EFFICIENCY ANALYSIS OF FIXED AND AXIS TRACKING OPTIONS OF PHOTOVOLTAIC SYSTEMS TO BE INSTALLED IN A MARINA

2023
MASTER THESIS
ENERGY SYSTEMS ENGINEERING

Hiwa Najmalddin NASRALDDIN

Thesis Advisor
Prof. Dr. Hacı Mehmet ŞAHİN

EFFICIENCY ANALYSIS OF FIXED AND AXIS TRACKING OPTIONS OF PHOTOVOLTAIC SYSTEMS TO BE INSTALLED IN A MARINA

Hiwa Najmalddin NASRALDDIN

Thesis Advisor
Prof. Dr. Hacı Mehmet ŞAHİN

T.C.
Karabuk University
Institute of Graduate Programs
Department of Energy Systems Engineering
Prepared as
Master Thesis

KARABUK
June 2023

I certify that in my opinion the thesis submitted by Hiwa Najmalddin NASRALDDIN titled “EFFICIENCY ANALYSIS OF FIXED AND AXIS TRACKING OPTIONS OF PHOTOVOLTAIC SYSTEMS TO BE INSTALLED IN A MARINA” is fully adequate in scope and in quality as a thesis for the degree of Master.

Prof. Dr. Hacı Mehmet ŞAHİN ....
Thesis Advisor, Department of Energy Systems Engineering

This thesis is accepted by the examining committee with a unanimous vote in the Department of Energy Systems Engineering as a Master of Science thesis. 21/06/2023

Examining Committee Members (Institutions) Signature

Chairman : Prof. Dr. Erol KURT (GÜ) ....

Member : Prof. Dr. Hacı Mehmet ŞAHİN (KBÜ) ....

Member : Prof. Dr. Mehmet ÖZKAYMAK (KBÜ) ....

The degree of Master of Science by the thesis submitted is approved by the Administrative Board of the Institute of Graduate Programs, Karabuk University.

Prof. Dr. Müslüm KUZU ....
Director of the Institute of Graduate Programs

“I declare that all the information within this thesis has been gathered and presented in accordance with academic regulations and ethical principles and I have according to the requirements of these regulations and principles cited all those which do not originate in this work as well.”

Hiwa Najmalddin NASRALDDIN

ABSTRACT

M. Sc. Thesis

EFFICIENCY ANALYSIS OF FIXED AND AXIS TRACKING OPTIONS OF PHOTOVOLTAIC SYSTEMS TO BE INSTALLED IN A MARINA

Hiwa Najmalddin NASRALDDIN

Karabük University
Institute of Graduate Programs
The Department of Energy Systems Engineering

Thesis Advisor:
Prof. Dr. Hacı Mehmet ŞAHİN
June 2023, 59 pages

Electricity consumption is an important cost in businesses operating in the service sector such as marinas. Although the use of solar power for electricity has become widespread in various fields in Turkiye, marinas have yet to fully utilize this technology. The aim of this study is to examine the feasibility of supplying the electricity needs of a marina with a photovoltaic (PV) system. For this purpose, a marina in Muğla (Bodrum) was selected, and monthly/yearly electricity needs were determined. In this study, the PV installed capacity needed to meet the marina's electricity demand was selected. Simulations were performed for three different options using the Photovoltaic Geographical Information System (PVGIS), these PV systems are single.axis tracking (SAT), dual.axis tracking (DAT), and fixed options. As a result of the calculations, a single axis tracking PV system with a capacity of 2012 kW will generate 4,469,618 kWh/year of electricity, which will be sufficient to meet the yearly electricity demand. It has been determined that the installation cost payback period is 3.91 years for SAT PV system. In addition, it was observed that both DAT and SAT PV systems were more efficient than fixed options.

Keywords : Solar Energy, Solar Panel, Inclination Angle Change, PVGIS
Science Code : 92805

ÖZET

Yüksek Lisans Tezi

BİR YAT LİMANINDA KURULACAK FOTOVOLTAİK SİSTEMLERİN SABİT VE HAREKETLİ İZLEME OPSİYONLARININ VERİM ANALİZİ

Hiwa Najmalddin NASRALDDIN

Karabük Üniversitesi
Lisansüstü Eğitim Enstitüsü
Enerji Sistemleri Mühendisliği Anabilim Dalı

Tez Danışmanı:
Prof. Dr. Hacı Mehmet ŞAHİN
Haziran 2023, 59 sayfa

Yat limanları gibi hizmet sektöründe faaliyet gösteren işletmelerde elektrik tüketimi önemli bir maliyettir. Türkiye'de güneş enerjisinin elektrik amaçlı kullanımı çeşitli alanlarda yaygınlaşmasına rağmen, yat limanları bu teknolojiden henüz tam olarak yararlanamamıştır. Bu çalışmanın amacı, bir yat limanının elektrik ihtiyacının fotovoltaik (PV) sistemle karşılanmasının fizibilitesini incelemektir. Bu amaçla Muğla'da (Bodrum) bir yat limanı seçilmiş ve aylık/yıllık elektrik ihtiyacı belirlenmiştir. Bu çalışmada yat limanının elektrik ihtiyacını karşılamak için ihtiyaç duyulan PV kurulu gücü seçilmiştir. Fotovoltaik Coğrafi Bilgi Sistemi (PVGIS) kullanılarak üç farklı seçenek için simülasyonlar gerçekleştirilmiş olup, bu sistemler tek eksen izleme (SAT), çift eksen izleme (DAT) ve sabit seçeneklerdir. Hesaplamalar sonucunda 2012 kW kapasiteli tek eksen takipli bir PV sistemi 4.469.618 kWh/yıl elektrik üreterek yıllık elektrik ihtiyacını karşılamaya yetecektir. SAT PV sistemi için kurulum maliyeti geri ödeme süresinin 3,91 yıl olduğu tespit edilmiştir. Ayrıca hem

DAT hem de SAT PV sistemlerinin sabit seçeneklere göre daha verimli olduğu gözlemlenmiştir.

**Anahtar Kelimeler : **Güneş Enerjisi, Güneş Paneli, Eğim Açısı Değişimi, PVGIS
**Bilim Kodu : **92805

ACKNOWLEDGMENT

Throughout my thesis research, I would like to express my gratitude to my thesis adviser, Prof. Dr. Hacı Mehmet ŞAHİN, for his keen attention and assistance in the creation of this thesis. In addition, I would like to express my gratitude to Dr. Ali Raza DAL for his support. I would also like to thank a head department of Energy Systems, Prof. Dr. Mehmet ÖZKAYMAK and all the staff members of the department.

CONTENTS

Page

TABLE OF FIGUERS

Page

LIST OF TABLES

Page

SYMBOLS AND ABBREVITIONS INDEX

GW : Giga watt
GT : Gigaton
CO_2 : Carbon Dioxide
E : Energy (j)
h : Planck’s constant
ν : frequency of the light
RMSE : Root mean square error
S : Entropy, (kJ / K)
T : Temperature (^{0}C)
t : Time (min)
P_{in} : Power input (kWh)
P_{out} : Power output (kWh)
PEC : Power conversion efficiency
FF : Fill factor
γ : azimuth angle [°]
α : sun elevation angle [°]
β : inclination angle [°]
G : radiation [W/m^2]
$G_\mathbf{d}$: diffuse radiation [W/m^2]
G_b : direct radiation [W/m^2]
$G_\mathbf{r}$: reflected radiation [W/m^2]
$G_\mathbf{0}$: total of solar radiation outside the atmosphere [W/m^2]
G_T' : total solar irradiance
T' : normalized panel temperature
k : coefficients
σ : solar zenith angle [°]
ρ : surface reflectivity
η : efficiency

ABBREVITIONS

(PV) : photovoltaic
(AC) : current
(DC) : direct current
Eg : energy of the gap
(mono c.Si) : Silicon monocrystalline
(poly c.Si) : Silicon polycrystalline
(poly c.Si) : Silicon Polycrystalline silicon
(CdTe) : Cadmium telluride
(CIGS) : Copper indium gallium selenide
(a:Si.H) : Amorphous Si
(GaAs) : Gallium arsenide
(BOS) : Balance of System
(Voc) : Open circuit voltage
(Isc) : Short circuit current
(Mpp) : Maximum power point
(PVGIS) : Photovoltaic Geographical Information System
DAT : double axis tracking
SAT : single axis tracking

PART 1

INTRODUCTION

Electricity is used in almost every aspect of our lives today. Many of our appliances and equipment have been updated to include electronic circuitry because of technological advancements over time. However, as the world's fossil fuel reserves diminish and developed nations have increased their use of fossil fuels burned since the Industrial Revolution, society's reliance on electricity is becoming problematic. Two of its major issues, on the other hand, have come to light over the past two decade. The first concern concerns energy security and the scarcity of fossil fuel resources. The world's oil reserves are considered a finite resource, and the demand for timber will continue to rise. This growth will put a lot of pressure on resources that are already limited. Additionally, these resources frequently exist in conflict zones like the Middle East, and their prices vary greatly. The second problem is manmade global warming, sometimes referred to as climate change. It is a commonly held belief that burning fossil fuels releases greenhouse gases (GHGs) into the atmosphere, including carbon dioxide and methane, which alter the planet's climate and weather patterns. According to the International Renewable Energy Agency (IRENA), renewable energy installed capacity in 2022 It is 3,372 GW in the world and 56 GW in Turkiye. While the solar energy installed power was 1053 GW in the world, it increased to 9.42 GW in Turkiye [1]. According to the report published by IRENA [2] It is stated that by 2050, 25% of the global electricity worldwide will be met by solar energy. It is stated that with the rapid use of PV technology alone, 4.9 GT (Gigaton) Carbon Dioxide (CO_2) emissions will decrease in 2050 and solar energy will continue to be a rapidly developing industry in parallel with the developments in the industry. Researchers foresee that because of environmental change, there will be more outrageous climate occasions, like floods and dry seasons, and worldwide normal temperatures will increase. Naturally, this has an effect on the planet's animals and plants. If nothing is done immediately, many species run the risk of disappearing. Manmade environmental change has been perceived by legislatures at all levels in both created and agricultural nations as the pressing requirement for global activity to moderate its effects. The measure calls for reducing the usage of fossil fuels and, as a result, cut down on emissions of greenhouse gases. The substitution of cleaner, lower emission technologies for fossil fuels will be crucial to the initiative's success. As a result, wind and solar energy based renewable energy technologies will contribute significantly to lowering global emissions of greenhouse gases and may eventually account for a significant portion of global energy production [3]. Due to their potential, cleanliness, and environmental friendliness, as well as from the need to fulfil this expanding demand and escape rising oil prices, interest in renewable energy technologies such as solar power is desired more than other energy sources [4].

Yacht tourism is a sector that allows people to travel on the seas. It contributes to the promotion of the country, especially in countries with a coastline. Marinas, on the other hand, are coastal structures built for safe accommodation of yachts. These ports constitute an important source of income for the country's economies. In our country, marinas are densely located in the Mediterranean and Aegean regions. There are 61 marinas on the Turkish coast with a total mooring capacity of 24,728 yachts. There are 4 marinas with a total mooring capacity of 2,425 3 yachts in Bodrum alone [5]. 9.8% of the total yacht mooring capacity in Turkiye is located within the borders of Bodrum district. In addition to the administrative and social buildings in the marinas, hot water and electrical energy are needed in the services provided to the yachts in the harbour. Marinas meet their electricity needs from the city grid. It is important that the electricity used in marinas is obtained by utilizing solar energy. Although the opportunity to benefit from solar energy varies according to geographical conditions and seasons, the convenience of solar energy in the Mediterranean makes it advantageous for marinas to benefit from solar energy. In addition, electricity generation from solar energy has started to be implemented by installing PV panels on the roof of the warehouses and sea surface of many passenger and cargo handling ports in the world. Although the use of electricity based on solar energy has become widespread in many sectors in Turkiye, this technology is not yet utilized in marinas.
Turkiye is at the forefront of the world in terms of solar energy potential due to its geographical location. In terms of solar energy potential, all regions except the Black

Sea Region are investment grade [6]. When the Solar Energy Potential Atlas (GEPA) [7] and the Global Solar Atlas (KGA) [8] prepared by the Ministry of Energy and Natural Resources (MENR) are examined It is understood that the south of the Aegean Region, the Mediterranean Region, the Central Anatolian Region and the Southeastern Anatolia Regions are advantageous regions in terms of solar energy potential. Bodrum, located in the Aegean Region of Turkiye, is one of the districts that receives more solar radiation. The solar radiation distribution of Bodrum district of Muğla is seen in Figure 1.1.

When the literature is examined, many studies have been carried out on solar tracking systems to measure solar energy potential and to achieve maximum efficiency in the world and in our country. Single axis moving solar tracking system increases energy efficiency by 31% compared to fixed system, and double axis moving solar tracking systems increase energy efficiency by 34.37% compared to fixed systems [45]. In the study conducted by Eke and Şentürk at Muğla University, they found that the dual axis solar tracking system is 30.79% more efficient than the inclined fixed system [46]. The study by Chang found that the single axis tracking system is 18.7% more efficient than the fixed panel [47]. In the study by Abdallah and Nijmeh was stated that the two-axis movable system showed an efficiency increase of up 5 to 41.34% in total energy compared to the fixed system [48]. It was suggested that PV panels should be adjusted to the optimum inclination angle of that month once a month with the help of a simple and economical mechanism, instead of being placed with constant tilt angles throughout the year or season [49]. In the use of PVs in the vertical shell of the building, it is imperative to take formal measures to provide the necessary inclination and orbital movement [50]. Huang et al., in their experimental study, stated that the power produced in a single axis three position solar tracker solar PV system in a region with high solar radiation would be 37.5% higher than the fixed PV system [51]. In solar panel system measurements with programmable tracking control by Sungur reported that the tracking. Controlled solar panel system produced 42.6% more energy compared to the fixed system [52]. In the study conducted by Yılmaz, it was stated that the efficiency of the dual. Axis movable system is 31.67% more annually than the fixed system, and this efficiency is measured as 70% in the winter months and 11% in the summer months [53]. In order to reveal the real energy production potential in

Greece, power and efficiency comparisons of 42 single axis movable and 82 double axis movable PV systems were made compared to the fixed system. According to these data, it was found that the single axis movable system was 25.2% more efficient than the fixed system, and the double axis movable system was 34.5% more efficient than the fixed system [54]. In another study, a fixed PV system with a panel power of 142.4 Wp and a uniaxial moving PV system were compared, and the system had an efficiency increase of 12% to 20% compared to the fixed axis system [55]. Maximum efficiency is obtained when the angle between the sun and the panel surface is steep. In order to achieve this, the PV panels must move so that the rays are perpendicular from sunrise to sunset.

Bodrum district is an important settlement for the application of PV system in terms of marinas. However, as in our country, there is no electricity generation application from the PV system in the marinas in Bodrum district. In this study, it is aimed to provide electricity consumption with the PV system to be installed at the facility without paying the electricity fee of the marina by using the minimum installed power in a model marina in Bodrum district. With the PV system to be installed in the marina, the process of meeting the consumption, selling the surplus electricity to the grid and purchasing electricity from the grid in case of need has been calculated. Calculations Efficiency analysis was made by simulating electricity generation in case of fixed axis, single axis tracking (SAT) and double axis tracking (DAT) options of PV systems.

Figure 1.1. Solar radiation distribution of Muğla / Bodrum district.

