23 PV modules each) are connected to the inverter on the first floor. 4 groups (12 PV modules each) are connected to each of the inverters on the second floor. Figure 4.14 shows these configurations.

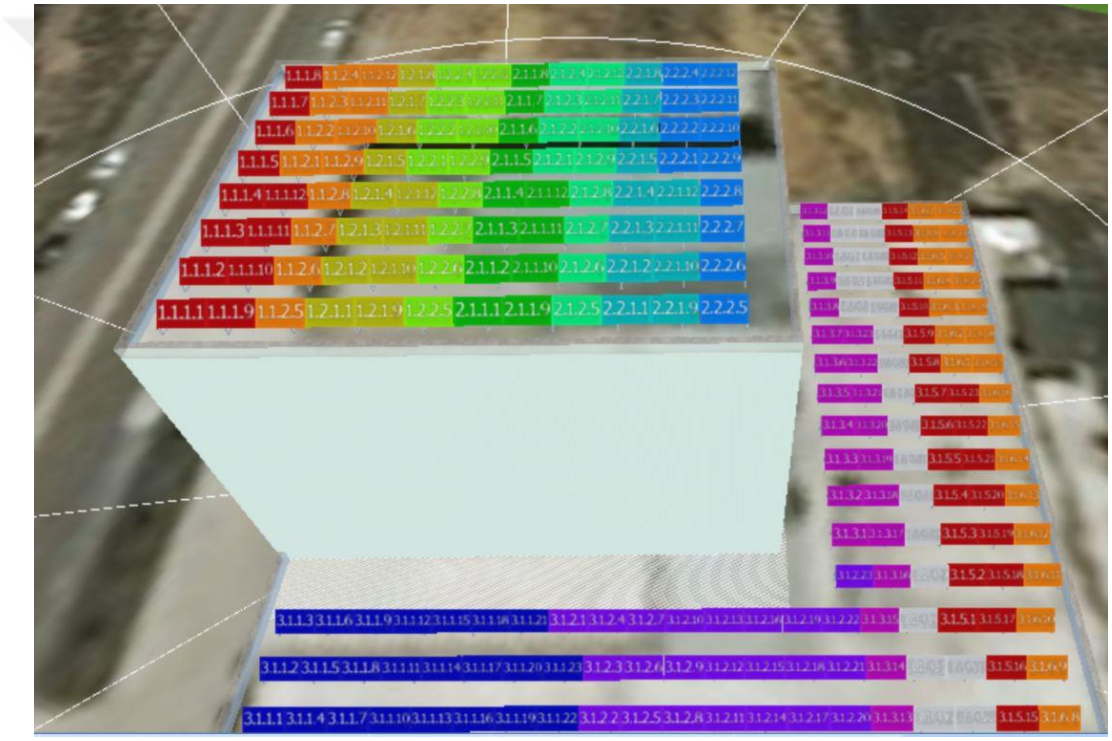


Figure 4.14 Inverter configuration

Since the system type selected in the PV*SOL software is the stand alone PV system, the "battery inverters and battery" window has been created. In this section, the software lists the batteries and battery inverters suitable for the system. Sunny Island 8.0H inverter of SMA Solar Technology has been selected as the battery inverter from the database of the software. Alpha ESS SMILE-BAT-5.8P 5.8kWh/48V/LifePo lithium iron phosphate battery of Alpha Energy Storage Solution company was

selected from the database of PV*SOL software. After the battery selection is made, the final circuit diagram of the PV system is shown in Figure 4.15.

