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An Experimental Investigation into the Influence of Tilt and ∓45° Azimuth Angle on the Performance Efficiency of Photovoltaic Modules

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is submitted to the Mechanical Engineering
Department in partial fulfillment of the requirements for the degree
of Bachelor of Science in
College of Engineering - Mechanical Engineering

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بِسْمِ ٱللَّهِ ٱلرَّحْمَـٰنِ ٱلرَّحِيمِ

﴿ قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَاۖ
إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ ﴾

صَدَقَ ٱللَّهُ ٱلْعَلِيُّ ٱلْعَظِيمُ

(البقرة : ٣٢)

SUPERVISOR CERTIFICATION

I certify that the preparation of this project entitled (**An Experimental Investigation into the Influence of Tilt and ∓45° Azimuth Angle on the Performance Efficiency of Photovoltaic Modules.),** prepared by **Hiba Kadhim Dirjal, Russel Ali Nazza, and Maha Abbas Jumaa,**

was made under my supervision at General College of Engineering, Mechanical Engineering Department, in partial fulfillment of the Requirements for the Degree of Bachelor of Science in College of Engineering - Mechanical Engineering.

Signature:

Name: Asst. Lec. Murtadha Saeed Mohammed

(Supervisor)

Date:

Dedication

الإهداء

إلى من علّمنا أن العِلم عبادة، وأن السعي إلى المعرفة طريقٌ إلى الله،
إلى الإمام علي بن أبي طالب (عليه السلام)،
نهدي هذا العمل تقديرًا ومحبةً لمن كان منارةً للعلم والحكمة.

وإلى الإمام المهدي المنتظر (عجّل الله فرجه الشريف)،
أمل المستضعفين، ونور الدرب في زمن الغيبة،
نهديك سعينا هذا، رجاءً أن نكون من أنصارك والممهّدين لظهورك.

إلى والدينا الأعزّاء،
الذين كانوا لنا دعمًا لا ينقطع، ودعاءً لا يغيب،
نهدي إليكم هذه الخطوة في طريق مستقبلنا، وفاءً وعرفانًا.

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I would like to thank our family, especially my parents, for their encouragement, patience, and assistance over the years. We are forever indebted to our parents, who have always kept me in their prayers.

ABSTRACT

This project presents an experimental investigation into the impact of tilt and ±45° azimuth angles on the performance efficiency of photovoltaic (PV) modules in Maysan, Iraq. Field experiments were conducted under varying tilt, azimuth angles, and temperature conditions to assess their influence on system performance. The results revealed that both tilt and azimuth angles significantly affect efficiency, power output, and fill factor. The optimal tilt angle for maximum performance was found to be approximately 13°, while the ideal azimuth angle was 0°, with the panels directly facing the sun.

Additionally, the study demonstrated that increasing temperature negatively impacts efficiency and voltage, although a slight increase in current was observed. These findings highlight the critical role of both geometric positioning and thermal management in enhancing PV system performance, especially in hot climates like Maysan.

Based on the outcomes, the study recommends installing PV panels at a tilt angle between 13° and 15°, maintaining an azimuth angle of 0°, or implementing sun-tracking systems. It also suggests employing cooling or ventilation strategies, using materials with low temperature coefficients, and adopting real-time monitoring systems to adapt t changing environmental conditions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

B	Beta
VT	Thermal voltage
Circ	Circuit
PV	Photovoltaic
PC-SI	polycrystalline silicon
c-Si	crystalline monocrystals
CIGS	Copper Indium Gallium Selenide
IPH	Including photocurrent
ID	Diode current
Rs	Series Resistant
Rsh	Shunt resistants’
$\mathbf{I_L}$	Light generated current
$\mathbf{I_D}$	Diode current
$\mathbf{I_0}$	Diodes reverse saturation current
$\mathbf{V_T}$	Thermal voltage
K	Boltzmann constant (1.38 $*10^{-23}$ J/k)

TC	Absolute temperature of the cell (in kelvin)
Q	Elementary charge ($1.6*10^{-19}$ C)
ISC	Short-circuit current
VOC	Open –circuit voltage
MPP	Maximum power point
FF	Fill factor
C-SI	Crystalline silicon
PC-SI	Polycrystalline silicon
CIGS	Copper indium gallium celenide
CdTe	Cadmium telluride
a-Si	Amorphous silicon
Φ	Tilt angle

CHAPTER ONE

INTRODUCTION

CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION

Photovoltaic cells, commonly known as solar cells, convert light energy, primarily from the sun, directly into electrical energy through the photovoltaic effect. This process occurs when photons (light particles) strike a semiconductor material within the cell, causing electrons to be knocked loose and generating an electric current. Photovoltaic cells are a cornerstone of renewable energy technology, providing a clean and sustainable alternative to traditional fossil fuels [1].

These cells are typically made from semiconductor materials such as silicon, which can absorb sunlight and produce an electric charge. Solar panels, consisting of many photovoltaic cells connected, are widely used in various applications—from residential and commercial buildings to large-scale solar power plants [2].

The primary advantages of photovoltaic cells include their environmental benefits, such as reducing greenhouse gas emissions, and their ability to generate electricity without the need for fuel or moving parts. As technology advances, the efficiency of photovoltaic cells continues to improve, making them a more cost-effective and accessible energy source globally. See **Figure 1.1**.

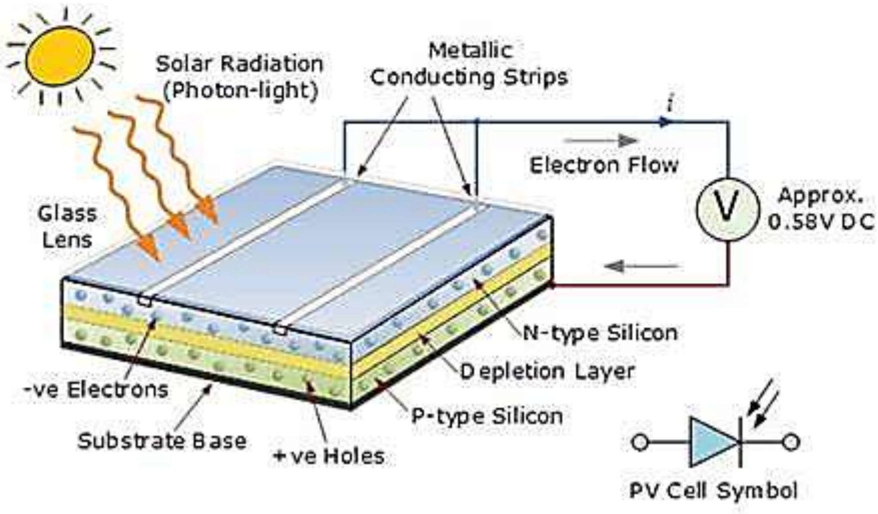


Fig. (1.1): Illustration of photovoltaic cells working

The ways of using solar energy can be divided into two parts: active and passive. The department that uses mechanical techniques is called to take advantage of the abundant solar energy in the universe, such as solar panels. A section that does not use mechanical methods to take advantage of solar energy is called the passive section.

1.2 CONCEPT OF PHOTOVOLTAIC PANELS

Photovoltaic (PV) panels convert sunlight directly into electricity using the photovoltaic effect. The term "photovoltaic" comes from the combination of "photo," meaning light, and "voltaic," meaning electricity. PV panels comprise many solar cells, typically constructed from semiconductor materials such as silicon [3].

When sunlight strikes a PV panel, it interacts with the semiconductor material in the cells, causing electrons to become excited and generate an electric current. This current flows through the material and is captured by electrical circuits within the panel, producing usable electrical power.

Here’s a straightforward step-by-step explanation of how the process works, illustrated in **Figure 1.2**:

1. **Absorption of Sunlight**: Solar radiation (sunlight) strikes the surface of the photovoltaic panel.
2. **Generation of Electrical Current**: The energy from the sunlight excites electrons in the semiconductor material, causing them to move and generate an electric current.
3. **Flow of Electricity**: This flow of electrons is harnessed by electrical conductors, and the resulting electrical current is sent to an inverter.
4. **Conversion to Usable Power**: The inverter converts the direct current (DC) electricity generated by the panels into alternating current (AC), the form of electricity most home appliances use and the power grid.

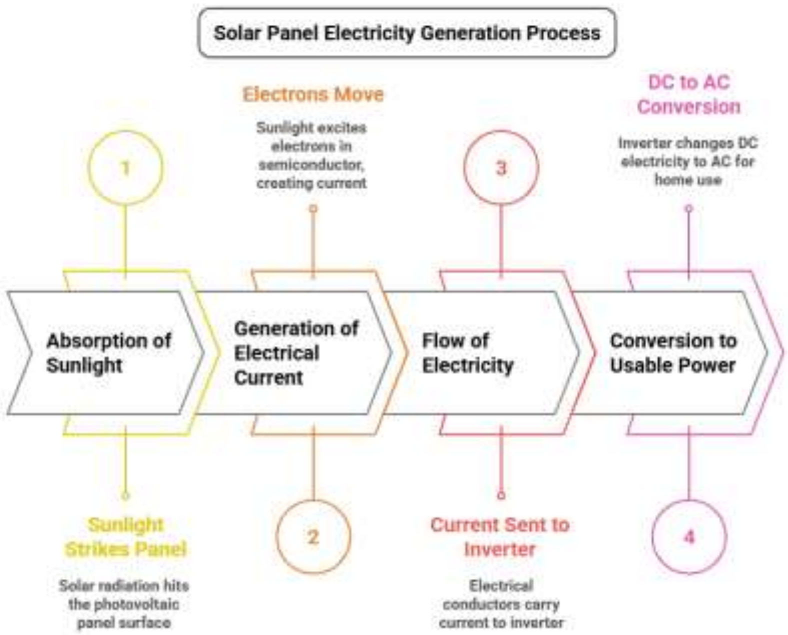


Fig. (1.2): The solar panel electricity generation process

1.3 PRINCIPLES OF PHOTOVOLTAIC PANEL OPERATION

Photovoltaic panels transform sunlight into electricity via a mechanism known as the photovoltaic effect. This section outlines the fundamental principles governing how photovoltaic panels operate [4]:

1- **The photovoltaic effect**: Sunlight (photons) strikes a semiconductor material (typically silicon), exciting electrons and generating an electric current. This energy frees electrons, which an electric field captures, creating a current flow.
2- **The structure of a photovoltaic cell**: It consists of semiconductor material, typically silicon, which is known for its efficiency in absorbing light and generating electricity. Additionally, a P-N junction comprises P-type silicon (positively charged, containing electron holes) and N-type silicon (negatively charged, featuring an excess of electrons). This junction establishes an electric field that guides the flow of electrons to produce current.
3- **Generation of electric current**: Sunlight excites electrons in the N-type silicon, causing them to move toward the P-N junction, generating direct current (DC).
4- **Current flow through an external circuit**: The photovoltaic cell is connected to an external circuit, allowing the electrons to flow and providing electricity to power devices or charge a battery. Multiple cells are wired together to form a solar array, generating more power.