Getting the most energy out of a solar panel while avoiding shading is a crucial goal when installing one. A PV panel must be positioned so that the sun's rays hit it vertically in order to capture the most sunlight possible. Otherwise, it will not generate the maximum amount of power. Using tracking systems is one way to collect as much energy as possible each day [9]. A mechanical instrument called a tracker moves in the same direction as the sun does during its daily arc across the sky. Trackers, however, are pricey and not necessarily necessary [10].

The purpose of this research is to determine whether it is feasible to use a photovoltaic (PV) system to meet a marina's electrical needs. For this purpose, a marina in Muğla (Bodrum) was selected, and monthly/yearly electricity needs were determined. In this study, the PV installed capacity needed to meet the marina's electricity demand was selected. Simulations were performed for three different options using the Photovoltaic Geographical Information System (PVGIS).

1.1. BACKGROUND

1.2. A BRIEF HISTORY OF PHOTOVOLTAIC TECHNOLOGY

Solar power is also referred to as photovoltaic (PV) technology. The Latin words photo (light) and voltaic are the origin of the name photovoltaic (energy). Photovoltaic systems utilise light energy, or the energy of the sun, to transform it into electricity.

The fundamental idea behind solar cells, also known as photovoltaic (PV) cells, is the process of converting light into electricity using a semiconductor material. The semiconductor absorbs photons when sunlight strikes it, which causes the electrons to flow and creates voltage. Direct current (DC) is then produced from this voltage by the cell's unidirectional flow of electrons. Although this technology appears to be recent, the first solar cells were made by Charles Fritts in 1883. [11]. The photoelectric effect, which is the scientific basis for solar cells, was discovered in the late 1830s, and Albert Einstein was awarded the Nobel Prize in Physics in 1921 for discovering it. [12]. In the 1950s, the first solar cell technology was created with space travel in mind. They are perfect for this application because they are dependable, require little upkeep (since there are no moving parts), and only need sunlight, which is almost always available. The solar cells continued to function for a few years after NASA did not anticipate them to, which allowed the satellite to continue sending data to earth even after it was no longer required and occupied bandwidth. Due to the oil crisis and OPEC in the middle of the 1970s [13]. Carlson and Wronski created the first amorphous silicon cell in an effort to build solar cells that are more affordable and effective. This discovery was important because amorphous silicon, which is also employed in the thin film transistors featured in contemporary flat panel displays, is less expensive than traditional crystalline silicon. The cost of these panels has significantly decreased as a result of their mass manufacture, and solar cell prices are following a similar pattern.

The solar PV industry made strides in the 1980s to increase efficiency and introduce new types of solar cells. made from materials such as GaAs, CdTe, $CuInSe_2$, TiO_2 dye-sensitized, and various types of silicon. By the 1990s, solar cells with more than 10% efficiency were being produced on a large scale. Today, prices for solar cells continue to drop, and research is actively being conducted on new "3. Generation" solar cells [14].

A photovoltaic device developed by the National Renewable Energy Laboratory (NREL) in August 2008 that could convert 40.8% of the light falling on it into energy set a new world record for solar cell efficiency. This is one of the highest efficiency levels for a solar cell that has ever been attained [15].

1.2.1. V Technology

PVs devices produce electrical energy directly from sunlight [16]. At the same time, PV systems convert sunlight into electrical energy have high investment costs and low operating costs [17]. The two categories of PV systems are those with storage and those connected to the grid. Battery powered storage devices hold the electrical energy generated by solar panels until it is needed. Grid connected systems (on grid) use a PV system to generate all of the electricity required, and any surplus is fed back into the power grid. The activation of the mains power in the absence of the sun provides continuous energy while the electricity produced by the PV system is in use. Given that daytime demand of power reaches its peak levels, the widespread deployment of grid connected systems will both lessen the load on the grid and ease the distribution of grid electricity by supplying the grid with any excess electricity generated [18].

1.2.2. Working Principle

The photovoltaic effect, which describes the formation of a potential difference at the interface of two different materials when subjected to electromagnetic radiation, serves as the foundation for solar cells' operation. This effect is closely related to the photoelectric effect, in which the emission of electrons results from the absorption of light with a frequency above a material specific threshold frequency. Albert Einstein created a hypothesis in 1905 that clarified this phenomenon by stating that light is made up of discrete energy packets known as photons. The frequency of a photon determines its energy.

$$E = h\nu, \tag{3.1}$$

where h is Planck's constant and ν is the frequency of the light. In 1921, Einstein won the Physics Nobel Prize for his explanation of the photoelectric phenomenon. Three fundamental mechanisms can be used to categorize the photovoltaic effect.

1.2.3. Creation of Charge Carriers as a Result of Photons Being Absorbed by the Junction's Materials

An electron gets excited from its initial energy level E_i to a higher energy level E_f when a photon is absorbed by a substance as shown in Figure 1.2. (a).

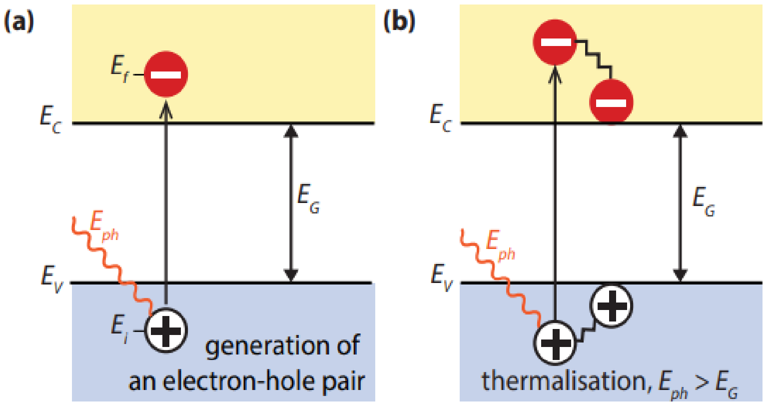


Figure 1.2. (a) Example of a bandgap semiconductor for the absorption of a photon. Eg. From Ei to Ef, an electron is excited by a photon with energy Eph = hv. Ei produces a hole. (b) If Eph > Eg, some energy is thermalized.

A photon can only be absorbed when it interacts with an ideal semiconductor if the electron has energy levels that meet the photon's energy requirement. The bandgap, or the difference between these energy levels, controls whether or not the photon may be absorbed. Between the valence and conduction bands, which are separated by the bandgap in an ideal semiconductor, there are no permitted energy states. A photon that interacts with an ideal semiconductor with less energy than the bandgap will travel through the substance without being absorbed. The valence and conduction bands of a true semiconductor are not flat; instead, they change according to the k-vector, which characterizes the crystal momentum of the semiconductor. An electron can be stimulated without changing the crystal momentum when the valence band maximum and conduction band minimum occur at the same k-vector. Direct bandgap materials are semiconductors that can be stimulated without changing the crystal momentum. On the other hand, a material is said to have an indirect bandgap if the electron cannot be stimulated without altering the crystal momentum. Because they have a higher absorption coefficient, direct bandgap materials are appropriate for thinner absorbers. A vacuum at E_i is generated when an electron is stimulated from E_i to E_f and behaves as a particle with a positive elementary charge known as a hole seen in Figure 1.2. (b). A photon's absorption causes the production of an electron-hole pair as described in Figure 1.3.

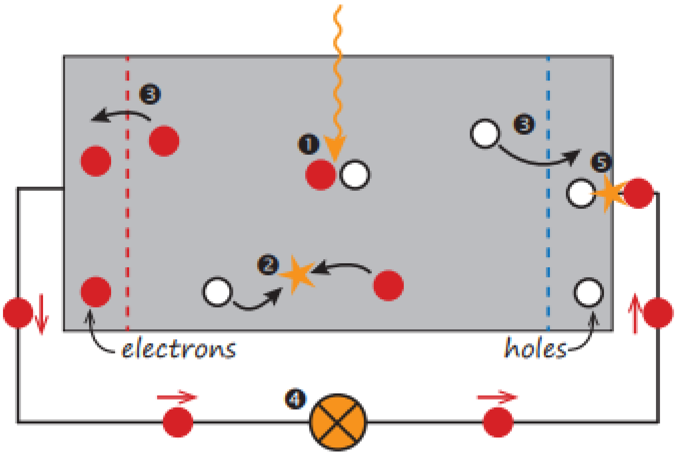


Figure 1.3. Basic model of a solar cell. ❶ an electron-hole pair is created as a result of photon absorption.❷ the electrons and holes will often merge.❸ the separation of electrons and holes is possible with semi.permeable membranes.. ❹ an electric circuit can be powered by the split electrons.❺ the electrons will unite with holes once they have completed the circuit.

A photon's energy is converted into the energy of an electron-hole pair. The rules of thermodynamics, however, prevent this process from operating at its maximum efficiency. The maximum efficiency varies from 67 percent for unconcentrated sunlight to 86% for fully concentrated sunlight [19].

1.2.4. Separation of the Charge Carriers Produced by Photons in the Junction Later

Figure 1.2. (a) and (b) show how an electron-hole pair often recombines after being created by returning to its initial energy level. A photon (radiative recombination) or additional electrons, holes, or lattice vibrations may be produced as a result of the energy released (nonradiative recombination). Semipermeable membranes are necessary on both sides of the absorber in order to use the energy held in the electron-hole pair. These membranes enable the passage of holes and electrons via one membrane, respectively 19], according to Figure 1.3. In most solar cells, these membranes are typically formed using n. and p-type materials. The solar cell must be built so that the electrons and holes may reach the membranes before they recombine to prevent recombination of the charge carriers before they reach the membranes. As

a result, the thickness of the absorber is constrained since the time it takes charge carriers to reach the membranes must be shorter than their lifetime.

1.2.5. Collection of the Photo-Generated Charge Carriers at the Terminals of the Junction at the Junction's Terminals, Charge Carriers Created By Photography are Collected

As depicted in Figure 1.2. (a) and (b), the solar cells remove the charge carriers via electrical contacts so that they can work in an external circuit. At this point, the electron-hole pair's chemical energy has fully been converted to electric energy. After flowing through the circuit, the electrons then recombine with the holes at a metal absorber contact, as shown in Figure 1.3.

1.3. PHOTOVOLTAIC MATERIALS

Solar cells are typically composed of semiconductors, with silicon being the most crucial one. Semiconductors possess unique electronic properties that determine their ability to conduct or insulate based on their chemical makeup. In the realm of photovoltaic materials, semiconductors play a significant role, with most doping occurring through the use of boron and phosphorous in silicon solar cells. There are numerous types of solar cells, including cadmium telluride (CdTe), with most of the doping occurring in silicon solar cells that employ boron and phosphorus. Solar cells come in a variety of forms, including cadmium telluride (CdTe), which is produced by utilizing cadmium and tellurium, as well as gallium arsenide and copper indium Di selenide seen in Figure 1.4. The fourth group of elements' semiconductor silicon has a diamond-like lattice structure with four valence electrons per silicon atom, as shown in Figure 1.5. The bulk of solar cells are made of silicon, which has four nearest neighbours and has the same location in the lattice with every other atom. With its nearest neighbours, the element silicon, which has four electrons, forms bonds. It is a semiconductor that is vital to the creation of integrated circuits, which are what give rise to contemporary computers [20].

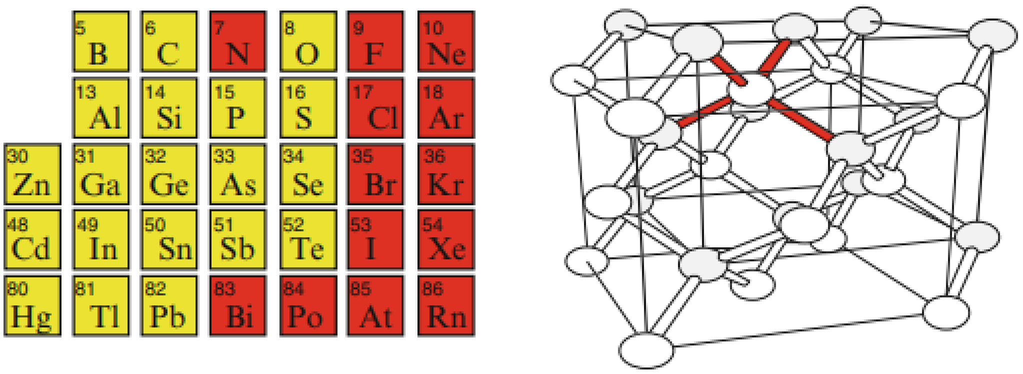


Figure 1.4. Silicon crystal.

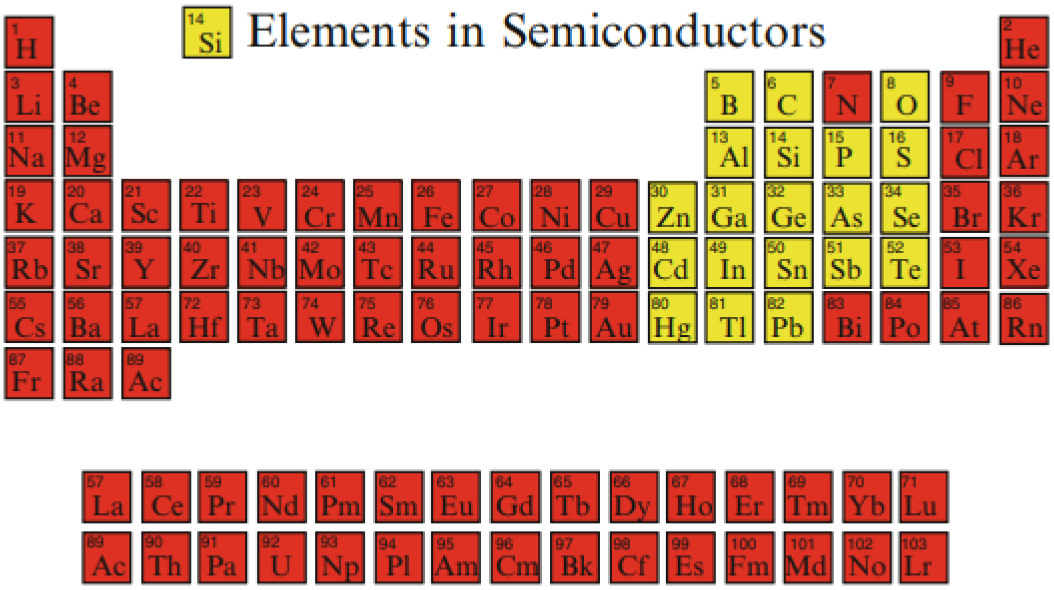


Figure 1.5. Periodic table.

1.3.1. Band Theory

In accordance with their electronic structure, materials can be divided into three groups according to band theory. insulators, conductors, and semiconductors. According to the hypothesis, energy gaps and bands exist and govern how electrons behave in solids. Many physical characteristics of solids, including as optical absorption and electric resistivity, have been successfully explained by this theory. The valence band in conductors is positioned below the conduction band, allowing for the simple movement of free electrons and electrical conduction. In insulators, on the other hand, the energy gap between the two bands is large, making it challenging for charge to pass from the bottom (valence) to the top (conduction) band [21]. The bandgap, also referred to as the space between the valence and conduction bands in semiconductors, is symbolized by the symbol E_g (energy of the gap). Both semiconductors and insulators are shown to have the Fermi energy (E_f). Starting with an empty system and gradually adding particles, filling the lowest-energy vacant quantum states in a row, the ground state of a non-interacting fermion system, such as one containing electrons, is created. If there is a level where half of the states are occupied with electrons, the level is known as the Fermi energy.