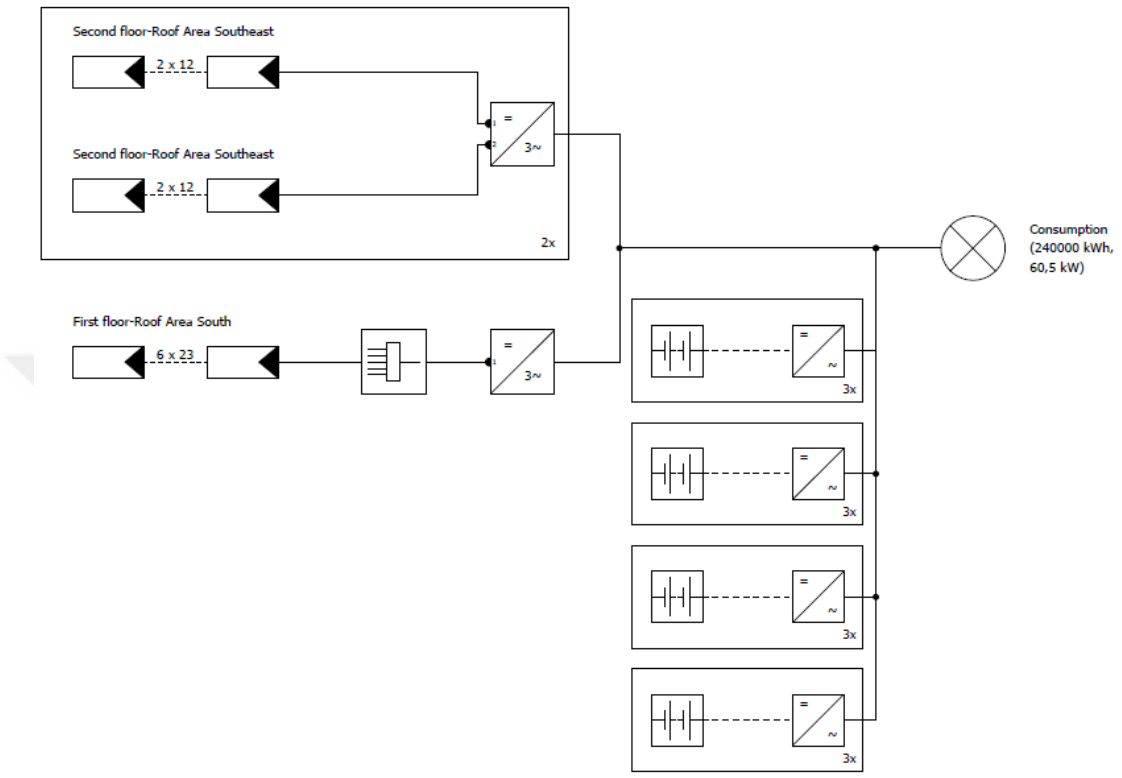


Figure 4.15 Circuit diagram of PV system

5.3 Economic Analysis

After the design is completed, the financial analysis page opens in the PV*SOL software. The components used in the design, the models, unit prices and quantities of these components are entered on this page by the user. Table 4.2 shows the type and quantity of equipment used in the designed PV system and the approximate unit prices for 2020.

Table 4.2 Type, quantity and approximate unit prices of the equipments

Component	Type	Unit Price	Quantity
Modules	CWT270-60P	960,00 ₺	234

Inverter-1	PVI-12.5-TL-OUTD	19.000,00 ₺	2
Inverter-2	PRO-33.0-TL-OUTD	31.000,00 ₺	1
Battery inverters	Sunny Island 8.0H	22.000,00 ₺	12
Batteries	Alpha ESS SMILE-BAT-5.8P	7.000,00 ₺	284
Cable costs	9.000,00 ₺		
Work costs	60.000,00 ₺		
Other costs	20.000,00 ₺		

CHAPTER 5

RESULTS AND DISCUSSION

First of all, the energy balance of the PV system will be calculated. Global radiation at module was calculated by adding / subtracting the radiation gains and losses to the global radiation (horizontal) of the selected region. Then, this value is multiplied by the total PV generator surface area, the total global PV radiation value is calculated and the results are given in Table 5.1. Then, the configuration losses are subtracted from the total global PV radiation,the energy at the inverter input(PV energy (DC)) is calculated and given in Table 5.2. And then, by subtracting the inverter losses from the energy at the inverter input, the PV generator energy (AC) was calculated and given in Table 5.3. According to the simulation result, the system will generate 70283 kWh of electricity annually.

Table 5.1 Irradiation losses and gains of all system

	All system	**Unit**
Global radiation – horizontal	1423.27	kWh/m^2
Deviation from standard spectrum	-14.23	kWh/m^2
Ground reflection (albedo)	31.40	kWh/m^2
Orientation and inclination of the module surface	87.86	kWh/m^2
Module-independent shading	-8.56	kWh/m^2
Reflection on the module interface	-13.61	kWh/m^2
Global radiation at the module	1506.13	kWh/m^2
(1506.13 kWh/m^2) x (383.704 m^2) =	577907.94	kWh