1.4 TYPES OF PHOTOVOLTAIC PANELS

Photovoltaic (PV) panels come in various types, each with distinct characteristics, efficiencies, and applications. The most common types of PV panels are shown in **Table 1.1** [5]:

Table 1.1: Comparative characteristics of photovoltaic panel types

Type	Material Composition	Efficiency	Cost Level	Lifespan	Advantages	Disadvantages
Monocrystalline Silicon	Single-crystal silicon	18–22%	High	25–30 years	High efficiency, long lifespan, good low-light performance	Higher cost, more material waste
Polycrystalline Silicon	Multi-crystalline silicon	15–18%	Moderate	20–25 years	Lower cost, easier to produce	Lower efficiency, less aesthetic, poor high-temp performance
Thin-Film (a-Si, CdTe, CIGS)	Amorphous silicon, CdTe, CIGS	10–12%	Low	10–20 years	Lightweight, flexible, and performs well in high temperatures	Requires more space, lower efficiency, and shorter lifespan
PERC (Mono-PERC)	Enhanced monocrystalline silicon	Up to 22%	High	25–30 years	Improved efficiency and light capture, better in low light	Higher cost, slightly less durable
Bifacial	Monocrystalline (dual-sided)	18–23% (plus 10–30% gain)	High	25–30 years	Captures reflected light, higher total energy yield	Expensive, requires reflective ground/mounting systems
Concentrated PV (CPV)	III-V semiconductor (e.g., GaAs)	Up to 40%	Very High	20–30 years	Extremely high efficiency with tracking systems	High cost, needs direct sunlight, and precise tracking
Perovskite	Organic–inorganic halide perovskite	>25% (lab scale)	Low–Moderate	<10 years (current)	High efficiency potential, low cost, tunable properties	Still under development, stability and toxicity concerns

1.5 PRACTICAL APPLICATIONS OF PHOTOVOLTAIC PANELS

Photovoltaic (PV) panels have become a versatile and widely adopted technology for harnessing solar energy. Their ability to convert sunlight directly into electricity makes them suitable for various practical applications across residential, commercial, industrial, and even aerospace sectors. **Table 1.2** summarizes the key areas where PV panels are commonly utilized, highlighting their functionality and scale of deployment.

Table1. 2: Practical applications of photovoltaic panels

Application	Sector	Scale	Description
Residential Systems	Residential	Small-scale	Used in homes to reduce electricity bills and provide an independent power supply.
Commercial & Industrial	Commercial / Industrial	Medium to large	Deployed in offices, factories, and warehouses to reduce energy costs.
Solar-Powered Transportation	Transportation	Small to medium	Integrated into EVs, buses, or solar cars to extend battery range.
Solar Water Heating	Residential / Industrial	Small to medium	Power water heating systems using solar thermal or PV-electric methods.
Off-Grid Power	Rural / Remote Locations	Variable	Supplies electricity to areas without grid access (e.g., cabins, villages).
Small Electronic Devices	Consumer Electronics	Micro-scale	Used in solar-powered calculators, lights, phone chargers, and gadgets.
Solar Farms	Utility	Large-scale	Massive PV arrays generate electricity to feed into the power grid.
Space Applications	Aerospace / Defense	Specialized/High-tech	Powers satellites, space stations, and exploratory missions beyond Earth.

1.6 IMPORTANCE OF PHOTOVOLTAIC PANELS IN MODERN TIMES

Photovoltaic panels play a crucial role in modern times by providing a clean, renewable energy source that reduces reliance on fossil fuels and helps combat climate change. They offer significant cost savings by lowering electricity bills and promoting energy independence, particularly in off-grid or remote areas. With continuous technological advancements, solar panels are becoming more efficient and affordable, making them accessible to a broader range of users. Additionally, they contribute to environmental sustainability by reducing carbon footprints and supporting job creation within the renewable energy sector. Photovoltaic panels are vital for a sustainable, cost-effective energy future [6].

1.7 CHALLENGES FACING PHOTOVOLTAIC PANELS

Despite their many benefits, photovoltaic panels face several challenges. One major issue is the **intermittency**, as they rely on sunlight, meaning energy production is limited to sunny days and is affected by weather conditions. Additionally, the **high initial cost** of installation can be a barrier, although prices have been decreasing [7]. Another challenge is the **space requirement** for large-scale solar installations, especially in densely populated areas. Furthermore, **energy storage** remains a key issue, as efficient and affordable battery technology is still developing. Finally, the **environmental impact** of manufacturing and disposing of solar panels, particularly related to the use of rare materials, needs ongoing attention for sustainability. Despite these challenges, technological advancements continue to improve the efficiency and accessibility of photovoltaic systems.

1.8 PROBLEM STATEMENT

The performance of solar panels depends on the cell temperature, where the photovoltaic module gives the highest efficiency at (25 °C and 1000 W/m2). The module efficiency decreases in each the photovoltaic cell temperature increase, which reduces the productivity of the cell for electrical energy, and the percentage of solar radiation converted to electrical energy ranges between (13-20) % and most of the solar radiation absorbed by the cell is converted into an unwanted thermal energy Increases cell temperature and reduces efficiency. However, the main problem of photovoltaic cells is the reduced cell efficiency and performance, due to the increase in the cell base temperature. To overcome this limitation, there is a strong motivation to reduce cell-based temperature through heat transfer and disposal techniques in the simplest and fastest method.

1.9 OBJECTIVES OF RESEARCH

The objectives of research are as follows:

1. **Analyze the effect of tilt angle**: Investigate how varying the tilt angle of photovoltaic panels impacts their efficiency in converting solar energy into electricity.
2. **Analyze the effect of temperature**: Examine how different temperatures affect the performance and efficiency of photovoltaic panels.
3. **Study the relationship between tilt angle and efficiency**: Identify the optimal tilt angle for photovoltaic panels that achieves the highest efficiency in different regions.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

Numerous research studies have been done in experimental studies related to the subject of the present study. Understanding the different scientific approaches to the PV unit cooling system is important to get acquainted with the different cooling techniques. At present, the technique of using air and water is.

2.2 THEORETICAL AND EXPERIMENTAL RESEARCH

Z. Syafiqah et al. [8] studied the effect of the cooled photovoltaic module by using air and water at the same time by passing air through a channel installed at the back of the PV module, and water was passed in front of the PV unit. The results were analyzed through the ANSYS simulation program, and showed a decrease in air cooling temperature of 19% and 53.2% by cooling water.

M. Abdolzadeh et al. [9] investigated the ability to improve the performance of the photovoltaic pumping system. This is done by spraying water over photovoltaic cells. Results were compared with conventional systems and showed that cell energy was increased due to removing heat from the front surface and absorbing heat generated from cells during the day by using a 225W water pumping system with water spray.

R. Hosseini et al. [10] used water to cool the photovoltaic cell by water spray technology. The effectiveness of this technique was studied instead of using water continuously above PV, and showed an increase in the electrical efficiency of the cell by 17%.

K.A. Moharramand et al. [11] used a spraying technique to reduce the water in the PV unit cooling plant. The cooling process was completed when it reached a temperature of 35 °C from 45 °C.

Salih Mohammed Salih et al. [12] used an experimental method of water spray technology to improve the efficiency of the photovoltaic (PV) unit. The result was achieved by increasing the power supply 7W / °C in the middle of the day.

Sayran. A. Abdulgafar et al. [13] increased the efficiency of the photovoltaic module by immersing the PV unit in distilled water and studying the effect of different depths. The results showed increased efficiency with increasing water depth. The appropriate depth was determined, where an increase of 11% was obtained at a depth of 6cm.

Ahmed Amine Hachicha et al. [14] used different water-cooling techniques: front, rear, and double cooling. The spray technology was used for front cooling, while direct contact water technology was used for rear cooling. The results were compared with those of a non-cooling PV unit to determine the performance of the PV module using different water-cooling techniques and to find the best module. The result showed that the front type is more effective than the rear cooling, which could reduce the temperature of the PV module on a larger scale.

M. Mohamed. Musthafa [15] used water through a sponge installed on the backside of the photovoltaic panels. The wet state was maintained by rotating the water droplets through the sponge to reduce the temperature of the PV module. The study confirmed that there is a linear relationship between efficiency and temperature. The temperature was lowered to 40 °C, and the PV efficiency increased by 12%.

Pascal Biwole et al. [16] used the PCM technique in an experimental and simulation study to maintain the temperature of the PV module. A non-pure phase change material, SP/PCM, was added to the PV base. The results showed that phase change material SP/PCM could keep the PV temperature under 40 °C for 80 minutes.

Maria C. Browne et al. [17] studied the effect of a phase change material on the performance of the PV module. The PCM type Capric-palmitic acid has a point of melting of 22.4 °C. The results showed that PV performance with the PCM was doubled compared to PV without the PCM.

Lip Pong Tan [18] used phase change materials (PCM) type RT27, which melts at 27 °C and has a thermal capacity of 184 kJ /kg, to cool the PV module. The result showed a decrease in PV temperature by five degrees compared to a PV without the PCM, which led to an increase in electrical efficiency by 1%. The efficiency could increase by increasing the amount of material.

M. Khaled et al. [19] used Petroleum jelly as a phase change material PCM to cool the PV module. The result was that using pure PCM could decrease the PV temperature by 6.5 °C and increase the electrical efficiency by an average of 5 %.

Abu Baker Younis et al. [20] used nanotechnology to cool the PV module using Al2O3-ZnO-2O nano-fluid. A dynamic test and analysis of several different nanotubes was carried out to confirm the improvement of heat transfer from the PV base and temperature reduction by practical methods and simulation.

J.K. Tonui et al. [21] study the effect of natural air flow to cool the PV module by using metal sheets suspended in the center or fins connected to the rear wall of the PV to improve heat extraction from the unit.

Joshi A. S. and Tiwari A. [22] theoretical study of PV / T system performance. The study was conducted on the climatic conditions of Srinagar in India. The numerical results of the system showed that an increase in the electrical efficiency of the PV / T system by air cooling leads to an increase in thermal efficiency. The electrical efficiency increased from 14% to 15%, resulting in a 2% to 3% increase in thermal efficiency.

Cezary Misiopecki et al. [23] discussed the effect of free convection cooling on PV modules, where practical results and 3D simulation results showed a problem in choosing the size of the air gap for air passage, as its smallness increases the temperature and requires a sufficient attenuation force to overcome the air force.

R.mazon-Hernandez et al.[24] Use air as a working fluid for cooling either by natural convection or forced by means of a fan to characterize the electrical behavior of solar panels in order to improve the design of PV installations placed in roof applications. The improvement result reached 15% in electric power because about 15 °C lowered the temperature, and it was confirmed that the depth of the flow channel under photovoltaic cells had a great effect on passive cooling.

D. Nebbali et al. [25] ensured that the PV module can be cooled by air and determined the highest fan consumption through which the airflow can be carried out on the base of the PV. Numerical simulation of the (C.F.D) program was performed. The results indicated that the optimum air mass is (0.008 Kg /s), increasing electrical efficiency by 1.35%.

A.Crăciunescu et al. [26] used forced air on the photovoltaic panel, where the study found that the voltage decreased in the case without cooling from the start of the exposure of the PV to the solar radiation, and the voltage increased in the case of cooling. The study found that the temperature of the PV increases whenever the PV is exposed to solar radiation, which negatively affects the PV's performance; therefore, the cooling systems are very important to PV.

Emad A. Sweelem et al. [27] examined a design of the PV module cooling system by using forced air technology for its availability, simplicity, and low cost through a DC fan. The experimental results showed an increase in electrical efficiency of 2%.

Hussein M. Maghrabie et al. [28] studied the effect of air forced cooling on photovoltaic cells using an air blower in a rectangular channel installed on the back of the PV module. The results showed a decrease in cell temperature by 11% when the air passes on the back of the PV unit, and the PV temperature drops by 10% when the air passes on the front of the PV. The rate of increase in PV efficiency is 3.7%.