1.3.2. Energy Bands in Semiconductors

According to Figure 1.6, there are three different types of semiconductors. 1. innate, n-type, and p-type

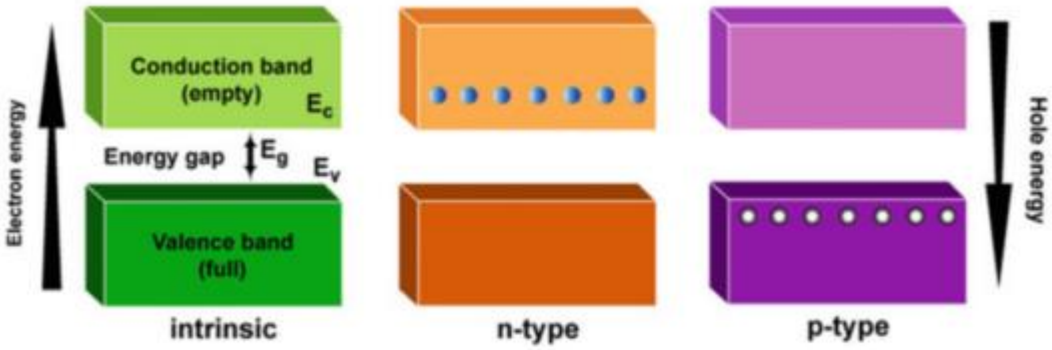


Figure 1.6. Intrinsic, n.type, and p.type semiconductor.

Types 2 and 3 semiconductors are those that conduct electricity. By doping, or alloying, a semiconductor with an impurity. Carriers removed from the valence band or carriers positioned in the conduction band.

1.3.3. The Integral Type

The semiconductor that is pure or intrinsic has an adequate number of electrons to fill its valence band, leading to an empty conduction band. Due to the electrons being in a full valence, the pure semiconductor functions as an insulator, preventing electron movement.

1.3.4. The n-Type

The silicon melts from which the crystal is produced has an atom from group 5 impurity added so that the negatively charged electrons carry the current. The outer 4/5 of the valence band is filled with electrons. After that, 1/5 is placed in the conduction band.

The "donors" are these impurity atoms. The crystal becomes a "conductor" when the electrons migrate within the conduction band.

1.3.5. The p-Type

The addition of Group 3 to silicon melt transforms the current carried by empty electron holes into positively charged particles. Doping causes an electron shortage in the valence band, where 4 of the 3 outer electrons are required. Current is carried by missing electrons, also referred to as holes. The primary carriers are what are currently being charged. "Electrons" are the current charge carriers in n-type. "Holes" are the current charge carriers in the p-type.

1.3.6. Creating a-Junction

There are four main types of semiconductor junctions n, p Schottky barriers, and heterojunctions. All these junctions have an inherent potential. Four different types of junctions can be created by joining two identical semiconductors, each of which has a unique inherent potential or voltage [22].

1.4. PV MODULES

1.4.1. Crystalline SILICON PV MODULE

The first generation of solar modules are these PV modules. C-Si modules currently hold the largest market share in the PV industry. Currently in the market, two different types of c.

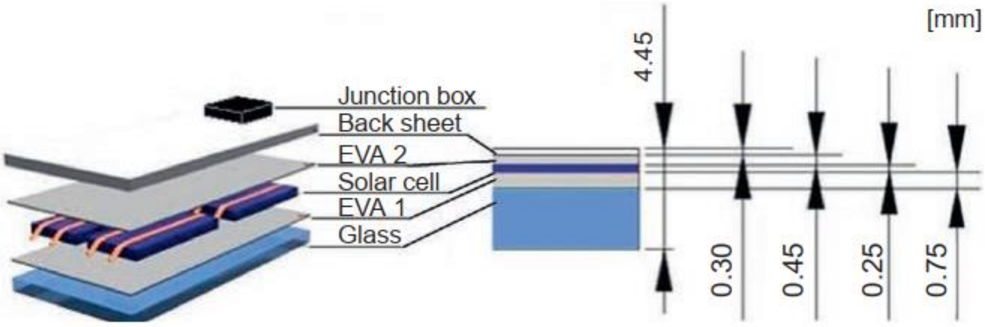


Figure 1.7. structure of a c-Si based PV module

Si modules are available. Polycrystalline and monocrystalline (mono c-Si) materials (poly c-Si). The c-Si PV cells are connected in series and parallel to create these modules. [23]. When examining the cell level structure, silicon wafers, which are slices of silicon, make up c-Si PV cells. On these wafers, the c-Si cells are produced, and after receiving the electrical connectors, they are mechanically joined. [24]. Figure 1.7. displays a straightforward stricture of a crystalline silicon photovoltaic module.

1.4.2. Crystalline PV Module Types

Two categories of thin-film modules exist. Silicon that is monocrystalline (mono c-Si). The PV market will continue to be dominated by this c-Si module because it is widely used. These modules appear to be easily accessible right now, and they already offer a wide range of advantages. The low price is the only primary motivator. P-doped wafers with p. n junctions make up the cells utilized to create c-Si modules. The c-Si ingot is initially produced during the fabrication process. Then, wafers with a size smaller than 0.3mm are created from this c-Si ingot. Together, these components make up the entire solar cell structure, which can generate 35mA current at 0.55V under full illumination. These modules typically feature a distinctive surface roughness that is most frequently. These modules typically feature a unique surface roughness that, in most cases, resembles a pyramidal shape.

These solar cells are put together to create a PV module based on the voltage and currents needed. These cells are organized in series and parallel patterns with conductive contacts during the module's fabrication [25].

Polycrystalline silicon (poly c-Si). The market for poly c-Si c-Si PV modules is a little bit less than for mono c-Si modules. Metal contamination is a problem with mono c-Si, so the industry developed poly c-Si cells to reduce these issues. Similar to the mono c-Si, modules are likewise constructed here by connecting cells in series and parallel configurations. The cells are created with various crystal formations in mind. In silicon, both melting and solidification occur. Through this procedure, crystals with a single orientation are created, which are later transformed into thin blocks and wafers. These solar cells come with an extra layer that reduces light reflection and have random patterns on their surfaces [25].

1.4.3. Thin-Film PV Modules

The second generation of solar systems is referred to as thin-film photovoltaics (PVs). A thin-film module is made up of multiple connected solar cells.

A thin layer solar cell's general anatomy layout is shown in Figure 1.8. The semiconductor is typically placed between two sheets of glass and sealed with an industrial laminate in a thin-film solar panel. Typically, an antireflecting coating is utilized to lessen light reflection from the panels' surface. The term "thin-film modules" refers to components that employ a few thin absorbent layers and consume more than 300 times less silicon than traditional crystalline silicon (c-Si). The PV active layer thickness ranges from a few nanometres to tens of micrometres. Reducing the high cost required to make the monocrystalline and polycrystalline silicon modules is one of the most significant objectives to be reached by manufacturing the thin-film modules. However, compared to first-generation c-Si solar panels, thin-film modules are less powerful and more fragile.

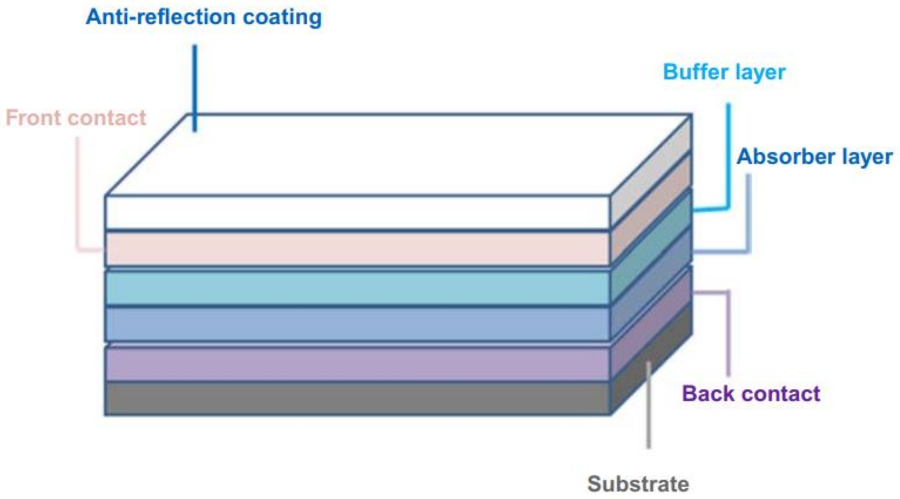


Figure 1.8. The anatomy of a thin layer solar cell.

1.4.4. Thin-Film PV Module Types

There are various kinds of thin-film modules, including. Tellurium-Cadmium (Cd-Te). This PV cell has a high light absorption rate due to its 1.45eV straight bandgap. Because it controls half of the thin film market, Cd-Te is a top thin-film technology. Closed-space sublimation (CSS), simple evaporation, electrodeposition, chemical vapor deposition, metal-organic spray deposition, and screen-print deposition are the most frequently utilized methods for depositing the Cd-Te thin layer [26]. The CSS method creates the most effective modules. The CdT-e modules' 2015 efficiency record stands at 180.5 percent. The toxicity of the Cd Materia in these modules is one of their key problems [27].

Copper indium gallium selenide (CIGS). It is a direct bandgap semiconductor material with interchangeable polycrystalline and chalcopyrite crystal structures. Due to its stoichiometry, CuIn(1x)Ga(x)Se2, the bandgap can be set between 1.0 and 1.7 eV. The amount of gallium and indium can range from 0 to 1. The module's highest efficiency ever is 19.5 percent [27]. Growing CIGS involves a variety of procedures, including the sequential and evaporation processes. The usage of selenium rich content and copper-poor amounts less than 25 at. percent results in high quality film with fewer shunts. Grading the bandgap by adjusting the amount of Ga and Se is one of the most effective ways to increase the efficiency of this technology. Alkali materials, such as sodium, can be used to increase the efficiency of CIGS because they passivate grain boundary flaws, which are one of the key problems limiting the effectiveness of CIGS. [28].

Amorphous Si (a-Si. H). It is Si in its nanocrystalline form. Between 1.7 and 1.9 eV are possible bandgap values [29]. Magnetron evaporation, plasma-enhanced chemical vapor deposition (PECVD), and very high frequency CVD are the deposition methods utilized to create a-Si. The ease of gas doping, the ability to stack without material limitations, and the capacity for deposition on flexible substrates are just a few benefits of a-Si. H. Its shortcomings include sensitivity to strong solar radiation, a short diffusion length, and poor charge mobility. Efficiency of the a-Si solar module is 9.8%. [29].

Gallium arsenide (GaAs). This 1.43 eV direct bandgap technique is used. Epitaxial growth, close-spaced vapor transport (CSVT), metal-organic vapor phase epitaxy (MOVPE), and the recently employed low-cost method, hydride vapor phase epitaxy (HVPE), are the well-known deposition processes in this technology [30]. Up to 25.10.8 percent of the module's efficiency was possible. Other promising thin-film technologies, such as organic, perovskite, copper zinc tin sulphide, and quantum dot solar cells, have recently been created on a laboratory scale or are in the early phases of commercialisation[30].The maximum module efficiency was 25.10.8 percent. Other promising thin-film technologies, such as organic, perovskite, copper zinc tin sulphide, and quantum dot solar cells, have recently been created on a lab scale or are in the early phases of commercialisation.

1.5. VARIOUS PV SYSTEM TYPES

Depending on the specific requirements, photovoltaic (PV) systems can be simple or sophisticated. A PV module and load are adequate for straightforward applications. For instance, a PV module can be used to directly power a water pump motor that only runs during the day. A more complex system that can run day and night, supply power throughout both the day and the night, and provide reserve power is needed for a whole house. A backup generator might also be included in specific circumstances. PV systems come in three basic varieties. Stand-alone, grid-connected, and hybrid. Although a PV system's basic components and principles stay the same, the kind and number of these components vary depending on the situation.

1.5.1. Stand-Alone Systems

Only solar energy is used by standalone solar power systems. Both PV modules and a load can be used in these systems, or batteries can be used to store energy. Charge regulators are placed in battery-powered systems to stop PV modules from producing extra energy once the batteries are fully charged. To stop the batteries from discharging below a specific point, the regulators may also turn off the load. Batteries must have enough storage space to be able to hold the energy produced during the day for usage at night or in inclement weather in order to function properly. Examples of standalone solar power systems are shown schematically in Figure 1.9., including a straightforward DC PV system without a battery (a) and a larger PV system with both DC and AC loads (b).

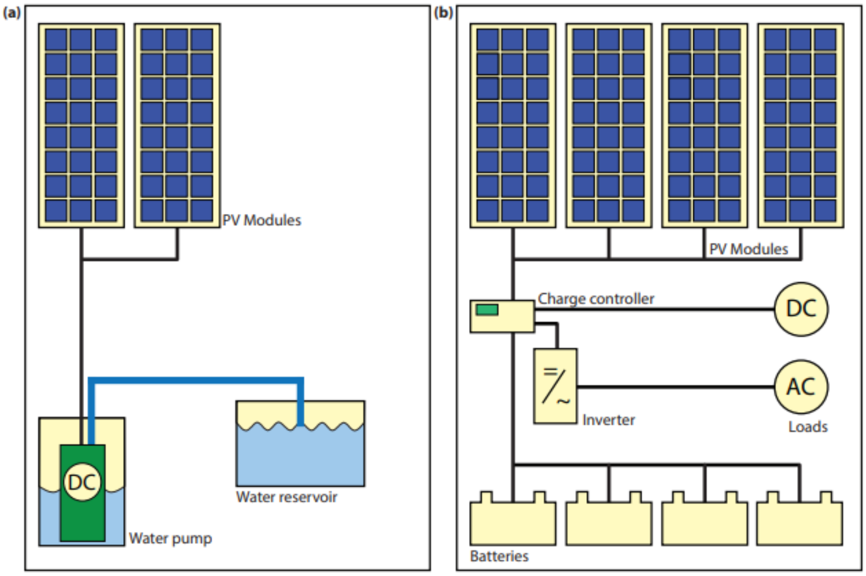


Figure 1.9. A simple DC PV system to power a water pump with no energy storage is shown schematically in (a), whereas a complicated PV system with batteries, power conditioners, and both DC and AC loads is shown schematically in (b).

1.5.2. Grid-Connected Systems

For developing integrated applications, grid-connected PV systems are growing in popularity.