Table 5.2 Configuration losses of the system

	All system	**Unit**
Global PV radiation	577907.94	kWh
STC conversion (rated efficiency of module 16,49 %)	-482614.95	kWh
Rated PV energy	95292.99	kWh

Module-specific partial shading	-10625.19	kWh
Low-light performance	-570.47	kWh
Deviation from the nominal module temperature	-3126.38	kWh
Diodes	-155.49	kWh
Mismatch (manufacturer information)	-1616.31	kWh
Mismatch (configuration/shading)	-4293.80	kWh
PV energy (DC) without inverter down-regulation	74905.36	kWh
Inverter down-regulation	-1910.09	kWh
PV energy (DC)	72995.27	kWh

Table 5.3 Inverter losses of the system

	All system	**Unit**
Energy at the inverter input	72995.27	kWh
Input voltage deviates from rated voltage	-408.21	kWh
DC/AC conversion	-1950.35	kWh
Standby consumption (inverter)	-35.84	kWh
Total cable losses	-353.18	kWh
PV energy (AC) minus standby use	70247.69	kWh
PV generator energy (AC grid)	70283.53	kWh

After calculating the maximum possible PV energy of the system, the performance ratio and specific annual yield, which are among the important criteria determining the performance of the system, have been calculated. Performance ratio (PR) refers to the relationship between the actual and theoretical energy output of the PV system. Performance ratio was determined according to formula in Equation 5.1.

$$Performance\ ratio(PR) = \frac{E_{PVuse}}{E_{in}.\eta_{STC}} \quad \textbf{(5.1)}$$

where E_{PVuse} is solar energy generated (AC side) - inverter power consumption, E_{in} is energy irradiated to the PV array surface and η_{STC} is efficiency of module at STC. The performance ratio was calculated as 65 % for the first floor and 84.6 % for the

second floor. And finally, the performance ratio of the whole system is calculated as 73.7 %. Specific annual yield means that how much energy (kWh) is produced for every kWp of module capacity. Specific annual yield was determined according to formula in Equation 5.2.

$$Specific\ annual\ yield(SAY) = \frac{E_{PVuse}}{P_{nom}} \quad \textbf{(5.2)}$$

where E_{PVuse} is solar energy generated (AC side) - inverter power consumption and P_{nom} is installed PV array output. The specific annual yield was calculated as 985.8 kWh/kWp for the first floor and 1294.5 kWh/kWp for the second floor. And finally, specific annual yield of the whole system is calculated as 1112 kWh/kWp. Table 5.4 shows calculations ofr each floor.

Table 5.4 Calculations for each floor

	Second floor	**First floor**
PV generator output [kWp]	25.92	37.26
PV generator surface [m^2]	157.4	226.3
Global radiation at the module [kWh/m^2]	1527.2	1514.5
PV generator energy (AC grid) [kWh/year]	33552.4	36731.1
Specific annual yield [kWh/kWp]	1294.5	985.8
Performance ratio (PR) [%]	84.6	65

According to the simulation results made by the software, the distribution of the annual electrical energy obtained from the PV system by months is shown in Figure 5.1. When this graph is analyzed, it is seen that the highest amount of electricity generation took place in July.