Gökhan Ömeroğlu [29] determined a number of fins installed on the base of the PV module and their effect on the process for making turbulent air transmit heat from the PV base. Fins are manufactured from cheap and easily made materials. The result of the CFD program showed that increasing the number of fins leads to a significant increase in thermal efficiency and a slight increase in electrical efficiency.

CHAPTER THREE

THEORETICAL ANALYSIS

CHAPTER THREE: THEORETICAL ANALYSIS

3.1 INTRODUCTION

This chapter presents a comprehensive theoretical foundation for understanding the performance and behavior of photovoltaic (PV) and hybrid photovoltaic/thermal (PV/T) systems. It begins by exploring the nature of solar radiation and the geometric relationship between the Earth and the Sun, which governs the intensity and distribution of solar energy. The importance of tilt angle is examined in detail, as it significantly affects energy capture and system efficiency. The chapter also delves into the electrical modeling of photovoltaic cells, outlining various equivalent circuit models that help evaluate and predict their performance under different environmental conditions.

Furthermore, hybrid PV/T systems are introduced as a solution to the thermal limitations of conventional PV modules, offering a dual benefit of electrical and thermal energy output. The physical properties of air and heat transfer coefficients are also discussed to understand better the thermal dynamics involved in PV/T system operation. Finally, the chapter distinguishes between thermal and overall efficiency to provide a clearer picture of system performance from energy and economic perspectives.

3.2 CONCEPT OF SOLAR RADIATION

Solar radiation is the energy emitted by the sun through electromagnetic waves, including visible, infrared, and ultraviolet rays.

This energy is considered the primary source of life on Earth, as it plays a significant role in natural processes such as photosynthesis, the water cycle, and climate regulation.

Components of solar radiation are shown in **Figure 3.1.**

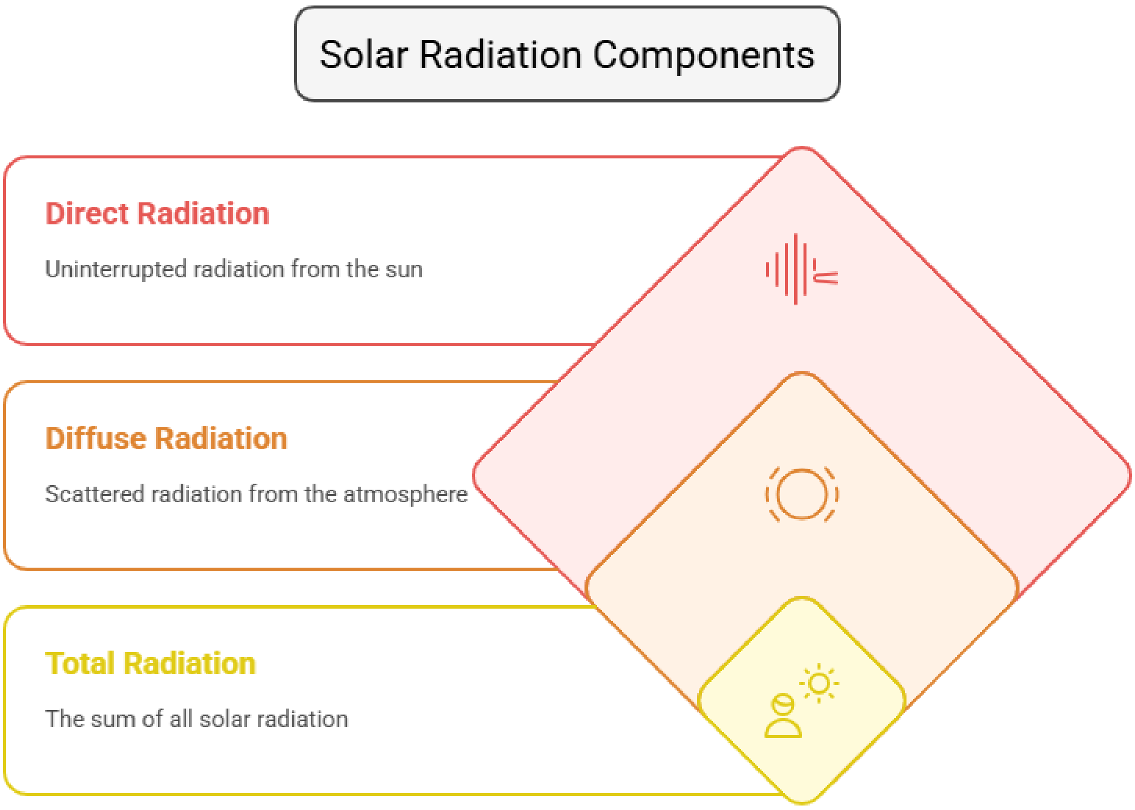


Fig. (3.1): The solar radiation components

Several natural and environmental factors influence solar radiation reaching the Earth's surface. As shown in **Figure 3.2**, these factors affect the intensity, direction, and duration of sunlight received at a specific location. Understanding these influences is essential for accurately estimating solar energy availability and designing efficient solar systems [30].

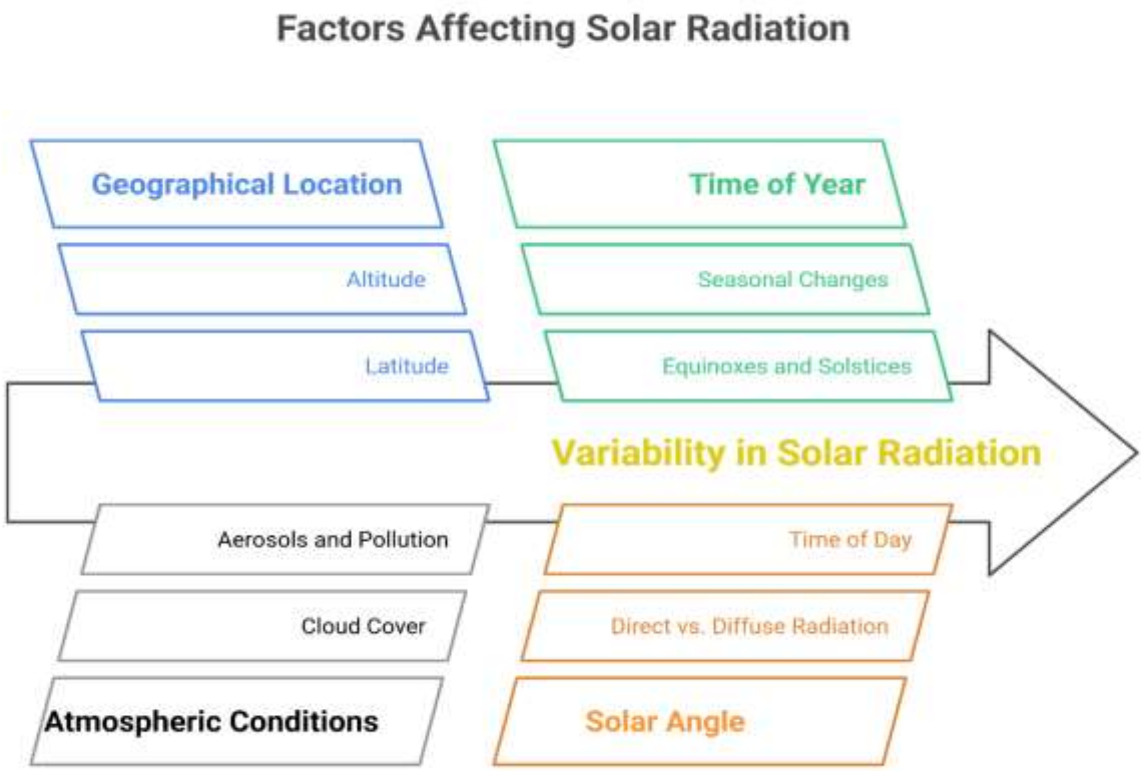


Fig. (3.2): The factors affecting solar radiation

3.3 SUN–EARTH GEOMETRIC RELATIONSHIP

The geometric relationship between the Sun and the Earth is fundamental in understanding the variations in solar radiation that reach the Earth's surface. This relationship determines the distribution and intensity of sunlight over different regions and times, and it directly influences climatic patterns, seasonal changes, and the efficiency of solar energy systems. The primary components of the Sun–Earth geometric relationship are discussed below:

3.3.1 Earth's Orbital Path

The Earth follows an elliptical orbit around the Sun, completing one revolution approximately every 365.25 days. This orbital motion defines the length of a year and introduces minor variations in the Earth–Sun distance. The average distance between the Earth and the Sun is about 150 million kilometers (93 million miles), one astronomical unit (AU). Although the orbit is nearly circular, the slight eccentricity affects the intensity of solar radiation slightly during different times of the year.

3.3.2 Earth’s Axial Tilt

The Earth's rotational axis is tilted at an angle of approximately 23.5 degrees concerning the plane of its orbit around the Sun (the ecliptic plane). This axial tilt is the primary reason for the occurrence of seasons. As the Earth revolves around the Sun, different hemispheres receive varying angles and durations of sunlight, leading to seasonal variations in temperature and daylight.

3.3.3 Sunlight Angle and Seasonal Variations

The angle at which sunlight strikes the Earth’s surface changes throughout the year. During the **summer solstice** (around June 21), the Northern Hemisphere is tilted toward the Sun, resulting in longer daylight hours and more direct solar radiation, causing warmer temperatures. Conversely, during the **winter solstice** (around December 21), the Northern Hemisphere is tilted away from the Sun, receiving less direct sunlight and shorter days. The **equinoxes** around March 21 and September 21 represent the times when the Sun is directly above the equator, leading to nearly equal day and night durations globally.

3.3.4 Earth’s Daily Rotation

The Earth rotates around its axis once every 24 hours, leading to the regular day and night cycle. As the Earth turns, different parts of its surface are exposed to sunlight, creating a rhythm of light and darkness that influences diurnal temperature variation and solar radiation availability.

3.3.5 Apparent Path of the Sun

Due to the Earth's rotation and axial tilt, the Sun daily moves across the sky from east to west. Over the years, its apparent position changes, creating varying solar paths. This affects the angle of solar incidence and the duration of solar exposure, which are crucial parameters in the design and orientation of solar energy systems.

3.3.6 Distribution of Solar Energy

Solar radiation is most intense when the Sun's rays strike the Earth perpendicularly, as is common near the equator. At higher latitudes, the solar rays hit the surface at an oblique angle, spreading over a larger area and reducing the energy intensity. This geographic variation is a key factor in determining the solar potential of different regions.

3.3.7 The Ecliptic Plane

The ecliptic plane is the apparent path the Sun traces across the celestial sphere over a year, as observed from Earth. The tilt of the Earth’s axis causes the Sun to appear higher in the sky during summer and lower during winter. This apparent motion is critical in solar geometry and affects solar panel orientation and energy harvest predictions.

In summary, the geometric relationship between the Sun and Earth governs the timing, intensity, and distribution of solar radiation on the Earth's surface. Understanding these dynamics is essential for optimizing the performance of solar photovoltaic and hybrid systems, as they directly influence system design parameters such as tilt angle, orientation, and tracking strategies.

3.4 FIXED TILT ANGLE (Β)

The fixed tilt angle, denoted as β (beta), refers to the inclination of a surface—commonly a solar panel—relative to the horizontal plane. This angle plays a crucial role in determining the amount of solar radiation received by a surface and is therefore vital for optimizing the performance of solar energy systems. Correctly selecting β can significantly enhance energy output by aligning the receiving surface more effectively with the Sun's apparent path.