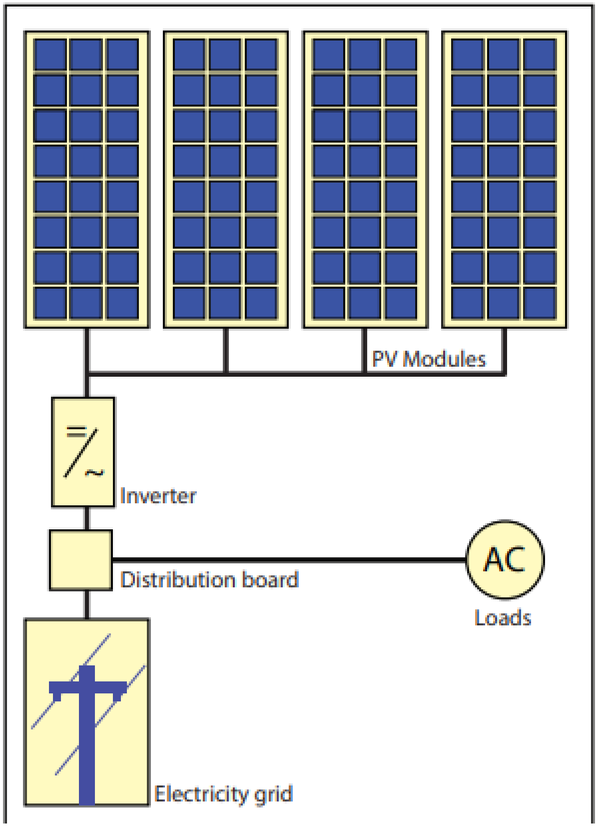


Figure 1.10. An illustration of a PV system that is connected to the grid

Figure 1.10. illustrates that by converting DC power into AC electricity, inverters are used to link these systems to the grid. Small systems, especially those installed in private residences, include an inverter attached to the distribution board. The grid or AC appliances in the house are powered by the electricity the PV produces. These systems are linked to the grid, which provides a buffer for transmitting excess PV power and a source of electricity for the residence at times when PV power generation is insufficient. Batteries are not needed for them. Large PV fields serve as power plants, sending all electricity produced by them directly to the electrical grid. Their peak power range can be in the several hundred MWp range.

1.5.3. Hybrid Systems

A hybrid system combines solar panels with an additional power source, such as a gas, diesel, or wind generator. A hybrid system is shown schematically in Figure 1.11. Hybrid systems need more sophisticated controls than standalone, or grid connected PV systems to optimize the multiple electricity producing techniques. In a PV/diesel system, for instance, the diesel engine should be turned on when the battery reaches a certain degree of discharge and off when the battery has sufficiently charged. The backup generator can be used to power the load or recharge batteries.

1.5.4. Items That Make Up a PV System

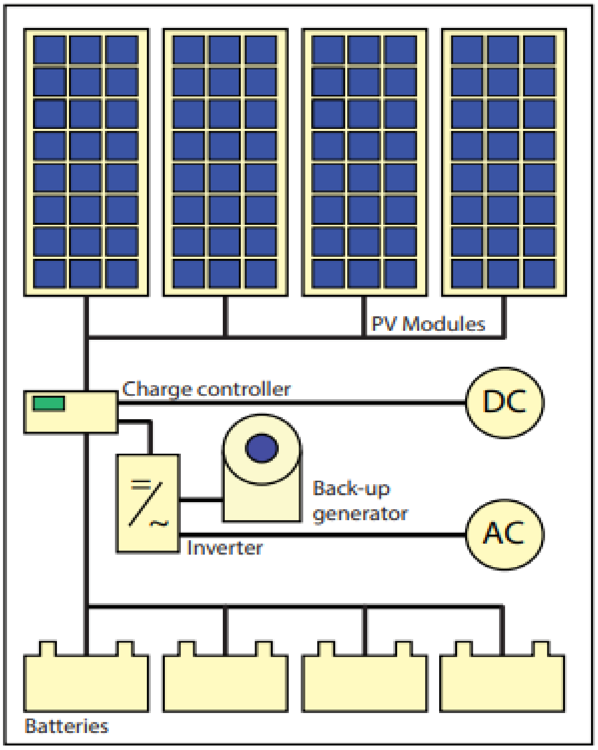


Figure 1.11. Diagram of a hybrid photovoltaic system with a diesel generator as a backup power source.

Solar cells can transform solar radiation into electrical energy, but because of their small size, they can only produce a limited amount of power under specific current-voltage parameters. Multiple solar cells must be linked together to create a solar panel, sometimes referred to as a PV module, in order to utilise solar energy for practical devices that need a specific voltage and/or current. Solar panels are joined to create solar arrays for large-scale solar electricity generation. In addition to the solar panels, which form the system's core, the PV system also includes numerous other parts, collectively referred to as the Balance of System (BOS). Whether a system is standalone or connected to the electrical grid determines the components needed to make it function. The following are the BOS's most crucial parts.

- A mounting structure is utilized to secure the modules and point them toward the sun.
- Energy storage is an essential component of standalone systems since it ensures the system's ability to deliver power at night and during periods of severe weather. Batteries are typically employed as energy storage devices.
- DC-DC converters are used to change the module output from a variable voltage that changes with the time of day and the weather to a constant voltage output that, for example, can be used to charge a battery or that is used as input for an inverter in a grid connected system.
- In grid connected systems, inverters or DC-AC converters are used to transform DC electricity generated by PV modules into AC electricity that can be sent into the power grid.
- The various parts of the PV system are connected to the electrical load and to one another using cables. To reduce resistive losses, it's crucial to use cables that are thick enough.

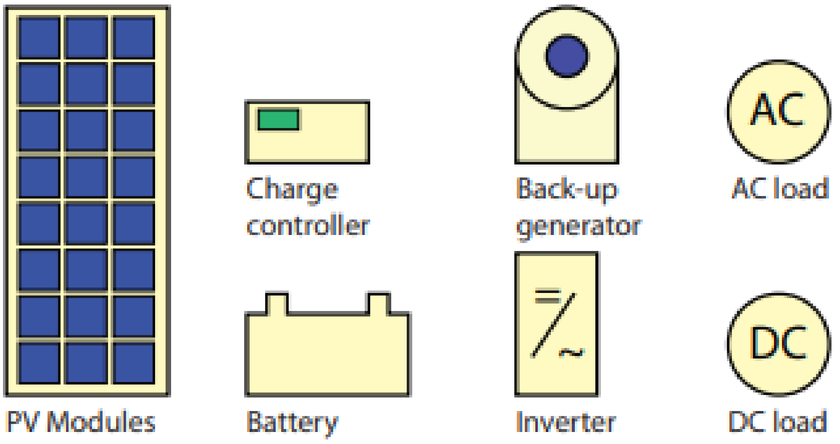


Figure 1.12. A schematic of the different components of a PV system

Solar radiation can be converted into electrical energy in a solar cell. However, because to its small size and limited power output, it is not viable for most applications. A solar panel, sometimes referred to as a PV module, is made by joining numerous solar cells together to harness solar energy for useful devices. Solar panels are connected to create solar arrays, which are used to generate solar electricity on a huge scale. A PV system needs Balance of System (BOS) components in addition to solar panels to function properly. Whether or not the system is connected to the electrical grid will determine whether BOS components are necessary.

1.6. SYSTEM CONFIGURATIONS

Before getting into the specifics of the many converter topologies utilized in PV systems for power conversion, a brief overview of various system architecture will be provided. How PV modules are connected to one another and how the grid interface is created are both governed by the system design. Which of these system architectures will be used in a certain PV plan relies on a few variables, including the plant's surroundings (such as whether it is in an urban area or in an open area), scalability, costs, etc. seen in Figure 1.12.

An outline of several system architectures is provided. The key benefits and drawbacks of the various architectures are covered here. Solar inverters should, in general, possess the following qualities. • Inverters should be extremely efficient because the owner of the solar system demands that the greatest amount of generated energy be transmitted to the grid or load.

- Specific requirements for the potential between solar panels and the ground (depending on the solar module type).
- Special safety features like the capacity to detect active islanding.
- Low limits for the line currents' harmonics. Since the harmonic limitations of both sources and loads connected to the grid are regulated, this requirement is usually enforced by legislation. Solar inverters should, in general, possess the following qualities.

- Inverters should be extremely efficient because the owner of the solar system demands that the greatest amount of generated energy be transmitted to the grid or load.
- Specific requirements for the potential between solar panels and the ground (depending on the solar module type).
- Special safety features like the capacity to detect active islanding.
- Low limits for the line currents' harmonics. Since the harmonic limitations of both sources and loads connected to the grid are regulated, this requirement is usually enforced by legislation.

Special demands on *electromagnetic interference* (EMI), which in most nations are governed by law. These are intended to reduce the unwelcome EMI influence on other equipment nearby or connected to the same source. Consider the impact of a cell phone on a vintage radio as an illustration.

- In many cases, the solar system must be deployed outside, and the inverters must meet strict requirements for humidity and temperature.
- Build with high ambient temperatures in mind.
- Built to operate for 20 years in challenging environmental conditions.
- Operation in silence (no audible noise).

We have to distinguish between *single-phase* and *three phase inverters*. Single-phase inverters are employed for modest powers, as they are frequently seen in tiny residential PV systems. They are linked to a particular grid phase. Three-phase inverters that are connected to all grid phases are utilized for higher powers. The currents traveling across the three phases would become extremely asymmetric if a large power was applied to one phase, which would cause a number of issues with the electrical grid. The term *inverter* is often used for two different things. First, the term "inverter" refers to the actual inverter, which is the electronic component that converts DC to AC. Second, the term "inverter" also refers to the entire manufactured unit, which in modern times typically includes an MPP tracker, a DC.DC converter, an AC converter, and possibly also a charge controller to which a battery is connected.

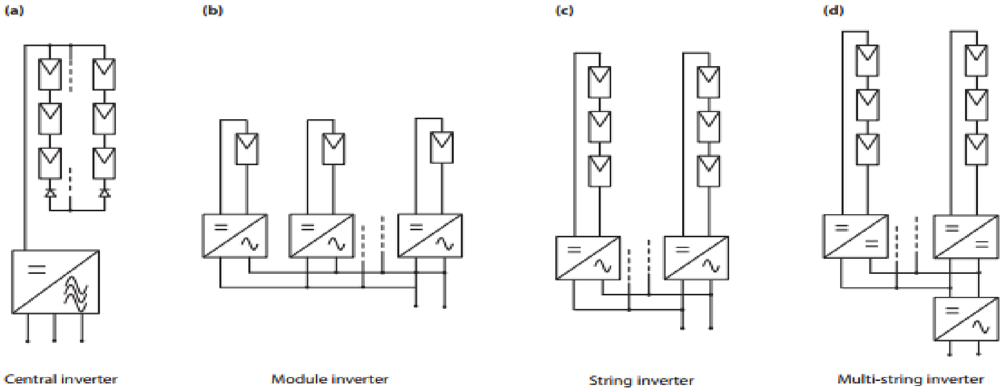


Figure 1.13. Different system architectures employed in PV systems.

1.6.1. Central Inverters

The simplest architecture used in PV systems is this one. PV modules are strung together in this instance, increasing the system voltage. The PV array, which is attached to a single central inverter, is created by connecting many strings in parallel. As shown in Figure 1.13. (a), three-phase inverter, the inverter carries out maximum power point tracking and power conversion. The majority of PV production on a very large scale uses this design, with a central inverter that is typically DC to three phases. A three-phase inverter can use a wide range of inverter topologies. They can be set up as three distinct DC.to.AC single phase units operating with a phase displacement of 120 degrees each or as a single DC to three phase unit, depending on the situation. The lowest specific cost is provided by connecting all PV modes in a single array in this centralized design (cost per kWp of installed power). Central inverters are the favoured choice in large-scale PV power plants since they are exceedingly dependable and only require a few components. Despite being straightforward and inexpensive specifically, the following drawbacks affect central inverters.

- The system's configuration allows for the use of DC wiring to transport a sizable amount of power across big distances. Due to the difficulty in interrupting fault DC currents, this may present safety concerns. It is necessary to take extra precautions, such thicker insulation on the DC cable and specialized circuit breakers, which might raise the cost.

- The same maximum PowerPoint is used by all strings, which causes mismatch losses in the modules. This is a serious drawback. With aging and partial shadowing of the array, mismatch losses grow even higher. Mismatches between the various strings may drastically lower the system's overall output.
- The system's lack of adaptability and expansion. Due of the high ratings, systems are typically created as a single unit and are therefore challenging to expand. In other words, there is not much flexibility in the system architecture. 4. The string diodes, which are connected in series with each string to stop current flow inside strings, suffer power losses.

1.6.2. Module Integrated or Module-Oriented Inverters

The construction of the module integrated inverters, as depicted in Figure 1.13. (b), is considerably different. These inverters have power ratings of several hundred watts and operate directly at one or more PV modules. The low voltage rating of the PV module necessitates a two-stage power conversion for these inverters. The DC voltage is increased to the desired level in the first stage of boosts, and in the second stage, it is reversed to AC. The full galvanic isolation provided by a high frequency transformer, which is frequently included, increases the system flexibility even more. These inverters, which go by the term "AC PV panels," are typically integrated with PV panels, as their name suggests. The system is made as flexible and expandable as possible in this way. The "plug and play" capability of this system, which enables the construction of a full (and easily extensible) PV system for a minimal investment cost, is one of its most distinctive features. The reduction of mismatch losses that can happen because of subpar MPPT is another benefit of these inverters. All of these benefits come with some costs. These inverters must function in challenging conditions, including high temperatures and significant daily and seasonal temperature changes, because they are mounted on a PV module. Additionally, the particular are the best inverter topologies. Numerous topologies for module integrated inverters have been put forth, and some of them have already been used in inverters that are now on the market.

1.6.3. String Inverters

String inverter, as illustrated in Figure 1.13 (c), combine with few trade-offs the benefits of both central and module integrated inverter designs. A PV string is made up of several PV modules connected in series, each with a power rating of up to 5 kWp and an open circuit voltage of up to 1 kV. The PV system can now be connected to the grid by using a number of smaller inverters.

The high DC voltage of the topology necessitates careful consideration, much as it did for the central inverter architecture, which is one of its drawbacks. Since string inverters are typically put in homes or on business buildings without a defined support structure or additional safety regulations, this issue is made even more crucial. The interconnection of the modules and the inverter is typically done by a licensed electrician. Special attention must also be paid to the system's protection, with a focus on appropriate DC cabling. The system's overall efficiency will be impacted by the partial darkening of the strings, but each string can be separately operated at its MPP. Additionally, series diodes are not required, unlike in PV arrays with multiple parallel strings, because there are no strings connected in parallel. As a result, these diodes have fewer losses. However, due to uneven current and power distribution within the string, there is still a chance that a hot spot will form.

1.6.4. Multi String Inverters

The Multi String inverter concept, shown in Figure 1.13. (d), was created to combine the benefits of a string inverter's higher energy production and a central inverter's less expensive operation. Individual PV strings are coupled to lower power DCDC converters, which individually optimize the energy production from each PV string. Each PV string has its own MPP tracking. Only a new string with a DC.DC converter needs to be added to expand the system within a specific power range. Through a central inverter and a DC bus, the grid is connected to all DC.DC converters.

1.6.5. DC-AC Converters (Inverters)

Different architectures utilized in PV systems for power conversion were previously covered in this section. The variable output from the PV modules was pushed to a level of constant voltage using DC.DC converters, which were also examined. MPPTs are typically employed in conjunction with these converters to achieve this goal.

Since most modern appliances are made for regular AC grids, most PV systems need a DC.AC converter. As was previously mentioned, the term "inverter" is used to describe both the DC.AC converter and the assembly of all the parts that make up the actual power converter.

1.6.6. The H-bridge inverter

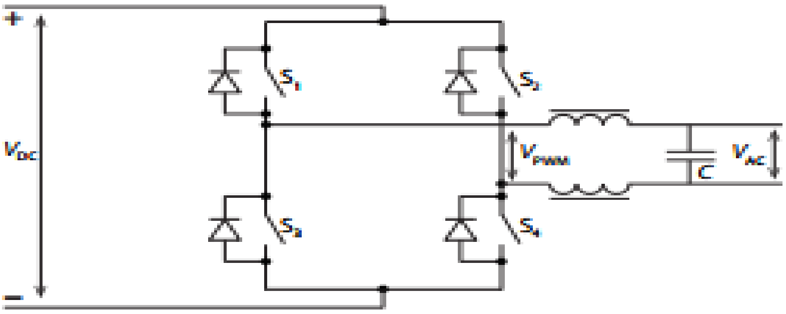


Figure 1.14. A simple representation of an H.bridge.