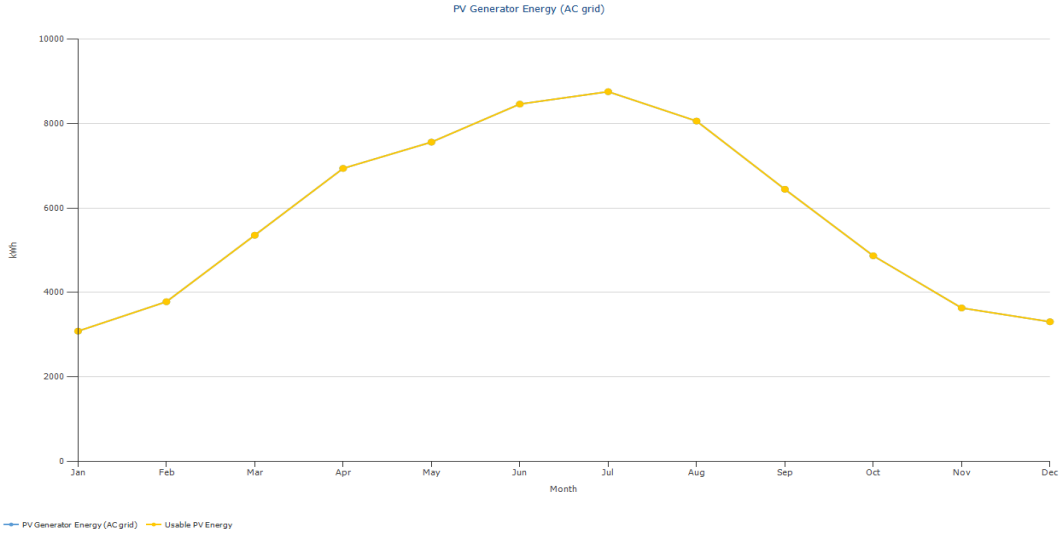


Figure 5.1 PV generator energy (AC grid)

We entered the annual electricity consumption value of the institute on the consumption page of the software. The software distributed this value monthly and presented it to us. This indicated consumption and covered consumption are shown in Figure 5.2.

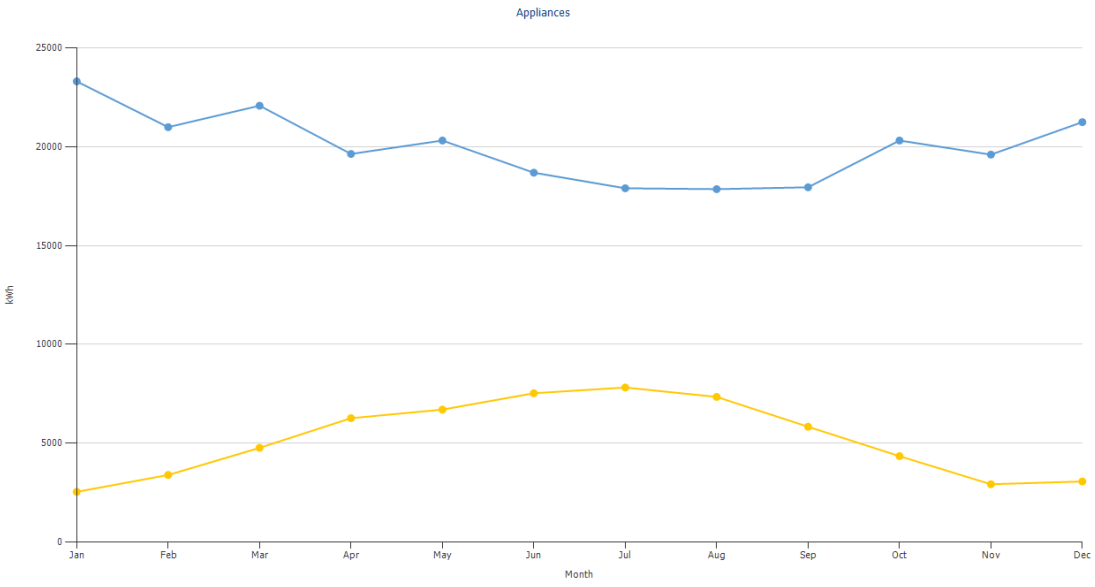


Figure 5.2 Indicated consumption and covered consumption

The energy flow graph of the system is shown in Figure 5.3. 16605 kWh of the 70283 kWh electricity generated by the system is directly consumed, while 53678 kWh is

used for battery charging. This distribution of usable PV energy is shown in Table 5.5 53678 kWh of electricity coming to the battery decreases to 46241 kWh after some losses. This value is means that coverage of consumption by the battery system. This distribution of total consumption is shown in Table 5.6.

Table 5.5 Distribution of usable PV energy

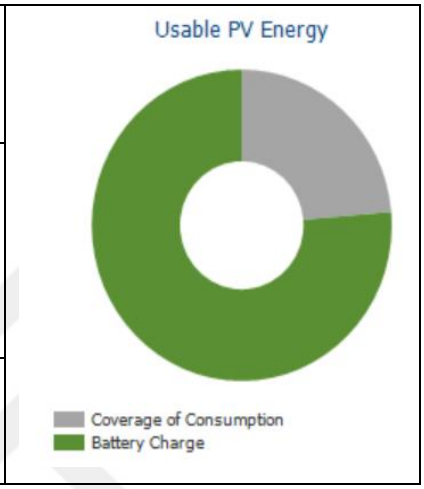
Usable PV energy	70283 kWh/year	
Covered of consumption	16605 kWh/year	
Battery charge	53678 kWh/year	