3.4.1 Tilt Angle in Solar Panel Applications

In solar photovoltaic (PV) systems, the fixed tilt angle β is defined as the angle between the plane of the solar panel and the horizontal ground surface. This angle affects the incident angle of solar rays and, thus, the intensity of solar radiation absorbed.

- **Latitude-Based Optimization**: A commonly used rule of thumb is to set the tilt angle approximately equal to the location's latitude (φ) to achieve optimal annual energy generation.
- **Seasonal Adjustments**: For improved performance in particular seasons, the tilt angle may be adjusted:
    - **Summer**: $\beta = \varphi - 15°$
    - **Winter**: $\beta = \varphi + 15°$

  For example:
    - At the equator (0° latitude), solar panels are typically installed flat ($\beta \approx 0°$).

   - At higher latitudes, the panels are tilted at steeper angles to compensate for the lower solar altitude during parts of the year.

3.4.2 Earth's Axial Tilt and Its Implications

Beyond solar panel applications, a notable fixed tilt angle in planetary geometry is the Earth's axial tilt, approximately 23.5°. Relative to the ecliptic plane, this tilt is responsible for the seasonal variations in solar radiation distribution across the Earth's surface. It leads to changes in solar declination and day length throughout the year, influencing the optimum design of solar systems in different seasons and regions.

3.4.3 Fixed Tilt in Other Engineering Systems

In engineering and applied sciences, β may also denote the fixed orientation of surfaces in systems like:

- **Solar reflectors and antennas**, where β influences exposure to the Sun or to signal sources.
- **Spacecraft or satellite modules**, where β is adjusted for optimal energy absorption or signal transmission.

In these contexts, correctly selecting β ensures operational efficiency based on geometric relationships and exposure requirements.

3.4.4 Empirical Tilt Angle Equations for Solar Design

Several empirical expressions are used to estimate the optimal fixed tilt angle for solar panels depending on application and design priorities:

- **For maximum annual output**:

$$\beta = \phi \tag{3.1}$$

- **For optimal winter performance**:

$$\square = \phi + 15^\circ \tag{3.2}$$

- **For optimal summer performance**:

$$\square = \phi - 15^\circ \tag{3.3}$$

These equations allow designers to tailor solar installations for annual, seasonal, or application-specific performance targets. [31]

3.5 ELECTRICAL MODELING OF PHOTOVOLTAIC CELL

Accurate electrical modeling of photovoltaic (PV) cells is essential for evaluating their performance and efficiency under various environmental conditions. Several equivalent circuit models are used to simulate the electrical behavior of PV cells. These include the three-parameter, four-parameter, and five-parameter models, as illustrated in **Figure 3.3.** Each model incorporates key elements that represent the real physical characteristics of a solar cell, including the photocurrent (Iph), diode current (ID), series resistance (Rs), shunt resistance (Rsh), and diode ideality factor (a), which is dependent on temperature and irradiance conditions [32].

The diode ideality factor is typically considered 1.2 for polycrystalline silicon PV modules, representing the deviation from ideal diode behavior due to recombination and other physical losses within the cell material.

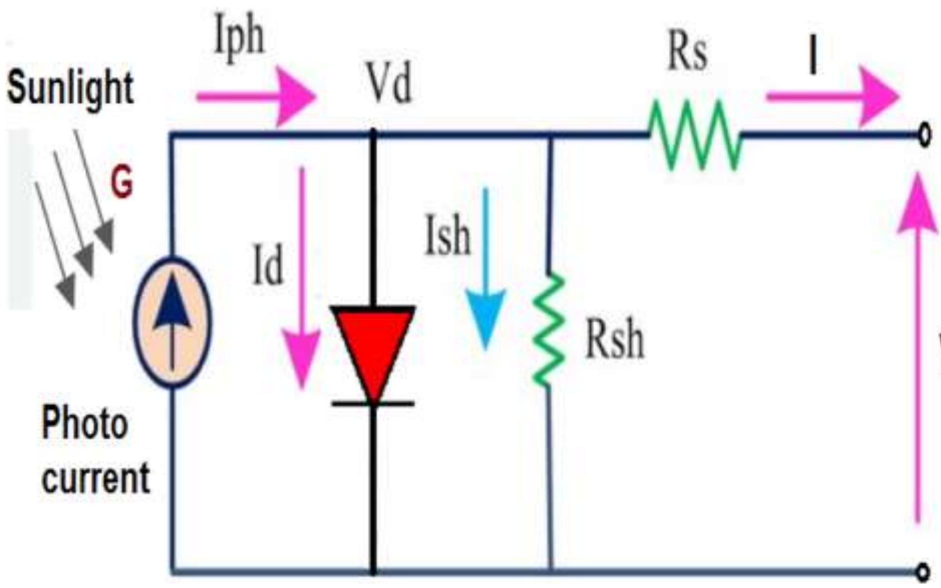


Fig. (3.3): Equivalent Circuit Models of a Photovoltaic Cell: Single-diode model, with series resistance Rs, and with both series and shunt resistances (Rs and Rsh) [33].

3.5.1 Mathematical Representation

Kirchhoff's current law can be applied to the single-diode equivalent circuit to derive the current output of the PV cell. The net current (I) from the PV cell can be expressed as:

$$I = I_L - I_D \tag{3.4}$$

Where:

- I_L is the light-generated current (photocurrent),
- I_D is the diode current.

The Shockley diode equation describes the diode current:

$$I_D = I_0\left[exp\left(\frac{V + IR_s}{V_T}\right) - 1\right] \tag{3.5}$$

Where:

- I_0 is the diode's reverse saturation current,
- V is the terminal voltage across the PV cell,

- Rs is the series resistance,
- V_T is the thermal voltage.

The thermal voltage (V_T) depends exclusively on the cell temperature and is defined as:

$$V_T = \frac{kT_c}{q} \tag{3.6}$$

Where:

- k is the Boltzmann constant (1.38×10^{-23} J/K),
- Tc is the absolute temperature of the cell (in Kelvin),
- q is the elementary charge (1.6×10^{-19} C).

These equations form the basis for simulating PV cells' current-voltage (I–V) behavior under varying operational conditions as illustrated in **Figure 3.4**.

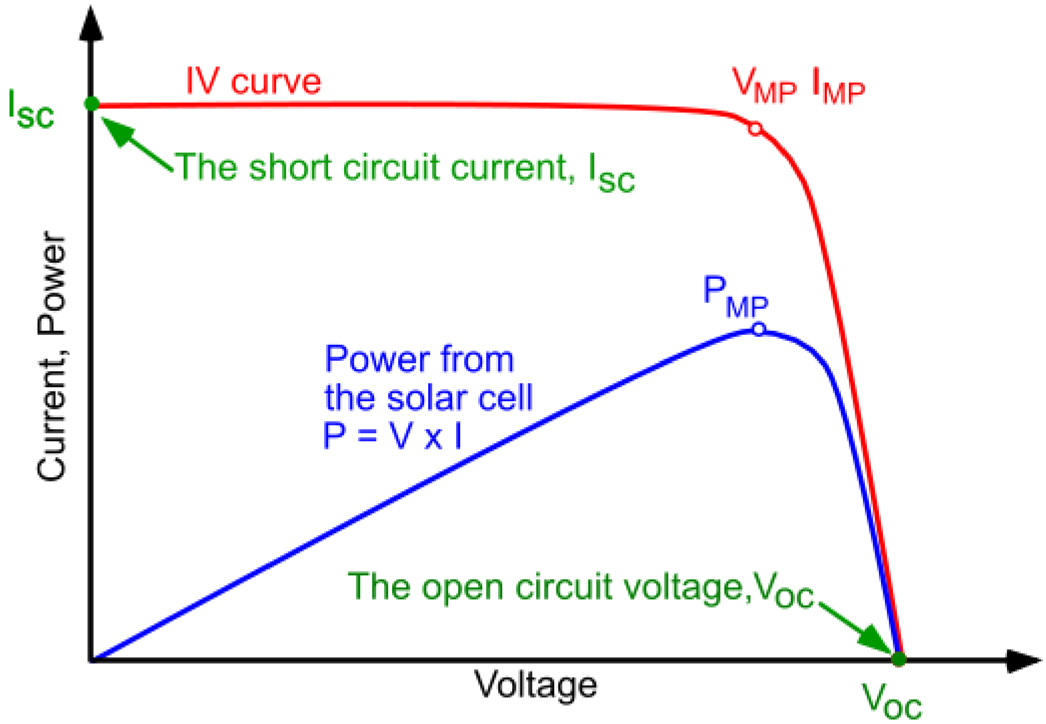


Fig. (3.2): Typical Current–Voltage (I–V) Characteristic Curve of a Photovoltaic Cell [29].

The I–V curve is a fundamental tool for analyzing PV performance. It illustrates how the output current varies with voltage. It helps determine key operational parameters such as short-circuit current (ISC), open-circuit voltage (VOC), maximum power point (MPP), fill factor (FF), and efficiency. Understanding and modeling this curve are essential for designing effective PV systems and optimizing their output under real-world conditions.

3.6 HYBRID PV/T SYSTEMS

Hybrid Photovoltaic/Thermal (PV/T) systems are designed to generate electrical and thermal energy from solar radiation simultaneously. These systems are particularly valuable in applications where both electricity and heat are required, such as residential buildings, industrial facilities, and greenhouses.

In standard PV modules, only a fraction of incident solar energy is converted into electrical power, while the remainder is transformed into heat. This heat increases the temperature of the solar cells, reducing their efficiency. For instance, in crystalline silicon (c-Si) or polycrystalline silicon (pc-Si) modules, the electrical efficiency typically drops by approximately 0.45% per °C rise in cell temperature. In contrast, amorphous silicon (a-Si) cells exhibit a lower degradation rate of around 0.2% per °C [34].

To counteract this thermal effect, a hybrid PV/T system often incorporates a simple air-cooling mechanism. By directing airflow across the back of the PV module, excess heat is removed, which enhances the electrical efficiency and overall system performance. Additionally, the recovered thermal energy can be utilized in various heating applications, thereby increasing the total energy output of the system. This integration of photovoltaic and thermal functionalities is referred to as an "integrated thermal photoelectric system," as shown in **Figure 3.5.**

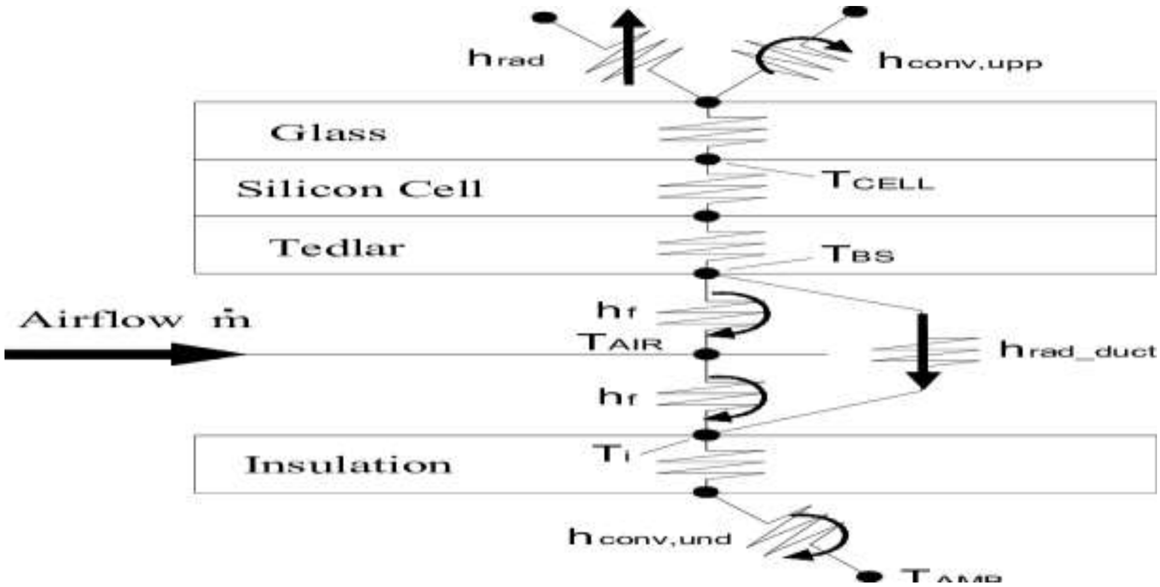


Fig. (3.5): Equivalent Thermal Resistance Circuit of a PV/T Air Collector [35].