A very basic example of a so-called, H-bridge or full-bridge inverter is shown in Figure 1.14. The DC input is positioned on the left. Four switches surround the load, or in our case, the AC output. We can distinguish between three circumstances during normal operation.

1.7. SUN GEOMETRY

The sun's location in relation to a solar array is ever changing because of the Earth's orbit and rotation. In order to create an array that would be able to capture the most solar energy, designers use a variety of geometrical methods. Two angles, which change both daily and annually, define the sun's position, seen in Figure 1.15.

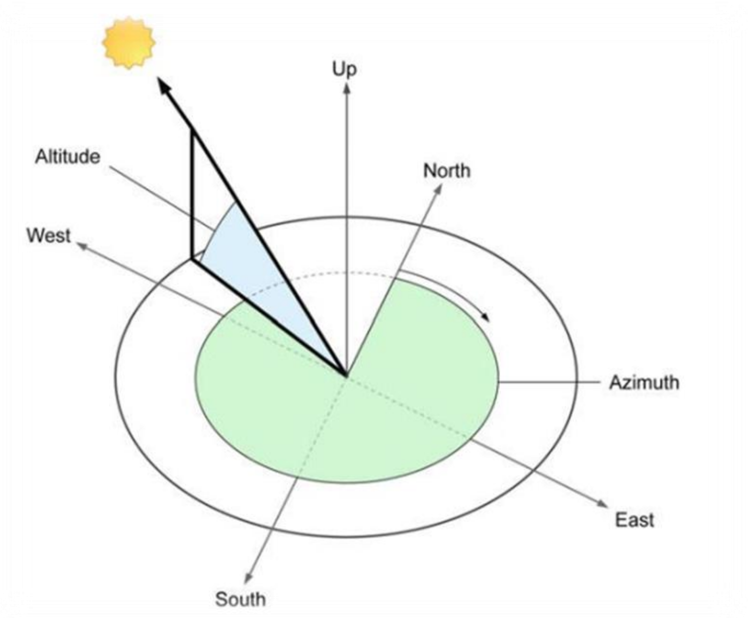


Figure 1.15. The sun’s altitude is.

Sun horizon angle; also known as solar altitude; it is always between 0° and 90° Azimuth. The angular relationship between north and the compass's sun cantered point. The azimuth angle changes during the day as the sun moves from east to west across the sky. Azimuth is typically measured clockwise from 0° (true north) to 359°. Solar arrays are typically constructed to face south in the northern hemisphere because the sun is always in the southern sky, and north in the southern hemisphere. There are periods of the year when the sun will be in the southern sky for people in the southern hemisphere and in the northern sky for people in the northern hemisphere in areas between the Tropics of Cancer and Capricorn, but this is not always the case. Due to the Earth's natural tilt, the sun will always be higher in the sky during the summer than it will be during the winter.

The summer and winter solstices, which occur alternately on June 21 and December 21, are the longest and shortest days of the year.

On the summer solstice and the winter solstice, the sun is at its highest and lowest points, respectively. The equinoxes, or midpoints between the two solstices, typically occur between 20 March and 23 September. In order to plan harvests and religious events, many prehistoric cultures developed the ability to recognize and anticipate the solstices and equinoxes. A sun path diagram can show the position of the sun in the sky for every specific place on a two-dimensional surface. The location of the sun in the sky at any hour of day, on any day of the year, may be calculated using this diagram. This information allows for the determination of the times when a region is shaded, which in turn enables the calculation of the annual insolation. The sun path diagram is made up of the following elements. azimuth angles, which are shown around the diagram's perimeter; altitude angles, which are shown as concentric circles; sun path lines, which run from east to west for various dates throughout the year; time of day lines, which cross the sun path lines; and location data, which is latitude related. For other regions, sun path graphs could appear completely different. The sun's path would run equally north and south if it were directly on the equator. Sun path diagrams outside of the tropics typically resemble the one below, albeit they will be inverted in the northern hemisphere. Take note of how the sun's course varies throughout the year. The sun always rises in the north or south of the observer outside of the tropics and only climbs to a low altitude during the winter. The sun rises at a greater altitude in the summer. At the solstices in every region, the sun will always be at its furthest north or south, north in June and south in December.

Solar array installation geometry: the orientation of a solar module is its position. This solar array's direction is crucial because it impacts how much sunlight reaches the array, which in turn determines how much power is generated. The tilt angle, or angle between the solar module's base and the horizontal, and the orientation, which is typically the direction the solar module is facing (i.e., due south), make up the orientation. Because of how the sun moves across the sky during the day, the amount of sunlight that strikes the array fluctuates depending on the time of day.

The solar panel will obviously capture all of the sun's rays if it is set flat on the ground with the sun overhead, as shown in the illustration below.

1.8. PV PERFORMANCE PARAMETER

I.V and P.V curves, where "I" stands for current, "V" for voltage, and "P" for power, are used to analyse the performance parameters of PV modules, as illustrated in Figure 1.16. The two primary techniques for analysing PV performance are I.V and P.V curve tracing. They calculate the maximum power point, the fill factor, the open-circuit voltage, and the short-circuit current.

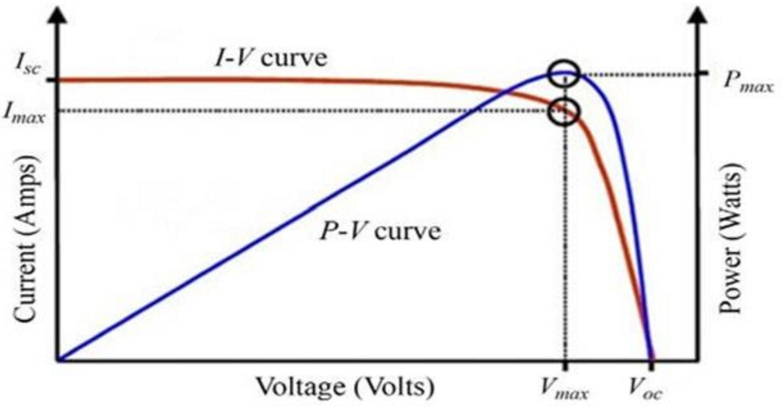


Figure 1.16. I.V and P.V curves indicating the maximum power point as well as the opencircuit voltage and short circuit

Below are brief definitions of various performance characteristic parameters. Table 1.1. highlights the mathematical equations used to assess the performance of PV modules.

voltage in an open circuit (V_{oc}) This is the voltage reading obtained by leaving the PV cell terminals in an open circuit under STC or real-time operation circumstances. The voltage value recorded under these circumstances will typically be greater than the highest voltage obtained at the maximum point [23].

Table 1.1. Description and the mathematical relation of major performance

Parameter	Mathematical relation	Description
Power input	P_{in}=Area * I	It is the product of the area of the PV module to the incident solar radiation and the quantity of solar energy potential that is now available. Units. kW
Power output	$P_{out}=V_{max}*I_{max}$	It is the result of the greatest voltage and current at any given moment. simply referred to as the terminal power output. the kW unit.
Power conversion efficiency	PEC= (Pout /Area*I) *100	The power output to power input ratio is what determines it. It often represents how well PV cell's function. Decimal. percent
Fill factor	FF=Pout /($V_{OC}*I_{SC}$)	It is one element that reflects the PV cell's quality. It is simply stated as the relationship between power output and the open.circuit voltage and current product. Units. n

Short-circuit current (Isc). When a solar PV cell is made to function in STC, or real-time conditions, the maximum current produced is known as Isc. The PV cell terminals are short-circuited by a load while this current is being measured. The value of the current at this time will be greater than the current at the point of maximum power. [23].

Maximum power point (Mpp). The maximum power point is the location where a PV cell can produce the most power, and it is where this power is produced at its maximum capacity. It is common to refer to the voltage and current measured at this point as the maximum voltage and maximum current. These values could change depending on the strength of the sun radiation as well as other aspects of the local weather [23].

1.9. SIMULATION PROGRAMS

The applied and theoretical studies of simulation programs are the subject of numerous studies in the literature [31] [32] [33] [34].

In addition, a Gökçeada based study found that Photovoltaic Geographical Information System (PVGIS) radiation data and the values of a grid independent power system are compatible [20] In their review, they expressed that the PVGIS program can be utilized for PV execution gauges [21].In a paper conducted a comparative analysis of the PV system using four distinct simulation programs in the Isparta study * SOL, making polysemic, and PVGIS are some of the tools. They stated that the PVGIS simulation program is the closest to the energy production value of the PV system, with a deviation of 1.3 percent [22].some researchers discovered in their research that the PVGIS performance estimate and grid-connected power value in Morocco correspond approximately to 2% [23].In the review utilizing the PVGIS program expressed that the proficiency was the most elevated on account of a framework that permits daylight to fall on the boards at a right point [24].concluded in their concentrate in Pakistan that the PVGIS information, the 4 assessments of sun oriented energy creation can be utilized as an emotionally supportive network for pol in the district [25].revealed that the PVGIS program has a statistically significant impact on the estimation of energy production values for the angle that the panels make to the horizontal. [35].

1.10. ENHANCEMENT AND INVESTIGATION

Due to the high cost of PV modules, the cost of electricity produced by PV systems is heavily influenced by both of those factors. [36]. PV modules should perform effectively and dependably for the duration of the 25-year guarantee period to offset the high expenses. PV modules must have a power degradation rate of no more than 0.8 percent annually to be eligible for the 25-year guarantee [37]. PV modules that have passed the International Electrotechnical Commission's (IEC) qualification testing do, however, occasionally fail or degrade to higher than expected levels when deployed in the field. [38] As a result, some of the PV systems that have been placed around the world, especially the off grid PV systems, haven't lived up to their owners' expectations. For instance, it was stated that more than 40% of end users were dissatisfied with the overall performance of their PV systems.[39]. Ismail et al. claim that certain Nigerian villages' PV systems weren't able to provide enough electricity, endangering the expected advantages of adopting them. [40] PV systems' poor performance and high rate of degradation reduce their predicted power generation, reduce their lifespan, and render them an undesirable alternative energy source.

PV system installers are extremely important to the success or failure of solar PV systems, especially during the design process. A PV system must be able to provide just the bare minimum of energy needed for its intended purposes. However, if installers are negligent during the design stage, owners of PV systems might not be able to fully utilize their systems. For instance, inadequate system efficiency and insufficient power production may come from the sizing of PV system components including batteries, inverters, conductors, and PV modules. PV modules must also have additional capacity to accommodate any potential power loss (module output derating and system losses). In order to account for module output derating and system losses, several PV module manufacturers recommend raising the minimum peak power value by 25% [41].

As a result, if the output rating of PV modules and system losses are not sufficiently accounted for, the PV system may be undersized, which could lead to system failure. In research to discover best practices for rural solar home system projects in Vanuatu, Jack found that one of the primary causes reducing the system longevity was the technical design error margin in the conceptual design life stage [42].

It's crucial to consider the orientation and tilt angle of PV modules when installing solar PV systems. These guarantee that the PV modules receive an adequate amount of sunlight all year long. The amount of solar radiation a PV module gets affects its performance, which in turn is determined by its orientation and tilt angle. In order to increase a solar system's output, PV modules should be slanted at the best orientation and tilt angle for the site in question. Modules normally face south in the northern hemisphere and north in the southern hemisphere. For maximum yield in the winter and summer, the tilt angle should be equal to the site's latitude, plus or minus 15 degrees, and it should be equal to the site's latitude, plus or minus 2 degrees, for maximum yield throughout the year [43].

However, even though a lot of work has been done to increase the efficiency of PV systems, the overall project cost is still rather high when compared to conventional power sources. Therefore, it is essential to precisely estimate the genuine capacity of PV systems and size the required system components, especially during the planning stage. Minimizing temperature and increasing solar radiation on a PV panel surface will result in the optimum performance. Irradiance and temperature are two important factors that directly impact the production of PV power, as is widely known. The amount of energy obtained from the solar plant may also be negatively impacted by aging and the environment. Particularly, the azimuth and tilt angles of the PV panel have a direct impact on its irradiance [44].

Solar tracking systems can change these angles throughout the day to increase the amount of solar radiation that falls on PV module surfaces. They are either thermal or electromechanical devices that actively adjust the angular locations of solar panels on either a single or dual axis in response to the position of the sun. These gadgets can, however, use energy while watching the sun and can also raise the price of the system's installation and upkeep. Additionally, they cannot be employed in every case due to installation area limits. It may therefore be advantageous to manually adjust the orientation and tilt angle of solar panels on a less frequent basis, such as monthly, seasonally, or semi-annually. The ideal azimuth angle for solar panels in the northern hemisphere is normally south (facing the equator), however the best tilt angle depends greatly on the location, the weather, and the time of year. Therefore, it is important to identify the ideal tilt angles for each site separately. The appropriate tilt angles for specific places in various countries have been the subject of extensive research to date 15]. The amount of energy generated by solar power plants is influenced by the weather. To account for this unpredictability and include solar power plants into the grid, it is critical to estimate energy production in advance.

PART 2

MATERIAL AND METOD

2.1. PVGIS COMPUTER PROGRAM

PVGIS, a free to use computer program, calculates the power obtained from solar radiation [56]. Depending on the geographical location, the average daily, monthly and annual irradiance values and the capacity power of the PV system can be calculated in different options according to the desired panel angular value from the PVGIS database. The problem can be solved without the need for a panel area of the PVGIS program. In the PVGIS simulation program, the total solar radiation incident on inclined surfaces is calculated by the equations given below, depending on the azimuth angle γ ,, sun elevation angle α and inclination angle β [57].

$$G_{\mathrm{T}} = G_{\mathrm{bT}} + G_{\mathrm{dT}} + G_{\mathrm{rT}} \tag{2.1}$$

Given in Eq 1, G is radiation incident on an inclined surface, G_{bT}, G_{dT} and $G_{\mathbf{rT}}$ are direct, diffuse and reflected radiation [W/m^2], respectively.

$$\mathrm{G} = G_{\mathrm{bT}} \frac{\cos\xi}{\cos\sigma\, z} \tag{2.2}$$

Given in Eq 2, the position of the sun G_{bT} varies according to inclined surface and azimuth angle. Here G_{b} is the solar radiation incident on the horizontal plane, ξ is the incidence angle of direct radiation [°], σ_{z} is the solar zenith angle [°].

Reflected solar radiation incident on an inclined surface is expressed as;

$$\mathrm{GrT} = \mathrm{G}.\,\rho.\,\frac{(1 - \cos\beta)}{2} \tag{2.3}$$

Defined as in Eq 3, G is total radiation incident on the horizontal plane [W/m^2], G_d is solar radiation incident on the horizontal plane [W/m^2] and G_b is direct solar radiation [W/m^2]. Also, ρ represents the surface reflectivity and β represents the inclination angle of the horizontal panel surface [°].

Diffuse radiation is a result of the scattering of solar radiation by the components of the atmosphere, and there is no homogeneous distribution in the sky. There are two approaches, the isotropic and anisotropic model.

The model implemented in PVGIS has been developed by Muneer [58] and classified in the category of anisotropic models. This model estimates G by choosing between clear or cloudy, sunny or shady skies [57].