Table 5.6 Distribution of total consumption

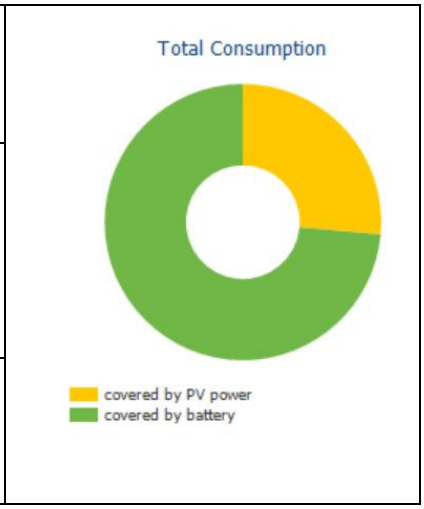
Total consumption	62846 kWh/year	
Covered by PV power	16605 kWh/year	
Covered by battery	46241 kWh/year	

Figure 5.3 shows energy flow of PV system. As can be understood from the energy flow, 16605 kWh of the 70283 kWh energy produced by the PV system is directly consumed by the institute. The remaining 53678 kWh energy is used for battery

charging. After the batteries are charged, 46241 kWh of energy is sent to be consumed by the institute. And Figure 5.4 shows production forecast with consumption.

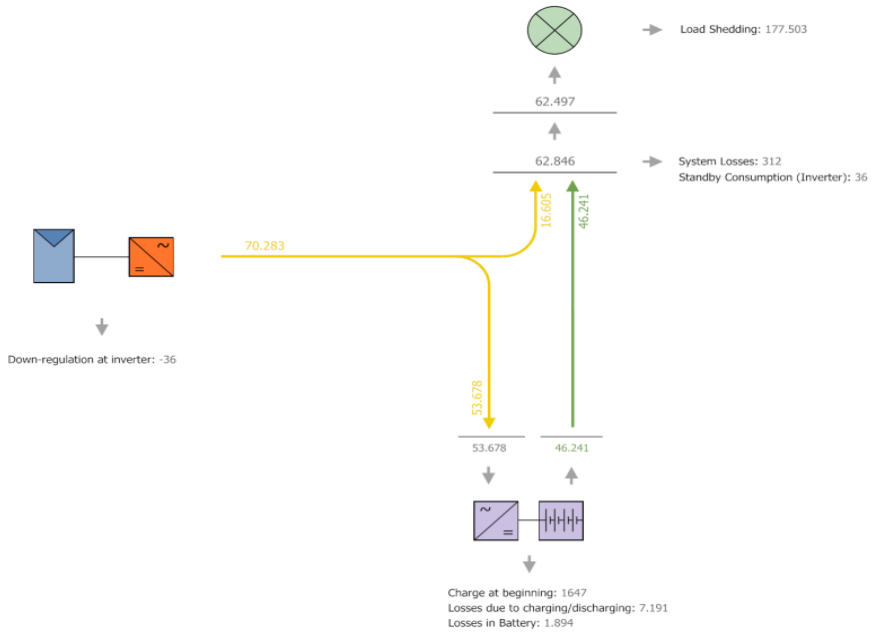


Figure 5.3 Energy flow graph of system



Figure 5.4 Production forecast with consumption

CHAPTER 6

CONCLUSION

In this study, an off-grid rooftop PV system was designed for the Turkish Standards Institute building and it was calculated how much of the energy that the system would produce could meet the real annual electricity consumption of the institute. PV*SOL software was used for design and simulation. According to simulation results total PV generator surface of the system is 383.7 m^2 and total PV generator output 63.18 kWp. Total number of PV modules used in the system is 234. Total number of inverters used in the system is 3. Total number of battery inverters used in the system is 12 and total number of batteries used in the system is 284. Maximum possible PV energy in this system is 70283 kWh. The specific annual yield of the system is 1111.87 kWh/kWp and performance ratio of the system is 73.1%.

When we entered the quantity of equipment used in the designed PV system and the approximate unit prices for 2020 to economic analysis page total cost of the PV system is 2,634,640 TL. It is seen that approximately 30% of the real annual electricity consumption of Turkish Standards Institution can be met with the electrical energy produced by the designed PV system. With a view to increasing the use of renewable energy sources, such studies should be increased and encouraged. According to the results of the analysis and feasibility studies, suitable PV systems should be put into operation.

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