3.7 HYBRID PV/T SYSTEM ANALYSIS

Figure 3.6 presents the schematic layout of a typical hybrid PV/T system. It consists of a glass-to-glass PV module mounted on a flat absorber plate, with insulation applied to minimize thermal losses. The air flows through a duct beneath the PV module and is heated by both the absorber plate and the underside of the PV module.

This design allows for effective thermal energy recovery while maintaining PV module efficiency. **Figure 3.7** illustrates the heat transfer coefficients and the system's thermal resistance network.

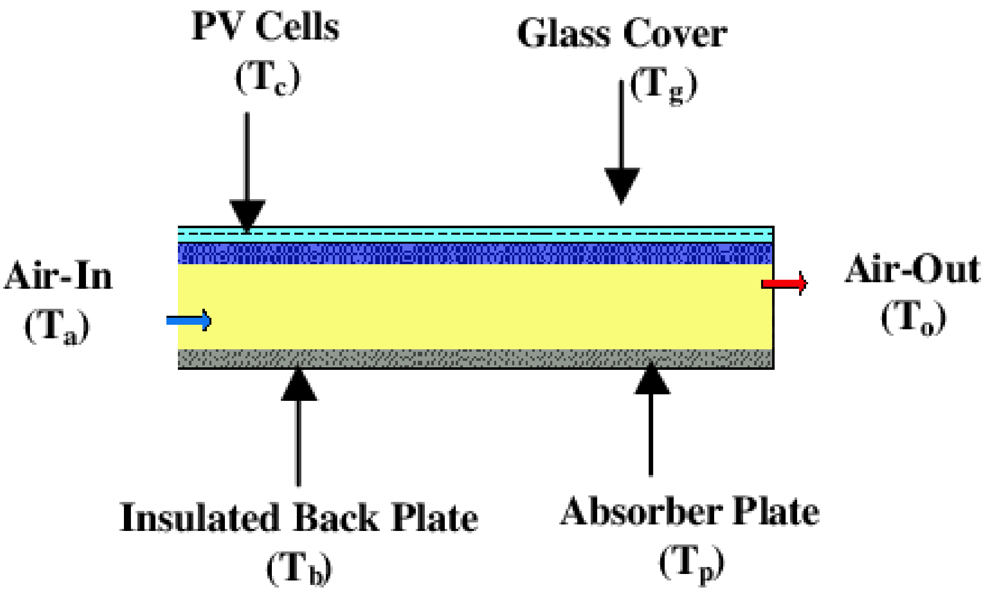


Fig. (3.6): Schematic Diagram of a PV/T Air Cooling System.

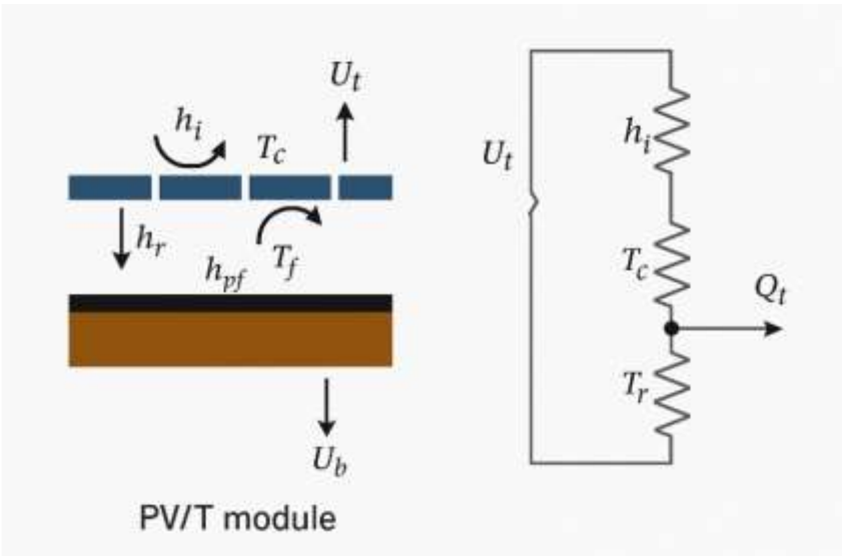


Fig. (3.7): (a) Heat transfer coefficients, (b) equivalent thermal resistance network for pv/t thermal system [36].

3.8 SOLAR CELLS OF THE PV MODULE

Photovoltaic modules, commonly referred to as solar panels, are composed of multiple interconnected solar cells. Each cell is built using semiconductor materials—primarily silicon—which exhibit the photovoltaic effect, converting sunlight directly into electrical energy.

The PV cells are mounted within support structures that ensure optimal orientation and tilt angle toward the Sun. These modules are equipped with two output terminals that transfer generated electricity to the power management system.

There are three main types of solar panels used in photovoltaic modules as shown in **Figure 3.8**:

1. **Monocrystalline Solar Panels** Made from pure silicon, monocrystalline panels are known for their high efficiency and compact design. They are ideal for applications where space is limited and aesthetics are important.

2. **Polycrystalline Solar Panels** Polycrystalline panels are more affordable and easier to manufacture. Though slightly less efficient than monocrystalline panels, they offer a cost-effective solution for large-scale installations.

3. **Thin-Film Solar Panels** These are made from materials such as Copper Indium Gallium Selenide (CIGS), Cadmium Telluride (CdTe), or Amorphous Silicon (a-Si). Thin-film panels are lightweight and flexible, offering versatility for various non-traditional applications.

Each type of solar cell presents distinct advantages depending on cost, efficiency, space, and intended use [7].

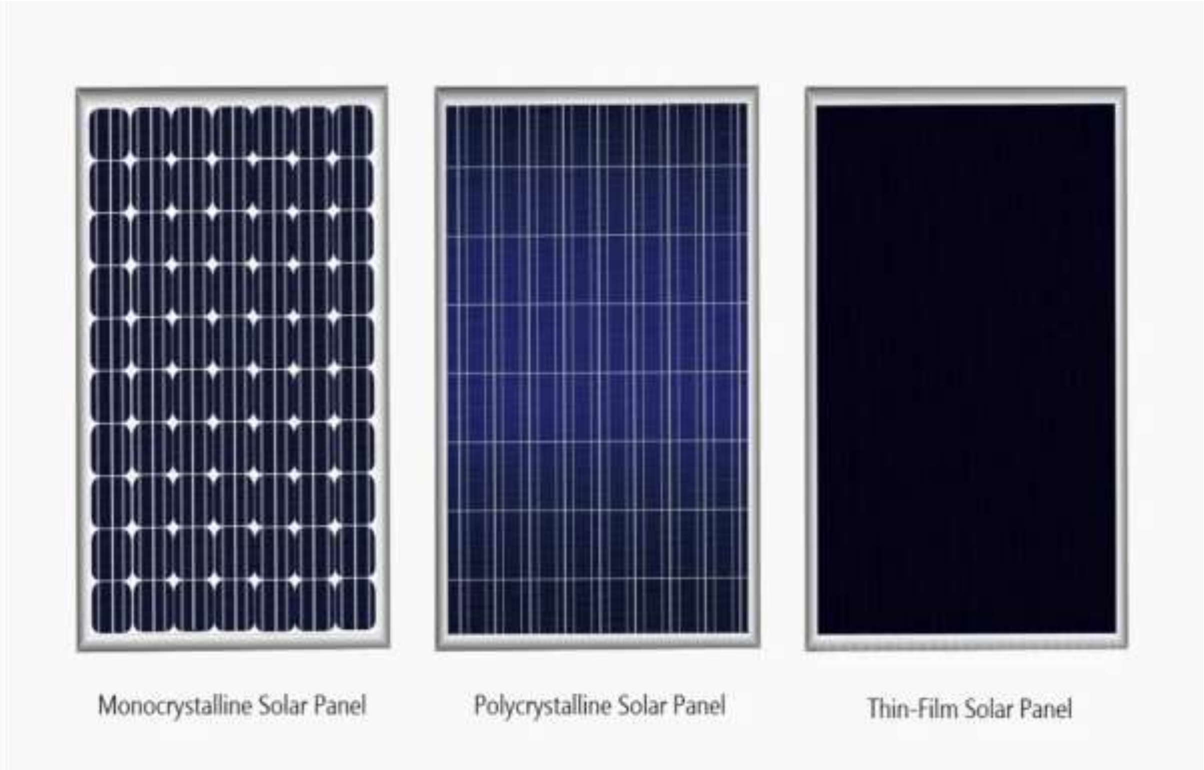


Fig. (3.8): Photovoltaic solar panel types.

3.9 PHYSICAL PROPERTIES OF AIR

Air, the gaseous envelope surrounding the Earth, is vital in thermal systems for its role in heat transfer. It is composed primarily of nitrogen (78%), oxygen (21%), argon (1%), with traces of other gases and water vapor. Its physical behavior significantly influences PV/T system performance.

- **Pressure Properties** Air pressure is a result of the weight of air molecules in the atmosphere. It increases with the number of air particles in a given area and decreases with altitude.
- **Thermal Properties** Air expands when heated as the molecules move faster and spread apart. This characteristic enables air to function effectively as a heat transfer medium in PV/T systems.

- **Density Properties** Air's density is affected by temperature, pressure, and humidity. Warm air is less dense due to increased molecular activity. Likewise, humid air is less dense than dry air, which can influence thermal transfer rates in ventilation or cooling systems.

Understanding these properties (**See Table 3.1**) is essential in designing efficient air-based cooling and heat recovery systems for hybrid PV/T applications [37].