Equivalent (Eq 4.) for shaded surfaces or overcast situations.

$$G = G_d \quad G_{dT} = G_d \ \frac{(1-\cos\beta)}{2} + 0{,}25227\,(sin\beta - \beta.\,cos\beta - \pi.\,(sin\frac{\beta}{2})^2] \tag{2.4}$$

For sunlit surfaces under non overcast sky conditions (Eq 5).

$$G_{dT} = G_d\,(\frac{(1-\cos\beta)}{2} + (sin\beta - \beta.\,cos\beta - \pi.\,sin\,(\frac{\beta}{2})^2\,).\,(0{,}00263 - 0{,}712.\,\frac{Gb}{Go} - 0{,}6883\,(\frac{Gb}{Go})^2.\,))\,(\,1 - \frac{Gb}{Go}) + (\frac{Gb}{Go}.\,\frac{\cos\xi}{\cos\sigma\,z})] \tag{2.5}$$

has been given with, where Go is the total of solar radiation outside the atmosphere [W/m^2]. Under these circumstances, a correction has to be applied when the solar elevation angle, αs, is low. Therefore, if $\alpha_s < 0{,}1$ [rad], G_{dT} is calculated following Eq. 6.

$$G_{dT} = G_d\,.\left[\frac{(1-\cos\beta)}{2} + (\sin\beta - \beta.\cos\beta - \pi.\sin(\frac{\beta}{2})2\,).(0{,}00263 - 0{,}712.\frac{Gb}{Go} - 0{,}6883.(\frac{Gb}{Go})2.)).(\,1 - \frac{Gb}{Go}) + (\frac{Gb}{Go}\,.\frac{sin\beta.\cos\,(\gamma T - \gamma s}{0.1 - 0.008\alpha s})\right] \tag{2.6}$$

The PVGIS simulation program calculates using the effects of solar radiation and panel temperature. Power P [W] is determined in Eq.7 depending on solar radiation and panel temperature [56] [57].

$$P(G_{T}', T') = G_{T}' \quad (P_{STC,m}, + k_1\, In(G_{T}') + k_2\, In(G_{T}')^2 + k_3\, T' + k_4\, T\, In(G_{T}') + k_5\, T\, In(G_{T}')^2 + k_6\, T'^2) \qquad (2.7)$$

Here, G_{T}' is total solar irradiance and T' is normalized panel temperature. The coefficients. k_1 ’ to k_6 ’are values based on data measured by the European Solar Test Establishment (ESTI) specific to the PV panel type. $P_{STC,m}$, refers to the maximum power [W] under standard test conditions [56].

$$G_{T}' \equiv G_{T} / G_{STC} \qquad (2.8)$$

$$T' \equiv T_{mod} - T_{STC} \qquad (2.9)$$

$$\eta(G_{T}', T') \equiv P(G_{T}', T') / P_{STC,m}\, G_{T}' \qquad (2.10)$$

In Eq. (8.10), T_{MOD} panel temperature [ºC] and in STC (standard test conditions) G_{STC} = 1000 [W/m^2], T_{STC} = 25 [ºC] and η_{ref} means efficiency [56].

The azimuth angle indicates the southward orientation of the PV panels, and the azimuth angle is 0° for south oriented panels, .90° for east and 90° for west [60]. Commercially available polycrystalline silicon solar energy conversion efficiencies range from about 14−19% [61]. They stated that the actual values of the off-grid power system located in Gökçeada are compatible with the PVGIS radiation data. During the monitoring period of the system, they calculated that the average total irradiance measurement results were 5.15 [kWh/(m^2.d)] and 5.35 [kWh/(m^2.d)] in the PVGIS database. Likewise, they stated that the PVGIS estimates are consistent with the real time temperature measurements obtained from the General Directorate of Meteorology of the Republic of Turkiye. In this context, they confirmed the consistency of the PVGIS database [62]. Energy analysis of a solar power plant in Isparta was carried out by Ceylan and Taşdelen with different simulation programs of PV*SOL, Helioscope, Polysun and PVGIS. It is stated that Isparta solar power plant is a PVGIS simulation program with a deviation rate of 1.3% according to the total energy production value [63].

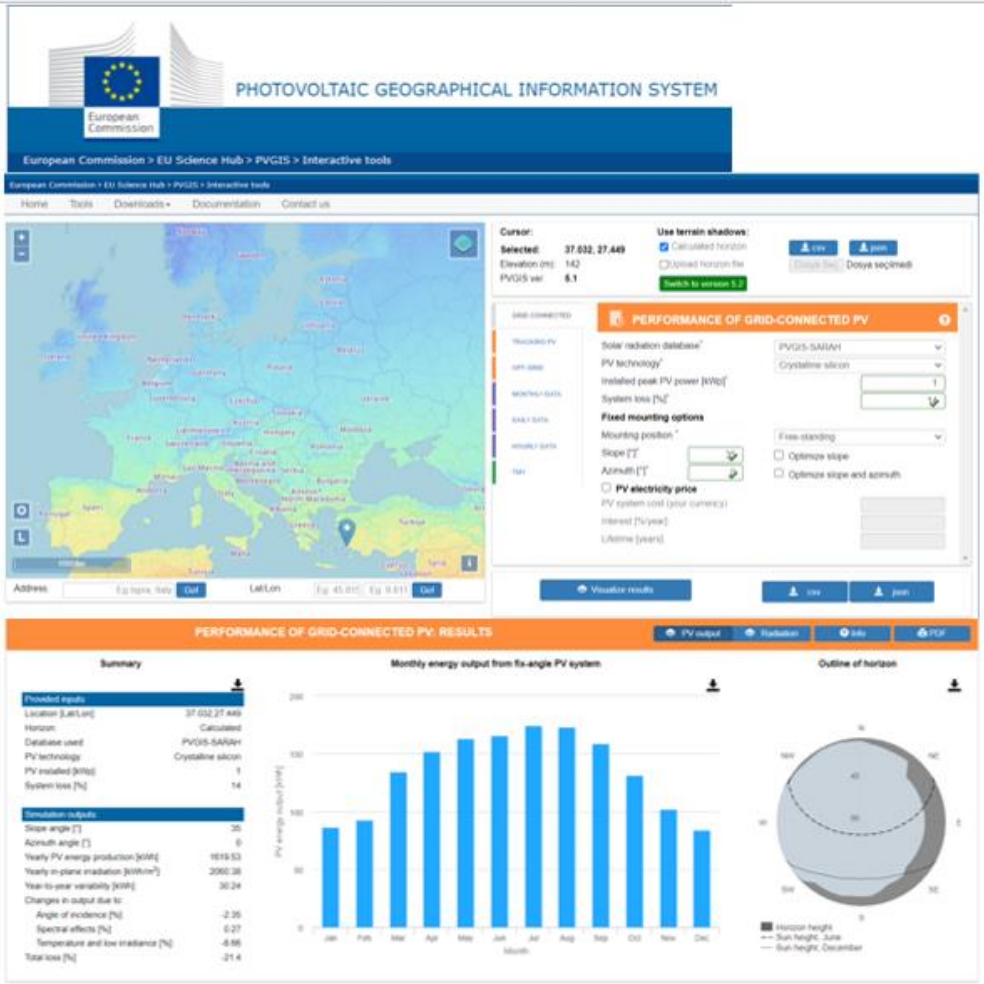
In the study, the location of the coordinates of the marina was selected from the PVGIS map base. Crystal silicon material technology was chosen as the PV panel for all three options, and the system efficiency was accepted as 14%. Since there is no snowfall in the Mediterranean Region, this loss has not been considered. In the fixed option, assuming that the panel is oriented to the south, its slope is selected by calculating the optimum with PVGIS and the azimuth angle is taken as 0°. In addition, there is no problem in terms of the arrangement of the PV panels on the ground and the panel installation area, where the marina is on the seafront and surrounded by unused jetties and quays. There is a generator and transformer system of sufficient power, since the system will operate connected to the mains, and the marina is outside the residential area.

2.2. BOUNDARY CONDITIONS

In this thesis, the following boundary conditions were used for the PVGIS computer package program. Figure 2.1. shows the results from the PVGIS screen using these boundary conditions. These are:

- In the study, the location of the coordinates of the marina was selected from the PVGIS map base.
- Crystal silicon material technology was chosen as the PV panel for all three options, and the system efficiency was accepted as 14%.
- Since there is no snowfall in the Mediterranean Region, this loss has not been considered.
- In the fixed option, assuming that the panel is oriented to the south, its slope is selected by calculating the optimum with PVGIS and the azimuth angle is taken as 0°.

- In addition, there is no problem in terms of the arrangement of the PV panels on the ground and the panel installation area, where the marina is on the seafront and surrounded by unused jetties and quays.
- There is a generator and transformer system of sufficient power, since the system will operate connected to the mains, and the marina is outside the residential area.



Cursor:
Selected: 37.032, 27.449
Elevation (m): 142
PVGIS ver: 5.1
☑ Calculated horizon
☐ Upload horizon file

Solar radiation database: PVGIS-SARAH
PV technology: Crystalline silicon
Installed peak PV power [kWp]: 1
Mounting position: Free-standing

Provided inputs:	
Location [Lat/Lon]:	37.032,27.449
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed [kWp]:	1
System loss [%]:	14
Simulation outputs:	
Slope angle [°]:	35
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	1619.53
Yearly in-plane irradiation [kWh/m²]:	2060.38
Year-to-year variability [kWh]:	30.24
Changes in output due to:	
Angle of incidence [%]:	-2.35
Spectral effects [%]:	0.27
Temperature and low irradiance [%]:	-8.88
Total loss [%]:	-21.4

Figure 2.1. Results from the PVGIS screen

2.3. USING THE PVGIS COMPUTER PROGRAM

In the study, PVGIS computer program was used to calculate the power, radiation, monthly and annual electricity production amounts of PV panels. This program receives meteorological data from satellite and calculates solar radiation accordingly.

Data can also be entered into the program by the user. In addition, data on the monthly electricity consumption amount of 2018 for a marina have been obtained, as seen in Table 2.1.

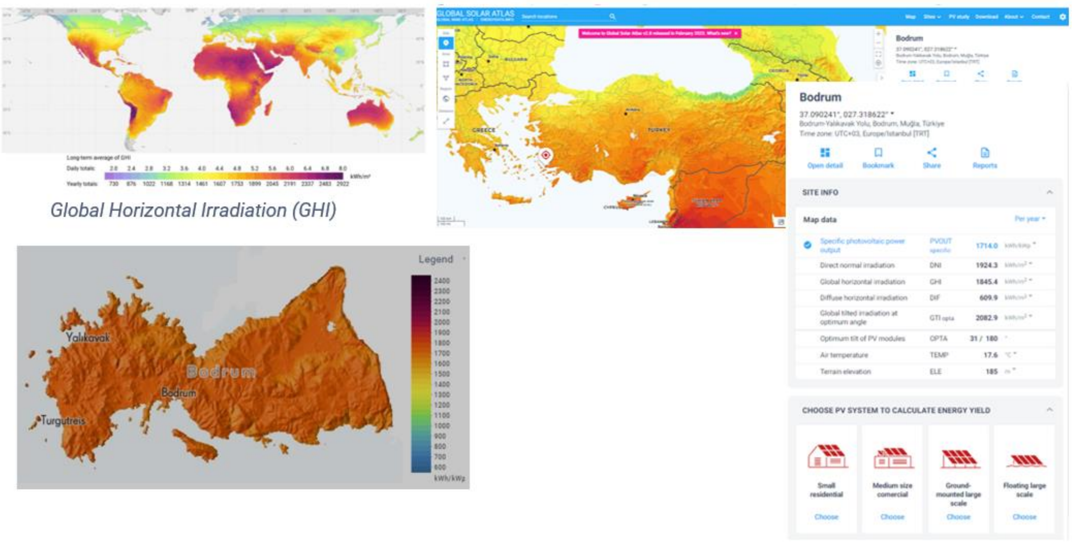
Table 2.1. Monthly electricity consumption of a marina in 2018.

Months	**Electricity Consumption (kWh)**
January	304.325
February	261.245
March	297.753
April	325.306
May	343.273
June	424.545
July	512.790
August	526.595
September	400.712
October	287.882
November	248.646
December	349.159
Total	4.282.231

The solar radiation was calculated based on the inclination angle, azimuth angle, system efficiency, panel material used and the coordinates of the ground, which must be entered in the program. In the PVGIS program, monthly / annual [kWh] amounts of electrical energy to be produced by the PV system were calculated depending on the marina PV installed power.

In the study, the distribution of electricity consumed in the marina by months was examined. Based on the electricity consumed, the minimum value of the PV installed power (kW) sufficient for itself, excluding the PV installation cost and the PV system planned for installation in the marina, has been calculated. The amount of electricity to be produced based on this power is simulated separately in the PVGIS simulation program on a monthly / annual basis in fixed option, TAT and DAT (three different) options. In addition, a formulation has been developed in the Microsoft Excel program between the amount of electricity produced monthly (kWh) and the amount of electricity consumed, depending on the power determined in PVGIS. The amount of electricity that will meet the marina need has been calculated separately for three different options over the electricity purchase / sale values of EMRA. Then, the yacht harbour efficiency analysis was made, and the most suitable option was selected.

In the study, the changing of electricity consumed in the marina according to the months was examined. Based on the consumed electricity, the minimum value of the PV installed power (kW) sufficient for itself, and except for the PV installation cost have been calculated. The amount of electricity to be produced depending on this power is simulated separately in the PVGIS simulation program in the fixed option, TAT and DAT (three different) options on a monthly / annual basis. In addition, a formulation has been developed in the Microsoft Excel program between the amount of electricity produced monthly (kWh) and the amount of electricity consumed, depending on the power determined in PVGIS. The amount of electricity to meet the marina need has been calculated separately for three different options over the electricity purchase / sale values of EPDK. Then, the yacht marina efficiency analysis was made, and the most suitable option was selected.



Bodrum

37.090241°, 027.318622°

Bodrum-Yalıkavak Yolu, Bodrum, Muğla, Türkiye

Time zone: UTC+03, Europe/Istanbul [TRT]

SITE INFO

Map data

Specific photovoltaic power output	PVOUT specific	1714.0	kWh/kWp
Direct normal irradiation	DNI	1924.3	kWh/m²
Global horizontal irradiation	GHI	1845.4	kWh/m²
Diffuse horizontal irradiation	DIF	609.9	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	2082.9	kWh/m²
Optimum tilt of PV modules	OPTA	31 / 180	°
Air temperature	TEMP	17.6	°C
Terrain elevation	ELE	185	m

CHOOSE PV SYSTEM TO CALCULATE ENERGY YIELD

Figure 2.2. Determining the location using the global solar atlas.

Global data representing the solar resource and PV power potential has been calculated by SOLARGIS. To set the screen, the long-term energy availability of the solar source at any location is characterized by its theoretical potential. This potential is illustrated by the physical variable of global horizontal irradiation (GHI), which is the sum of direct and diffuse irradiation components received by a horizontal surface. GHI is measured in (kWh/m^2). However, at a given site, GHI is modulated by local air temperature, wind and snow, atmospheric pollution, dust, and some other geographical factors. GHI is considered as a simplified approximation, and it does not fully describe the actual potential for PV power production. Figure 2.2 shows determining the location using the global solar atlas and the result screen.

PART 3

RESULTS AND DISCUSSIONS

3.1. SOLAR RADIATION AMOUNT OF THE MARINA REGION

In PV systems, the intensity of radiation coming to the panel surface is a factor that determines the power of the panel [64]. As can be seen in Table 3.1, solar radiation values at the location of the marina operation were calculated in three different options with the PVGIS program. When the fixed option is compared, it is seen that the highest solar radiation is 36.2% for the SAT option and 32.1% for the DAT option.

Table 3.1. Annual solar radiation values under three different options in the marina region [56]

	Fixed option	**DET option**	**TET option**
Solar irradiance [W/m^2]	2111,95	2875,47	2788,91
Solar radiation increase rate	1,000	1,362	1,321

3.2. MONTHLY COMPARISON OF THREE DIFFERENT OPTIONS OF PV SYSTEM

Three different options were simulated by selecting the PV installed power for sufficient electricity generation in a marina operation. The simulation results were calculated in Microsoft Excel, considering the electricity purchase / sales values of EMRA. In these calculations, optimum values were found between the amount of electricity to be produced monthly by the PV system and the marina consumption for each option. These values have been calculated by considering the marina does not pay the electricity price for the network buying and selling transactions. The monthly distributions of the marina consumption with the three calculated options are given in Table 3.2. and Figure 3.1.

When Table 3.2. and Figure 3.1. are examined, it is seen that the electricity consumption amount of the marina and the increase and decrease in the monthly distribution of the electricity to be produced in the three different options of the PV system overlap with each other. In all options, the highest electricity generation occurs in July, while the lowest electricity generation occurs in January and December. However, from the point of view of the monthly electricity produced to meet the consumption, the electricity produced in January, February, August, and December is not sufficient for the consumption in all three different options. In the case of three options, it was observed that production was higher than consumption and electricity was sold to the grid in March, April, May, June, September, October, and November. Moreover, in July, it was observed that only the fixed option generation did not meet the consumption and purchased electricity from the grid, while the other two options produced excess and sold the surplus to the grid.

Table 3.2. Monthly distribution of the electricity production amount obtained under optimum conditions in the marina region [56].

Electricity generation on fixed option (kWh)		**Electricity generation on SAT option (kWh)**	**Electricity generation on DAT option (kWh)**	**Electricity generation in the marina (kWh)**
January	234.317	207.069	214.047	304.325
February	256.727	234.356	233.288	261.245
March	365.635	348.441	339.203	297.753
April	417.994	417.177	407.615	325.306
May	449.194	463.732	463.770	343.273
June	460.019	502.964	512.489	424.545
July	488.215	541.451	546.799	512.790
August	481.641	516.254	507.623	526.595
September	431.787	434.470	422.186	400.712
October	363.295	345.131	341.210	287.882
November	277.611	252.127	258.780	248.646
December	232.224	206.446	217.186	349.159
Total	4.458.661	4.469.618	4.464.196	4.282.231

As can be seen in Table 3.2. and Figure 3.1., the fact that there is a parallelism between the monthly electricity consumption at the marina and the amount of electricity expected to be produced in three different options in the PV system, except for January and December, means less solar panels and equipment use. This will reduce the initial investment cost of the PV system and positively affect the efficient use of the system. With the PV system that is foreseen to be established, it will be possible to benefit at the maximum level both in the tourism season and in other months. The optimum amount of power required in the PV system installation required for the electricity need by performing the purchase and sale transactions of the marina without paying any electricity consumption fee was calculated with PVGIS among three options and is given in Table 3.3. The optimum PV system installed power required for the marina has been determined as 1952.77 kW for the option with DAT (double axis tracking), 2012.31 kW for the option with SAT (single axis tracking) and 2671.41 kW for the fixed option. In case a PV system is established with these installed powers, the marina management will have the opportunity to generate sufficient electricity for itself by buying / selling from the grid without paying any electricity consumption fee.

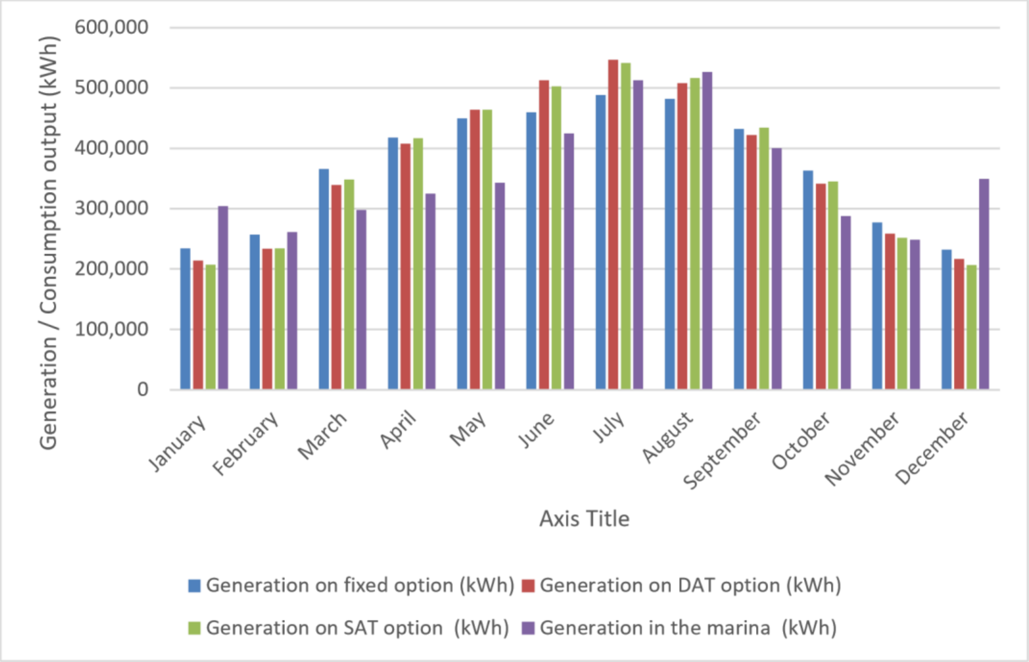


Figure 3.1. Correlation between yacht marina electricity consumption and electricity production in three different options of the PV system.

When the values are examined, it is seen that the same amount of electricity generation sufficient for the marina consumption is the option with DAT with the lowest installed power.

Table 3.3. Minimum PV installed power values for three different options [56].

	Fixed option	DAT option	SAT option
Maximum Power	**2671,41 (kW)**	1952,77	2012,31
Power decrease rate	**1,000**	1,368	1,328

In Table 3.3, the PV installed power will be able to produce the same electricity with 36.8% less installed power requirement of the option with DAT compared to the fixed option. The electricity produced with a minimum installed power of 1952.77 kW will be able to meet the need of the marina. It means that the electricity to be produced with this power is sufficient for the marina, that the marina can both meet its consumption and continue its activities without any electricity costs from the enterprise by buying / selling with the tariffs determined by EPDK. Compared to the fixed option, the option with SAT will be able to meet the electricity required for the marina with 32.8% less power by making network purchases and sales transactions.

If the marina operator does not pay any electricity consumption fee, it has been determined that the minimum PV system installation is the option with DAT, with a power of 1952.77 kW, for electricity that will be sufficient for it.

Table 3.4. Correlation between radiation and power for three different options

	Fixed option	DAT option	SAT option
Solar radiation increase rate	1,000	1,362	1,321
Power decrease rate	1,000	1,368	1,328
Difference	0,00	0,006	0,007

In addition, Table 3.1. and Table 3.3. are compared, the difference between the rate of increase in solar radiation and the rate of decrease in installed power is given in Figure 3.1. As can be seen in Table 3.4., the difference between solar radiation and power is around 0.6% in the DAT option. The same situation shows that the marina need will be met with 0.7% less power in the SAT option. This means that in productions made with PV system in marinas, production with less power can be achieved in both options compared to the fixed option.

3.3. INITIAL INVESTMENT COST OF THE PV SYSTEM INSTALLED IN THE MARINA

The numbers of PV panels, inverters, and carrier systems to be used in the PV system are given in Table 3.5. In addition, market research and the average of the costs were accepted as the initial investment cost. The PV panel, inverter and copper energy cable, panel and consultancy services required for the installation of the PV system, which are required for the installation of the system, are purchased as a set and the costs are given in Table 3.6 [65].

Table 3.5. Number and characteristics of the equipment used.

Material list			
	Fixed option	Single option	Dual option
PV panel (Poly 275 W)	**9.716**	7.327	7.102
Inverter (40 KW)	**66**	51	49
Static system (Aluminum.tool set)	**9.716**	184	177
Total initial investment cost of PV systems			
Options	**Fixed axis**	Single axis	Dual axis
Initial investment cost (USD)	**2,205,420**	1,897,405	2,013,375

3.4. CALCULATION OF ELECTRICITY PRODUCTION COST IN PV SYSTEMS IN TURKIYE

The electricity purchase / sale price tariff of the marina management, determined by EMRA, is given in Table 3.7. by converting it to USD. In the calculations, the price of excess electricity in the PV system to be installed and sold to the grid is 0,071834 USD/kWh. However, if the energy produced in the PV system is not sufficient for the marina requirement, the electricity price to be received from the grid is 0.120394 USD/kWh.

Table 3.5. Republic of Turkiye Energy Market Regulatory Authority (EMRA) Price Tariff.

	Unit price	Unit
Sale price	0,071834	USD/kWh
Distribution	0,021599	USD/kWh
Taxes and funds	0,026961	USD/kWh
Total price	0,120394	USD/kWh

Table 3.6. Correlation between the installation of PV system options in the marina and the annual energy production / consumption.

	Fixed axis	Single axis	Dual axis
The amount of consumption before the PV system is installed	4.282.231	4.282.231	4.282.231
The amount of energy from the grid after the PV system is installed	260.990	277.199	269.180
Annual direct electricity savings	4.021.241	4.005.034	4.013.050
The amount of energy sold to the grid after the PV system is Installed Total electricity production amount of the PV system	437.420 4.458.661	464.584 4.469.618	451.146 4.464.196
Annual total savings	515.557 USD	515.557 USD	515.557D

The purchase/sale of the electricity produced by the PV system for the marina consumption to the grid was made according to the price tariff given in Table 5.7 and applied by EMRA. According to the marina need, electricity generation and consumption are calculated monthly in the Microsoft Excel program. In the calculation, with the optimum power to be installed in the marina operation, the total annual electricity generation of the PV system options is 4,458,661 kWh in the fixed option, 4,469,618 kWh in the SAT option and 4464.196 kWh in the DAT option. The electricity cost of the marina before the PV system is installed is 515,557 USD/year. This means that the total annual savings for all three options will be $515,557.

When Table 3.8 is examined, if a PV system is installed, the marina will directly use the electrical energy itself. In case of excess production, electricity will be sold to the grid, and in case of excessive consumption, electricity is purchased from the grid.

3.5. CALCULATION OF THE PAYBACK PERIOD OF THE PV SYSTEM TO BE INSTALLED AT THE MARINA

The cash flow and payback period of the investment in the PV system installation at the marina are calculated separately in three options using the NPV method (Eq. 12) [66].

$$NPV = \sum_{t=1}^{m} \frac{It}{(1+k)^t} \tag{3.1}$$

Here t is the time period (year), I is the net cash flow in t years, m is the economic life of the investment (25 years), and k is the discount rate.

In this study, it is predicted that the power plant income will vary depending on the discount rate. In this context, the discount rate for July 2020 was taken as 0.25% by the United States [67]. In the study, it is predicted that the PV system installation will be completed and put into operation within one year. In addition, the payback period of the PV system installation at the marina with the NPV method is calculated for the three option cases and given in Table 10.

Table 3.7. The payback period for three options of PV system installation with NPV method (years).

	Fixed axis	**Single axis**	**Dual axis**
The payback period	4,58	3,91	4,16

In the calculations, the payback period of the initial investment cost of the PV system to be installed in the marina is calculated as 4.58 years for the fixed axis option, 4.31 years for DAT option, and 3.91 years for THE option.

When evaluated in terms of initial investment cost and payback period for all three option cases, it is seen that it will reach positive cash flow in less than 5 years. It has been determined that SAT option at the marina PV system is more advantageous than the other options, and it will be 8 months earlier than the fixed option and 3 months earlier than the DAT option. The calculated results agreed with similar studies. When the results are compared with the results in Table 5.1, it is seen that the most solar radiation is in the DAT option, which means that the electrical energy will be produced the most but depending on the consumption in the marina and the network buying and selling process, the electricity generation in the SET option is more advantageous for the marinas. In addition, profit and loss status was calculated for all three options in the PV system installation and is given in Figure 3.2.

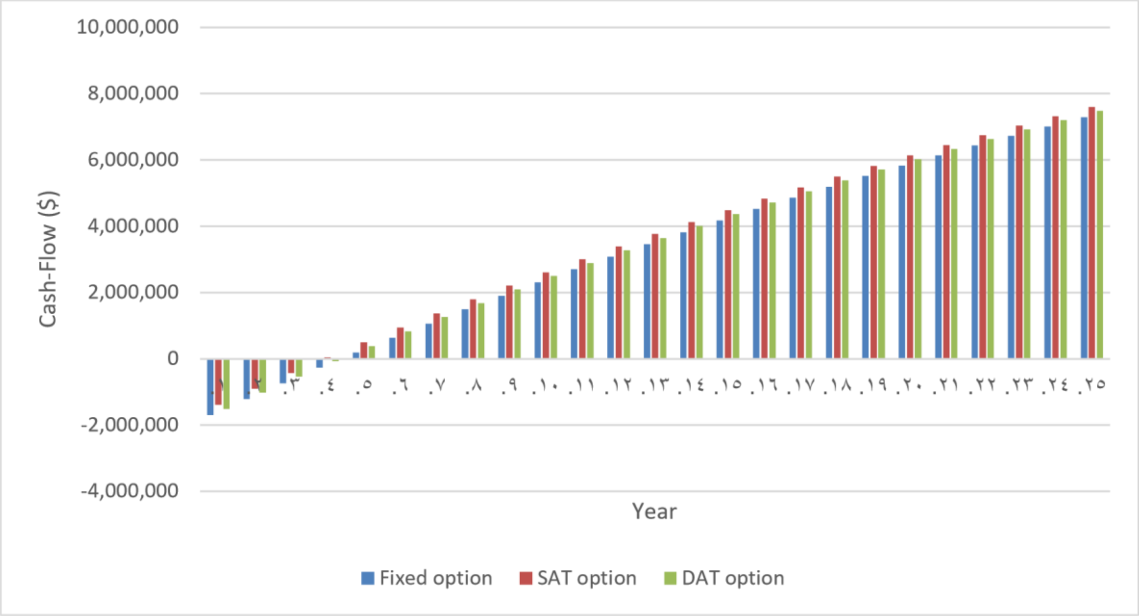


Figure 3.2. Profit and loss status for three options in PV system installation at the marina.

PART 4

CONCLUSIONS

In this study, the availability of solar energy for the electricity requirement of a marina was investigated for fixed axis, SAT (Single Axis Tracking) and DAT (Double Axis Tracking) options. The most important results are summarized below.

As a result of the calculations made, it will be possible to produce 4,469,618 kWh of electricity per year with the PV system with a minimum installed power of 2012.31 kW with SAT option. Similarly, a PV system with a minimum installed power of 1952.77 kW with DAT option will produce 4.464.196 kWh per year, and with a PV system with a minimum installed power of 2671.41 kW with fixed axis option, 4.458.661 kWh electricity will be produced annually. It has been determined that this production can be provided by the PV system without any electricity costs from the marina operation.