Table 3.1: Practical applications of photovoltaic panels

Property	**Value**
Density	1.225 kg/m³
Specific heat (Cp)	1006.43 J/(kg·K)
Thermal conductivity	0.0242 W/(m·K)
Viscosity	1.7894×10−51.7894 \times 10^{-5} kg/(m·s)

3.10 HEAT TRANSFER COEFFICIENTS

3.10.1 Radiation Heat Transfer Coefficient

The radiation heat transfer coefficient (h_{rad}) quantifies the heat transfer rate via thermal radiation between surfaces. It depends on the emissivity (ε), Stefan-Boltzmann constant (σ_{SB}), and the absolute temperature of the radiating surface. It exhibits a nonlinear relationship with temperature. As shown in **Figure 3.9.**

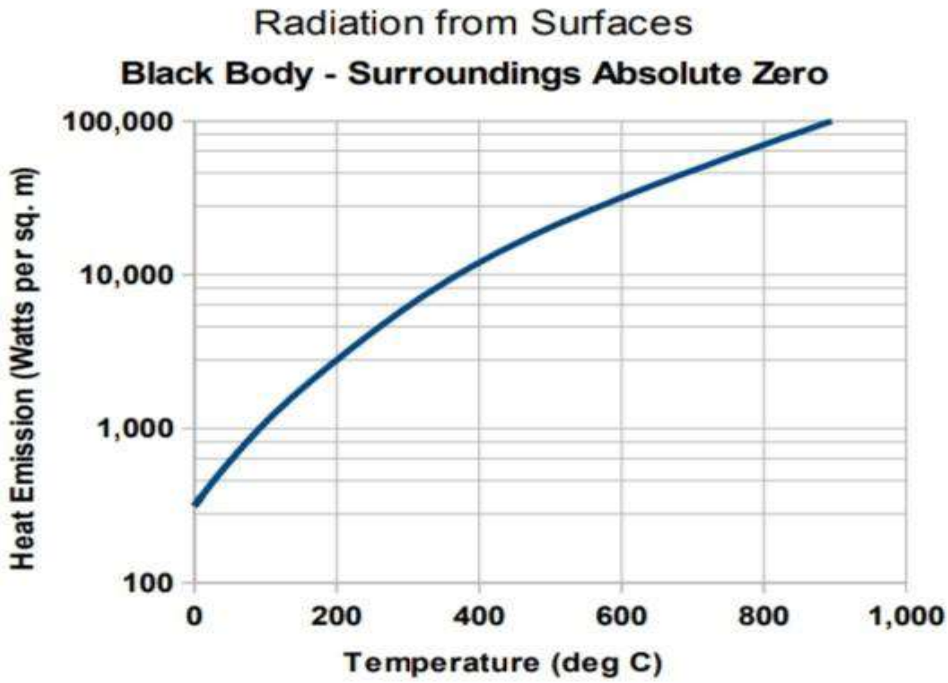
$$h_{rad} = \varepsilon \cdot 4\sigma_{SB}T^3 \qquad (3-7)$$

Where:

ε = Emissivity of the surface

$\sigma_{SB} = 5.67 \times 10^{-8}\, W/m^2 \cdot K^4$ (Stefan-Boltzmann constant)

T = Absolute temperature (K).



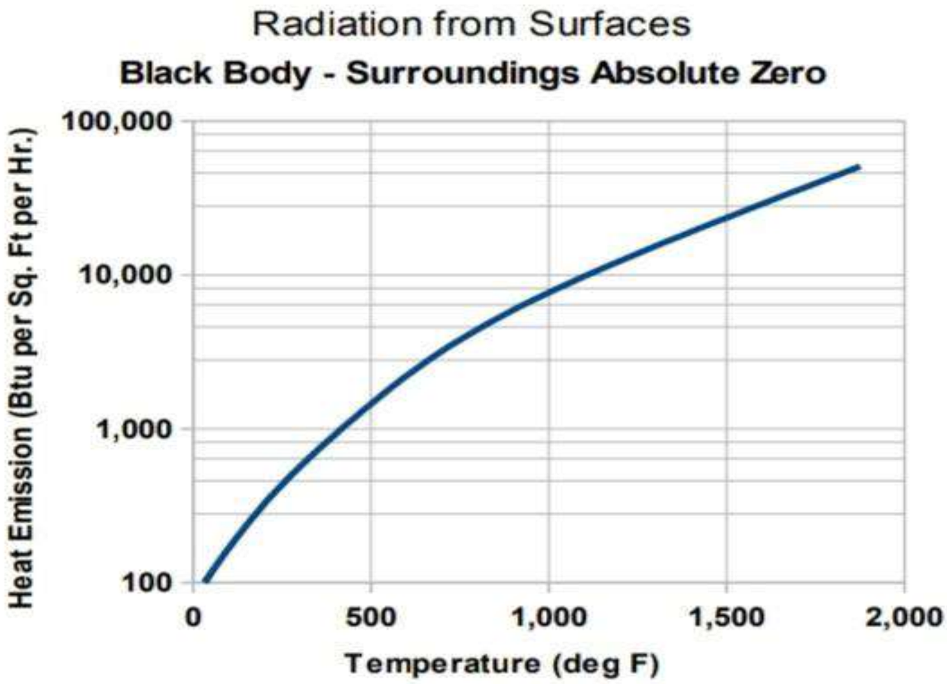


Fig. (3.9): The variation of heat emission with temperature.

3.10.2 Convective Heat Transfer Coefficient

The convective heat transfer coefficient (h_c) measures the resistance to heat transfer through a fluid in motion near a solid surface. It is influenced by fluid properties and flow conditions, such as:Pipe diameter d_p, length L_pFlow velocity $v_{f,i}$Dynamic viscosity, μ_fDensity ρ_f,Specific heat $c_{p,f}$,Thermal conductivity λ_f

For forced convection in cylindrical geometry:

$$h_c = \frac{q_s}{T_s - T_f} = \left(\frac{\lambda_f}{r_p}\right)\left[\frac{\partial(T_s - T)}{\partial\left(z/r_p\right)} \div \left(T_s - T_f\right)\right] \qquad (3-8)$$

Where:

q_s = Surface heat flux

T_s = Surface temperature

T_f = Fluid temperature

r_p = Radius of the pipe

Turbulent flow enhances h_c due to greater mixing than laminar flow, making it preferred in many thermal applications, see **Figure 3.10**.

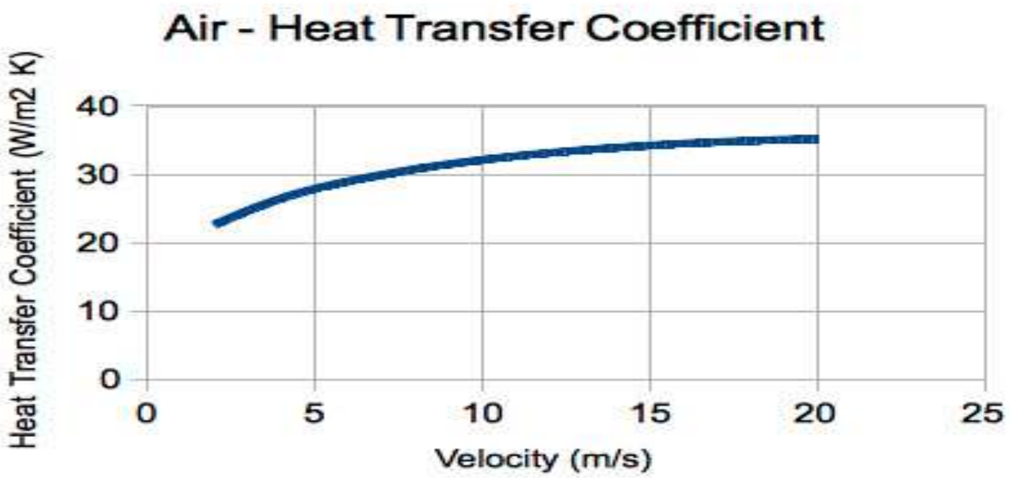


Fig. (3.10): The variation of heat transfer coefficient with velocity.

3.10.3 Heat Loss Coefficients

The **heat loss coefficient** quantifies how much thermal energy a storage system loses to the environment. It's vital in sensible thermal energy storage design to estimate losses and improve efficiency.

General expression:

$$Q_{loss} = h \cdot A_{surf} \cdot \left[T_{avg}(t) - T_{amb}\right] \cdot t_{tot} \qquad (3-9)$$

Where:

h = Heat loss coefficient (W/m²·K)

A_{surf} = Surface area for heat transfer

$T_{avg}(t)$ = Time-varying average temperature

T_{amb} = Ambient temperature

t_{tot} = Total time duration Minimizing h is crucial for efficient energy storage.

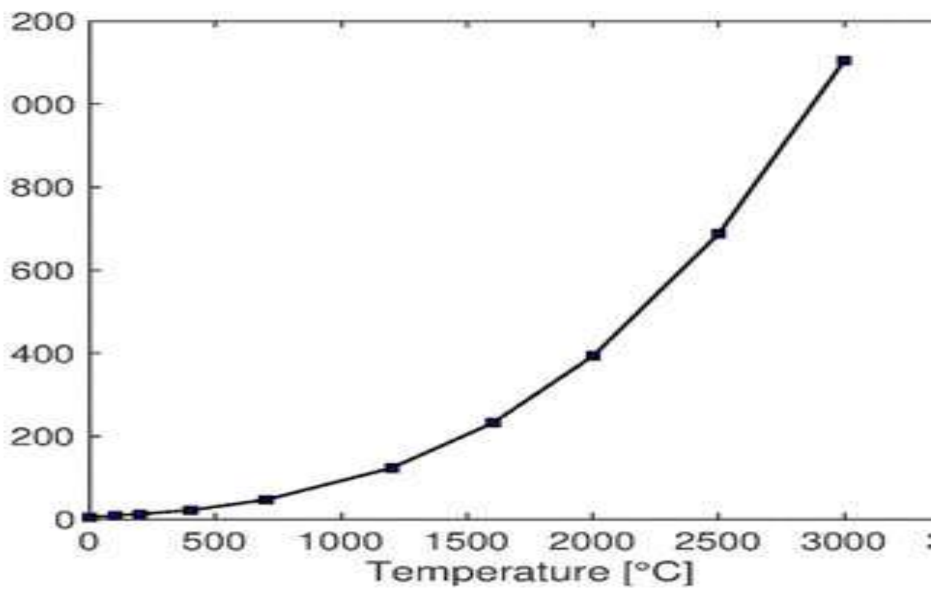


Fig. (3.11): Variation of heat loss coefficient h with temperature

3.10.4 Thermal and Overall Efficiency

Thermal Efficiency ($\eta_{thermal}$): Measures the effectiveness of converting heat into useful work.

$$\eta_{thermal} = \frac{Work\ Output}{Heat\ Input} \qquad (3-10)$$

- Expressed as a percentage (< 100%)
- Focuses only on thermal-to-mechanical energy conversion

Overall Efficiency (η): Considers all types of energy losses in the system, including thermal, mechanical, and electrical.

$$\eta = \frac{Useful\ Output}{Total\ Input\ Energy} \qquad (3-11)$$

Cell efficiency (ηc) represents the maximum power of the solar cell to the solar irradiance receiving by the solar cell, it can be expressed as following [29]:

$$\eta_c = \frac{P_{mix}}{G * A} \qquad (3-12)$$

Fill factor (FF) represents the ratio of maximum power divided by the open-circuit voltage and short circuit current as following [31]:

$$FF = \frac{P_{mix}}{V_{oc} * I_{sc}} \qquad (3-13)$$

CHAPTER FOUR

EXPERIMENTAL WORK

CHAPTER FOUR: EXPERIMENTAL WORK

4.1 GENERAL

The experimental work aims to evaluate the performance of photovoltaic (PV) panels under varying environmental conditions, with a focus on tilt angle and temperature. The study involves setting up PV modules at different tilt angles and exposing them to natural sunlight across various times of the day and weather conditions. Key electrical parameters such as voltage, current, and power output will be recorded using appropriate measuring instruments. Additionally, ambient and panel surface temperatures will be monitored to assess their influence on panel efficiency. The collected data will be analyzed to understand the relationship between tilt angle, temperature, and the efficiency of solar energy conversion. This work seeks to identify the optimal installation parameters for maximizing PV performance in real-world conditions.