In the SET option, the difference between solar radiation and power is around 0.7%. This means that consumption will be met with less power installation in marinas compared to the fixed option. The fact that the months when the marina consumes minimum and maximum electricity and the months when the PV system will generate minimum and maximum electricity are largely parallel makes it advantageous to install a PV system in marinas with both DAT and SAT options.

Although the initial investment cost per unit kW is expensive in the DAT and SAT options, the shortening of the investment payback period makes mobile options advantageous.

This study has shown that choosing the other two options in the PV system to be installed in marinas with the increase in electricity consumption will be more appropriate in terms of efficiency of the system compared to the fixed option. It has been observed that the electricity produced in January, February, August and December with the PV system planned to be installed in the marina does not meet the consumption.

In the calculations, the payback period of the initial investment cost of the PV system to be installed in the marina is calculated as 3.91 years for the most advantageous SAT option.

It is predicted that the total annual savings of the marina management will be 515,557 USD. It is considered that this study will contribute to the literature.

REFERENCES

[1] "International Renewable Energy Agency.," Renewable capacity statistics 2023. ,[Online]. Available. https.//www.irena.org/Publications/2023/Mar/Renewable.capacity.statistics.2023 Accessed 15 3 2023].

[2] F. o. S. Photovoltaic., "International Renewable Energy Agency," [Online]. Available. https.//www.irena.org/./media/Files/IRENA/Agency/Publication/2019/Nov/IRENA_Future_of_Solar_PV_summa Accessed 10 7 2020].

[3] G. S. a. S. Neill, Grid.connected Solar eleictric systems, New york. Earthscan, 2012.

[4] M. T. G. Kamil B. Varınca, "Türkiye'de Güneş Enerjisi Potansiyeli ve Bu Potansiyelin Kullanım Derecesi, Yöntemi ve Yaygınlığı Üzerine Bir Araştırma," *Ulusal Güneş ve Hidrojen Enerjisi Kongresi,* pp. 270.275, 2006.

[5] "Directorate.General of Shipyards and Coastal Structures. Yatch Marina Information," [Online]. Available. https.//tkygm.uab.gov.tr/uploads/pages/limanlar.ve.kiyi.yapilari/3.yat.limanlari.bilgileri.pdf Accessed 10 7 2020].

[6] Onat N., "Electricity generation from renewable sources in Turkiye. current situation and prospects," *Journal of Intelligent Transportation System and Application,* vol. 1, no. 1, pp. 8.15, 2018.

[7] M. o. E. a. N. Resources., "Solar Energy Potential Atlas (GEPA)," [Online]. Available. http.//www.yegm.gov.tr/MyCalculator/. Accessed 10 7 2020].

[8] W. B. G. C. Yield, "choose PV System to Calculate Energy," [Online]. Available. https.//globalsolaratlas.info/map Accessed 10 7 2020].

[9] c. Sungur, "Multi.axes sun.tracking system with PLC control for photovoltaic panels in Turkiye," *Renewable Energy,* vol. 34, no. 4, pp. 1119.1125, 2009.

[10] N. Stefan, "Potentials for tracking photovoltaic systems and V.throughs in moderate climate," *Solar Energy,* vol. 45, no. 6, pp. 385.393, 1990.

[11] A. Smee, london. Longman, Brown,Green, and Longmans, 1845.

[12] T. N. p. i. p. 1. A. Einstein., "Nobel Price official," [Online]. Available. https.//www.nobelprize.org/.

[13] a. H. H. A. Alkholidi, "“Solar energy potentials in southeastern european countries. a case study”, International Journal of Smart Grid„" *International Journal of Smart Grid,* vol. 3, pp. 108.119, 2019.

[14] A. S. Editor, Photovoltaics for Sustainable Electricity and Buildings, switzerland. Springer International, 2017.

[15] N. R. E. L. NREAL., "NREL Solar cell sets world efficiencyrecord at 40.8 percent, 21 Oct, 2008," 2008.

[16] v. A. M. A. I. Yeşilata B., "investigation of design principles of photovoltaic power system water pumps," *Engineer and Machinery,,* vol. 42, no. 493, pp. 29.34, 2001.

[17] V. J. Messenger R.A., Photovoltaic Systems Engineering, florida. 2. Edition Taylor & Francis e.Library, 2003.

[18] Q. G. E. P. Agency., "http.//www.soe.townsville.org," [Online]. Available. 10. Queensland Government Environmental Protection Agency. Grid Connected Photovoltaic Systems. http.//www.soe.townsville.org/data/Gridconnected_photovoltaic_systems.pdf. Access date. July 10, 2020. Accessed 10 july 2020].

[19] P. Würfel, Physics of Solar Cells, Weinheim, Germany. WILEY.VCH Verlag, 2005.

[20] L. L. Kazmerski, "Photovoltaic. history, technology, markets, manufacturing, applications, and outlook," in *84th International Seminar in Brighton, Renewable Energy Policy, SecurityElectricity, Sustainable Transport, Water Resources/Management and Environment,* Brighton, UK, 2011.

[21] A. V. DaRose, Fundamentals of renewable energy processes, Elsevier, 2005.

[22] S. e. 2. e. (. U. o. S. U. Tomas Markvart, Solar electricity, 2nd edition, (Wiley, University of Southampton, UK).

[23] N. M. K. R. P. i. K. Mobi Mathew, "Outdoor measurement of mono and poly c.Si PV modules and array characteristics under varying load in hot.humid tropical climate,," *Materials Today. Proceedings,* vol. 5, no. 2, pp. 3456.3464, 2018.

[24] K. S. M. S. Nallapaneni Manoj Kumar, "Performance comparison of BAPV and BIPV systems with c.Si, CIS and CdTe photovoltaic technologies under tropical weather conditions," *Case Studies in Thermal Engineering,* vol. 13, 2019.

[25] I. S. G. R. Parida B, "Parida B, Iniyan S, Goic R. A review of solar photovoltaic technologies," *Renew Sustain energy Rev,* vol. 15, no. 3, pp. 1625.1634, 2011.

[26] B. A. R. A.] Romeo N, "An innovative process suitable to produce high.efficiencyCdTe/CdS thin.film modules," *Sol Energy Mater Sol Cells,* vol. 95, no. 1, pp. 2.7, 2010.

[27] D. E. L. D. H..E. J. Y. M. H..B. A. Green MA, "Solar cellfficiency tables (version 54)," *Prog Photovoltaics Res Appl,* vol. 27, no. 7, pp. 565.575, 2019.

[28] P. S. A. E. W. R. W. C. M. F. T.] Powalla M, "Thin.film solar cells exceeding 22% solar cell efficiency. an overview on CdTe.,Cu(In,Ga)Se 2., and perovskite.based materials.," *Appl Phys Rev,* vol. 5, no. 4, 2018.

[29] C. R. I. R. M. Slaoui A, "Encyclopedia of Materials. Science and Technology," in *Photovoltaics. advanced inorganic materials.*, elsevier, 2008.

[30] S. K. S. J. J. S. P. A.] Metaferia W, vol. 10, no. 1, p. 3361, 2019.

[31] s. a. T. jaymin gajjar, "Solar PV Energy Genaration Map of Karantaka,INDIA," *Smart Grid and Renewable Energy,* vol. 6, no. 12, 2015.

[32] T. A. H. &. E. D. D. Marcel Šúri, "PV.GIS. a web.based," *International Journal of,* vol. 24, no. 2, pp. 55.67, 2005.

[33] M. C. D. M. L. e. a. Baghdadi, "Reciprocal signalling by Notch–Collagen V–CALCR retains muscle stem cells in their niche," *Nature,* vol. 557, no. 7707, pp. 714.718, 20018.

[34] A. Pinna, "A Procedure for Complete Census Estimation of Rooftop Photovoltaic Potential in Urban Areas," *Smart Cities,* vol. 3, no. 3, 2020.

[35] F. A. R. a. K. F. Durmaz, "Affordability of Electrical Energy Needs of Agricultural Enterprises with Photovoltaic Energy. Case of Manisa – Turgutlu," *Journal of Agricultural Machinery Science,* vol. 13, no. 3, pp. 193.199, 2017.

[36] I. (2005), "Crystalline silicon terrestrial photovoltaic (PV) modules—Design qualification andtype approval,," International Energy Agency (IEA), paris, 2020.

[37] D. C. &. K. Jordan, "zPhotovoltaic degradation rates — An analytical review. Progress inPhotovoltaics. Research and Applications," . *Progress inPhotovoltaics. Research and Applications,* vol. 21, no. 1, pp. 12.19, 2013.

[38] V. &. C. S. S. Sharma, "Performance and degradation analysis for long term reliability of solar photovoltaic system. a review," *Renewable and Sastainable Energy* , vol. 27, pp. 753.767, 2013.

[39] C. T. &. S. H. Mgonja, " Effect of dust accumulation on performance of photovoltaic solar modules in sahare enviroment," *jornal of basic and applied scientific research,* vol. 2, no. 11, pp. 11030.11036, 2012.

[40] O. S. A. O. O. &. A. F. Ismail, "performance assessment of installed solar PV system. A case study of nigeria," *Engineering,* vol. 4, pp. 453.458, 2012.

[41] &. N. (. USDA, "Design of small photovoltaic (PV) solar.powered water pump systems," united state of agriculture and Natural resources conservation service, portland, 2010.

[42] T. C. Jack, Assessment of Solar Home Systems (SHS) for isolated rural communities invanuatu using project lifecycle/sustainability framework, houghton, 2010.

[43] S. P. D. &. J. P. Djordjevic, " Detectable faults on recently installed solar module in western Australia," *Renewable Energy,* vol. 67, pp. 215.221, 2014.

[44] B. T. E. K. I. C. a. M. K. Ö. M. Demirtas, "Effects of aging and environmental factors on performance of CdTe andCIS thin.film photovoltaic modules," *Jounal of Electronic Materials,,* vol. 48, pp. 6890.6900, 2019.

[45] B. Z., Bilgin Z., Designing and realizing a sun tracking system, M.Sc. Thesis, Gazi University,, Ankara.Turkiye. Institute of Science and Technology, 2006.

[46] S. A. Eke R., "Performance comparison of a double.axis sun tracking versus fixed PV system," *Solar Energy,* vol. 86, pp. 2665.2672, 2012.

[47] Chang T. P., " Output energy of a photovoltaic module mounted on a single.axis tracking system," *Applied Energy,* vol. 86, no. 10, pp. 2071.2078, 2009.

[48] N. S. Abdallah S., "Two axes sun tracking system with PLC control," *Energy Conversion and Management,* vol. 45, no. 11, pp. 1931.1939, 2004.

[49] Y. B. Aydın M., "Experimental determination of tilt angle effect in photovoltaic panels," *Journal of Thermodynamics,* vol. 148, pp. 88.89, 2004.

[50] Ç. G., "Using principles of photovoltaic panels on vertical building envelope," *Journal of the Faculty of Engineering and Architecture of Gazi University,* vol. 17, no. 3, pp. 17.33, 2002.

[51] D. W. H. Y. Huang B.J., "Long.term field test of solar PV power generation using one.axis," *solar energy,* vol. 85, pp. 1935.1944, 2011.

[52] S. C., "Multi.axes sun.tracking system with plc control for photovoltaic panels inTurkiye," *Renewable Energy,* vol. 34, pp. 1119.1125, 2009.

[53] Yılmaz M., "Determination of methods deriving electrical energy from solar energy and optimum efficiency by solar tracking system, Ph. D. Thesis, Marmara University," *Institute of Pure and Applied Sciences,* 2013.

[54] Z. G. C. L. K. V. Vokas G. A., "Single and Dual Axis PV Energy Production Over Greece. Comparison Between Measured and Predicted Data," *Energy Procedia,* vol. 74, pp. 1490.1498, 2015.

[55] L. M. R. M. P. M. Lazaroiu C. G., "Comparative analysis of fixed and sun tracking low power PV systems considering energy consumption," *Energy Conversion and Management,* vol. 92, pp. 143.148, 2015.

[56] E. C. P. G. I. S. (PVGIS), "https://joint.research.centre.ec.europa.eu/," [Online]. Available.

https://joint.research.centre.ec.europa.eu/pvgis.online.tool/getting.started.pvgis/pvgis.data.sources.calculation.methods_en Accessed 10 April 2023].

[57] F. G. S. A. K. R. S. T. F. M. D. E. Huld T., "A power.rating model for crystalline silicon PV modules," *Solar Energy Materials & Solar cells,* vol. 95, pp. 3359.3369, 2011.

[58] W. H. P. H. Z. C. D. S. S. S. Nuri Gökmen, "Investigation of wind speed cooling effect on PV panels in windy locations,," *ISSN 0960.1481,* pp. 283.290, 2016.

[59] M. Ç. M. Cubukcu, "Modeling, comparative simulation and practical performance analysis of a stand.alone PV hybrid power system in Turkiye," *Journal of Optoelectronics and Advanced Materials,* vol. Journal of Optoelectronics and Advanced Materials, pp. 352.360, 2013.

[60] T. Huld, ". A power.rating model for crystalline silicon PV modules," *Solar Energy Materials and Solar Cells* , vol. 95, pp. 3359.3369, 2011.

[61] O. a. T. K. Ceylan, "Investigation of The Accuracy of Photovoltaic Programs," *Afyon Kocatepe University Journal of Science and* , vol. 18, no. 3, pp. 895.903, 2018.

[62] A. a. B. M. Barhdadi, "PVGIS Approach for Assessing the Performances of the," *The African Review of Physics,* vol. 7, no. 38, pp. 337.344, 2012.

[63] V. A. C. a. Y. G. Başay, "The Factors Determining The Efficiency Of Solar Power Plant Established In Mid.Height Mountainous Regions Around Uludağ," *Uludağ ,* vol. 24, no. 1, pp. 181.192, 2019.

[64] S. R. L. B. S. a. S. M. Tajbar, "2Photovoltaic Geographical Information System module for the estimation of solar electricity generation. A comparative study in Khyber Pakhtunkhwa Pakistan," *Journal of Energy Systems,* vol. 4, no. 1, pp. 12.21, 2020.

[65] I. (2020), "Renewable Energy Statistics," The International Renewable Energy Agency, abu dhabi, 2020.

[66] C. J. M. &. B. C. (. E. o. d. m. t. e. Demain, "Evaluation of different models to estimate the global solar radiation on inclined surfaces," *Renewable Energy* , vol. 50, pp. 710.721, 2013.

RESUME

Hiwa Najmalddin NASRALDEEN, Masterdegree in Energy System Engineering at Karabuk University, Turkey, from 2020 to 2023. During this program, I focused on energy systems and conducted research on the topic of "Efficiency analysis of fixed and axis tracking options of photovoltaic systems to be installed in a marina." Prior to that, I completed a Bachelor's Degree in Chemical Engineering at Koya University from 2014 to 2019. My final year project involved the production of Nitrobenzene.

Proficient in Microsoft Office package, including Microsoft Word, Excel, and PowerPoint. I have experience using Process Simulation software and possess skills in MATLAB for data analysis and process optimization. Additionally, I am adept at process engineering drawing using AutoCAD and familiar with PVGIS GRASSfor solar energy analysis.

I am a native speaker of Kurdish and have an intermediate level of proficiency in English, enabling effective communication and technical writing. I am also well-versed in Arabic, both spoken and written, and possess beginner-level skills in Turkish, with a basic understanding and conversational ability.

In 2017, I completed T TOPCO summer training courses in Drilling, Production, and HSE, where I gained practical knowledge in these areas of the energy industry.