4.2 SYSTEM COMPONENTS

The PV tilt angle system consists of two photovoltaic modules mounted on an aluminum frame. The first module is fixed at a constant tilt angle to serve as a reference. The second module is adjustable and can be tilted at different angles to study the effect of inclination on performance. Both panels are connected to measuring instruments for data collection. The entire structure is built from aluminum, providing stability and allowing for controlled testing of varying tilt angles, as shown in **Figure 4.1.**

Figure (4.1): Schematic Diagram of the PV Tilt Angle System.

4.2.1 Photovoltaic module

The core component of this system is the photovoltaic (PV) module, whose specifications are detailed in Table 4.1 and illustrated in **Figure 4.2.** The selected module is of the monocrystalline type, known for its high efficiency, extended lifespan, and superior performance in low-light environments.

Table 1.4: Specifications of the Photovoltaic Module (Values are based on Standard Test Conditions: AM1.5, 1000 W/m², 26 °C, ±6%)

Rated Power (−0, +6 W)	**50 W**
Open Circuit Voltage (Voc)	**21.6 V**
Short Circuit Current (Isc)	**2.92 A**
Voltage at Maximum Power	**18 V**
Rated Current (Imp)	**2.78 A**
Maximum System Voltage	**1000 V**
Module Efficiency	**21.01 %**

Fig. (4.2): Photovoltaic module.

4.2.2 Digital multimeter

One of the tools used in this work is the Digital Multimeter (Model: MT9205) in **Figure 4.3**. It is utilized for measuring various electrical parameters, such as DC and AC voltage, current, resistance, and continuity. This device is essential for assessing the performance of electrical systems, including solar power systems, as it helps measure key variables that affect the system’s efficiency when adjusting the tilt angle of the panels.

Figure (4.3): Digital Multimeter (Model: MT9205)

4.2.3 Solar power meter

The SM206 digital solar power meter **Figure 4.4** an instrument used to measure light intensity in solar systems. This device is highly accurate in measuring the light reaching solar panels. It provides precise readings in units of watts per square meter (W/m^2), helping to determine the efficiency of solar panels in collecting solar energy and converting it into electrical power.

Figure (4.4): Solar Power Meter (SM206).

4.2.4 Solar charge controller

The charge controller **Figure 4.5** used to regulate the flow of energy from solar panels to the battery, protecting it from overcharging or deep discharging. This model operates using Pulse Width Modulation technology and features an LCD screen for data display, dual USB ports, and automatic voltage recognition (12V/24V). It also provides multiple protection functions, including overcurrent and short circuit protection.

Figure (4.5): Solar Charge Controller

4.2.5 Thermocouple

This electronic device **Figure 4.6** is used to measure ambient temperature and humidity levels and displays the readings directly on the screen. It is known for its high accuracy and is equipped with an external temperature sensor for more precise environmental monitoring. Additionally, it features a clock and alarm function, making it a practical tool for tracking environmental conditions in solar panel systems.

Figure (4.6): Thermocouple

4.2.6 Battery

This 12V, 9Ah battery **Figure 4.7** is used in solar power systems for energy storage. It should be charged at a constant voltage, with 14.5–14.9V for cycle use and 13.0–13.6V for standby use. The initial charging current should not exceed 2.25A.

Figure (4.7): Battery (Model: NP9-12)

4.2.7 Angle meter application

As part of the practical study in this graduation project, the "Angle Meter" application **Figure 4.8** was utilized as a digital tool for accurately measuring angles using the smartphone's built-in sensors, such as the gyroscope and accelerometer. The app facilitated the process of verifying tilt and slope angles during experimental procedures, saving time and improving accuracy compared to traditional tools.

The application was easy to use, featuring a simple interface and the ability to zero the reference angle for relative measurements. It also allowed for recording and storing results efficiently. The "Angle Meter" proved to be an effective and supportive tool in mechanical and engineering measurements, contributing to the overall precision and quality of the project's practical outcomes.

Figure (4.8): Angle Meter Application

4.2.8 Infrared thermometer device

The infrared thermometer **Figure 4.9** was used in the project to quickly measure the temperature of solar panels without contact. The device is easy to use and provides accurate readings that help monitor how tilt angle affects panel temperature and efficiency. This method improved experiment accuracy compared to traditional tools and helped achieve reliable results.

Figure (4.9): Infrared Thermometer Device

4.3 WORKING PROCEDURE

The procedure for evaluating the effect of tilt angle on the performance of photovoltaic (PV) panels, using one fixed and one adjustable panel, includes the following steps:

1. Setup of PV Panels: Install the panels, one fixed and one adjustable, ensuring proper alignment to receive natural sunlight throughout the day.

2. Initial Measurements: Measure environmental parameters such as ambient temperature, panel surface temperature, and solar radiation at the start of the experiment.

3. Tilt Angle Adjustments: Adjust the tilt angle of the adjustable panel to the predefined set points, maintaining each angle for a specified time to collect data.

4. Electrical Parameter Measurements: Measure voltage, current, and power output from the PV panels.

5. Temperature Monitoring: Continuously monitor ambient temperature and panel surface temperature to assess their effect on panel efficiency.

6. Data Logging: Record all measurements for later analysis.

7. Data Analysis: Analyze the data to examine the relationship between tilt angle, temperature, and PV efficiency.

8. Recording and Analyzing Readings: Record and analyze the readings according to the equations in Chapter 3, then plot the results and discuss them in Chapter 5.

CHAPTER FIVE

RESULTS AND DISCUSSION

CHAPTER FIVE RESULTS AND DISCUSSION

5.1 INTRODUCTION

This chapter presents and analyzes the experimental results related to the performance of solar photovoltaic (PV) panels under various tilt and rotation angles. Measurements were taken for solar radiation intensity, panel surface temperature, voltage, and current, which were then used to determine the actual power output, fill factor (FF), and the panel efficiency (η). The objective is to evaluate the effect of different orientations on performance and determine the optimal tilt and rotation angles that yield maximum efficiency.

5.2 THE RESULTS

This section presents and analyzes the experimental results of testing the photovoltaic (PV) system under various tilt and rotation angles. The measurements included solar radiation intensity, panel surface temperature, voltage, current, and power output. These parameters were used to calculate the PV panel's fill factor and overall efficiency. Both fixed and dynamically adjusted (moved) panels were tested to evaluate the impact of orientation on performance. The aim was to identify the optimal tilt and rotation settings that yield the highest energy conversion efficiency under real outdoor conditions.

5.2.1 Efficiency vs Tilt Angle

The efficiency analysis of the tilt angle revealed a distinct nonlinear trend for the moving panel at zero rotating angle. **Figure 5.1** illustrates the relationship between the tilt angle and the energy conversion efficiency of a solar panel under dynamic positioning conditions. The analysis reveals that the efficiency tends to decrease as the tilt angle increases, indicating optimal energy capture at lower tilt angles. The study results indicate that the secondary optimization of the tilt angle by PVsyst, in conjunction with the geographic factors of a region in **Maysan, Iraq**, reveals that the optimal installation tilt angle for maximum power generation benefit is around 10°-15°, so the best efficiency is at 13° (adjacent to 15°).

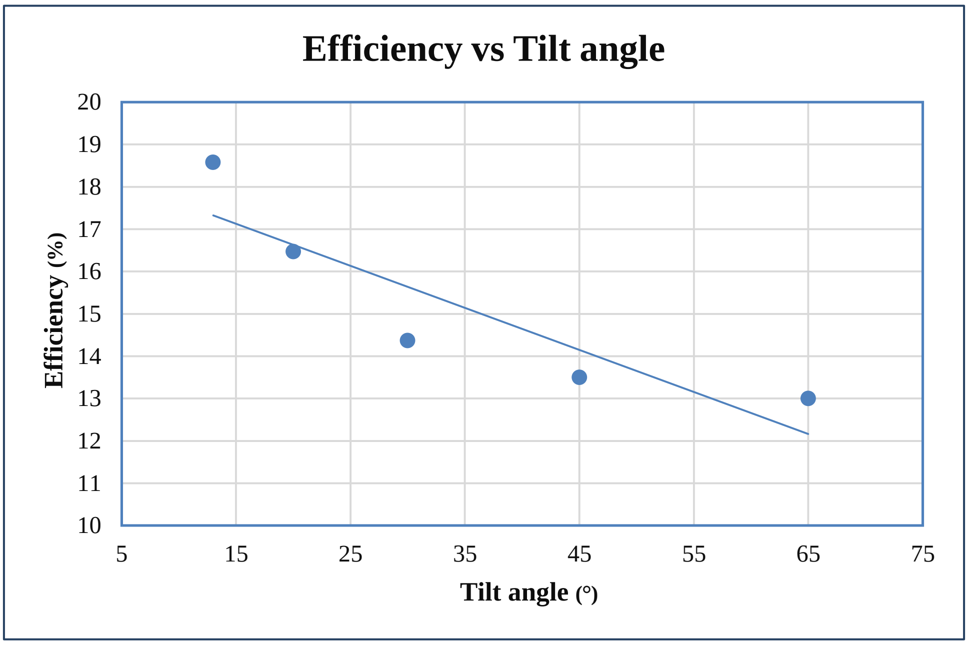


Fig. (5.1): Efficiency vs. tilt Angle for a moving solar panel (Rotation Angle = 0°).

5.2.2 Power vs Tilt Angle

The analysis of power output as a function of tilt angle as shown in **Figure 5.2** reveals a clear trend indicating that lower tilt angles result in higher power generation. According to the data, the power output increases steadily from 33.4 W at a tilt angle of 65° to a maximum of 34.713 W at 13°. Intermediate values follow this trend, with 33.969 W at 45°, 34.17 W at 30°, and 34.542 W at 20°. This improvement in power output with decreasing tilt angle suggests that the incident solar irradiance is maximized when the panel surface is more directly aligned with the sun's rays, particularly relevant in Maysan, Iraq, where the optimal tilt angle was found to be between 13° and 15°. These results emphasize the importance of geometrical optimization in solar panel installations to achieve maximum energy yield.

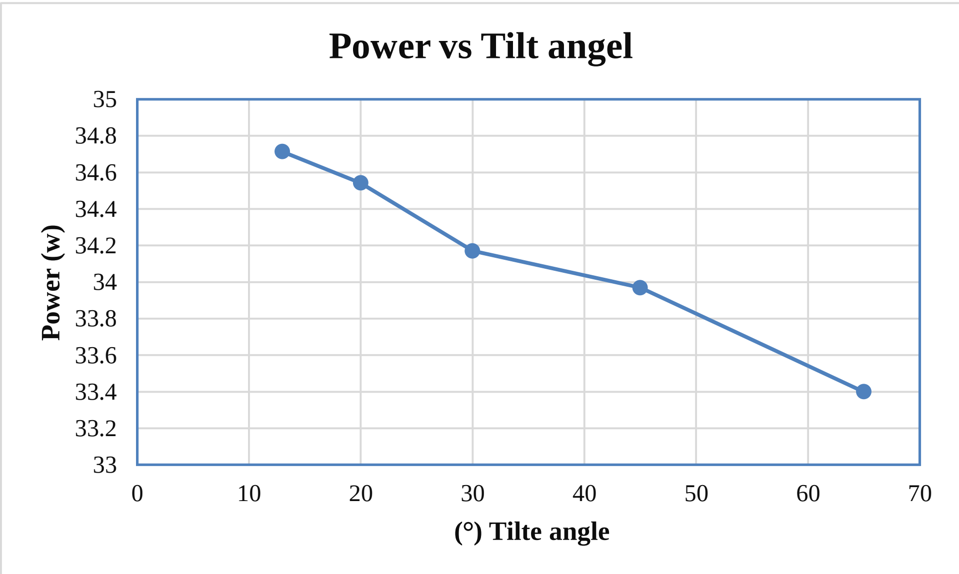


Fig. (5.2): Power vs. tilt Angle for a moving solar panel (Rotation Angle = 0°).

5.2.3 Efficiency vs Rotation Angle

The effect of rotation angle on solar panel efficiency shows a symmetric and nonlinear behavior as shown in **Figure 5.3**, with the highest efficiency occurring at the zero-degree position. According to the data, the efficiency peaks at 13.5% when the rotation angle is 0°, and decreases equally to 12% at both +45° and -45°. This indicates that when the panel is aligned directly facing the sun (0°), solar irradiance is maximized, resulting in better energy conversion. Conversely, rotating the panel away from the optimal orientation reduces the effective sunlight hitting the surface, thereby lowering efficiency. These results highlight the importance of precise rotational tracking or fixed positioning strategies that maintain direct solar alignment, especially in regions like Maysan, Iraq, where maximizing solar gain is critical.

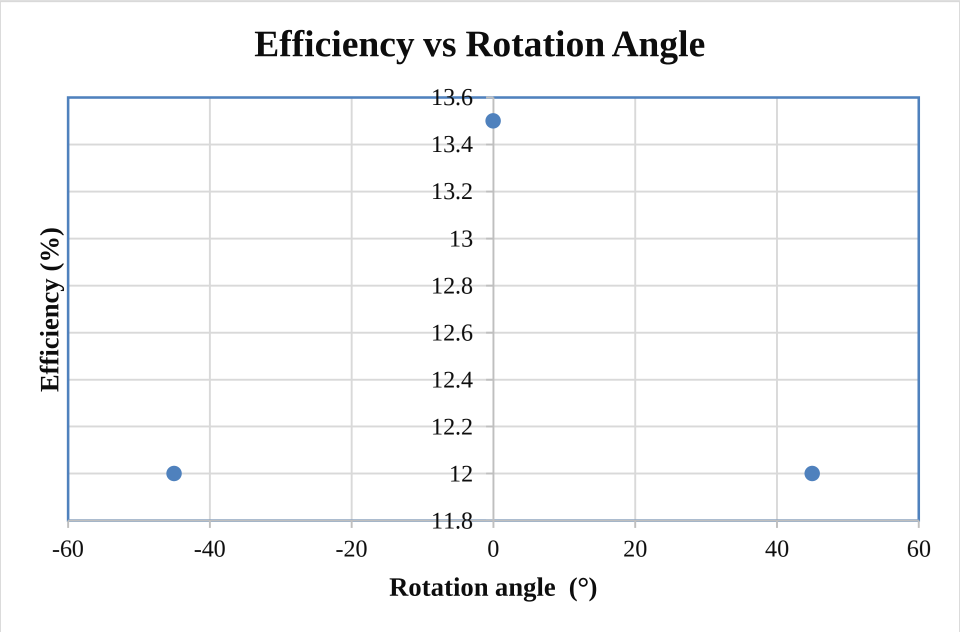


Fig. (5.3): Efficiency vs. Rotation Angle for a moving solar panel

5.2.4 Full Factor vs Tilt Angle

The relationship between **tilt angle** and **fill factor (FF)** as shown in **Figure 5.4** demonstrates a clear trend in which optimal panel orientation significantly improves performance. The data shows that the fill factor increases steadily as the tilt angle decreases from **65° to 13°**, reaching a maximum value of **0.69426** at **13°**. Specifically, the fill factor rises from **0.668** at 65°, to **0.67938** at 45°, **0.6834** at 30°, **0.69084** at 20°, and peaks at 13°. This trend indicates that **lower tilt angles allow for more effective solar irradiance capture**, which enhances the current and voltage at the maximum power point, thereby improving the fill factor. These results confirm that the **optimal tilt angle for maximum efficiency in Maysan, Iraq is around 13°**, supporting the importance of geometrical optimization in photovoltaic system design.

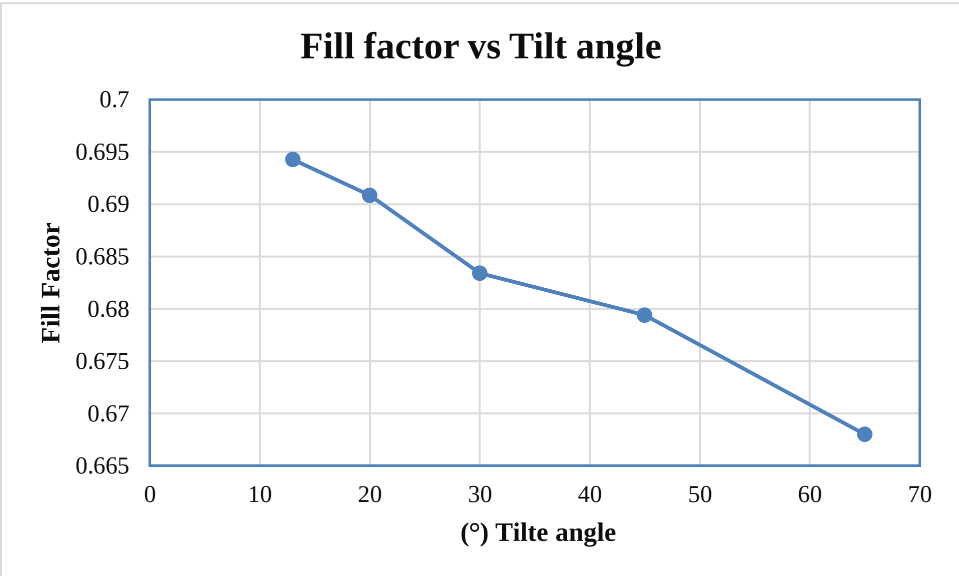


Fig. (5.4): Fill Factor vs. tilt Angle for a moving solar panel (Rotation Angle = 0°).

5.2.5 Fill Factor vs. Temperature

The relationship between **fill factor (FF)** and **temperature** as shown in **Figure 5.5** demonstrates a distinct inverse trend, where the fill factor increases as the temperature decreases. Based on the recorded data, the fill factor improves from **0.668 at 58.2°C** to **0.69426 at 53.3°C**. Intermediate values further support this trend, with FF measured at **0.67938 at 57.8°C**, **0.6834 at 55.8°C**, and **0.69084 at 54.8°C**. This gradual increase in fill factor with decreasing temperature is attributed to the **reduction in thermal losses**, particularly the stabilization of voltage levels and improved electrical characteristics of the photovoltaic cells. The results confirm that **lower operating temperatures enhance the quality of power output**, reinforcing the importance of thermal management in maintaining optimal PV system performance, especially under hot climate conditions such as those in **Maysan, Iraq**.

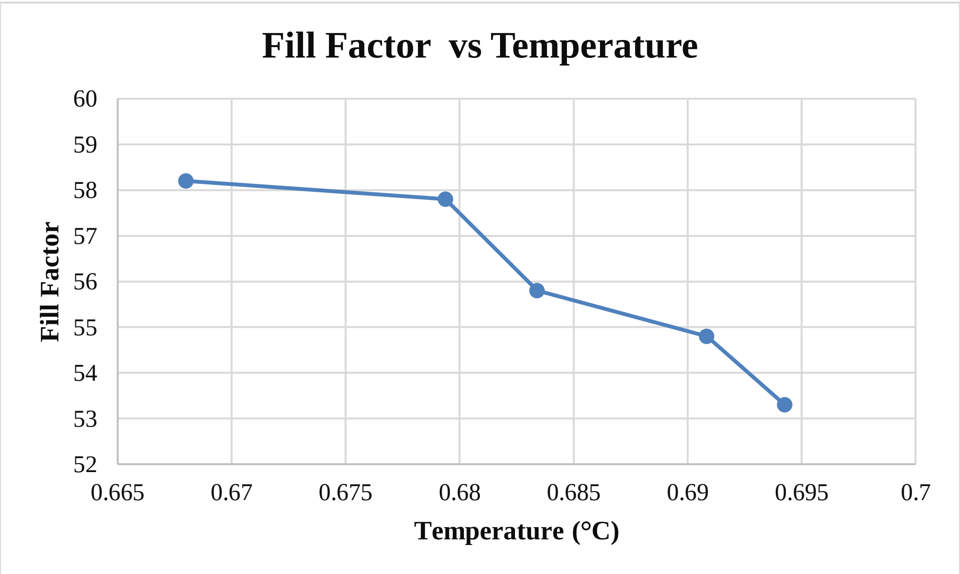


Fig. (5.5): Fill Factor vs. Temperature for a moving solar panel (Rotation Angle = 0°).

5.2.6 Power vs Temperature

The analysis of power output in relation to temperature, as shown in **Figure 5.6**, reveals a slight inverse correlation, where power generation increases as the temperature decreases. According to the collected data, at a high temperature of 58.2°C, the power output is 33.4 W, while at a lower temperature of 53.3°C, the output increases to 34.713 W. Intermediate values show a gradual rise in power with decreasing temperature: 33.969 W at 57.8°C, 34.17 W at 55.8°C, and 34.542 W at 54.8°C. Although the change appears modest, the trend reflects the thermally sensitive nature of photovoltaic systems, where high temperatures reduce voltage and slightly limit power generation. These results highlight the importance of thermal regulation in maintaining stable and efficient energy output, particularly in high-temperature environments such as Maysan, Iraq.

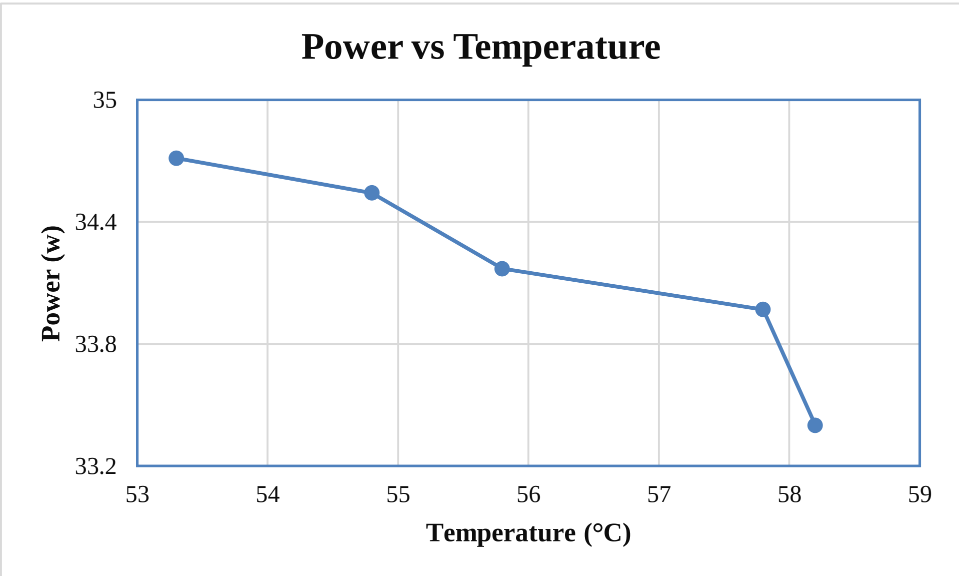


Fig. (5.6): Power vs. Temperature for a moving solar panel (Rotation Angle = 0°).

5.2.7 Efficiency vs Temperature

The relationship between temperature and solar panel efficiency as shown in **Figure 5.7** exhibits a clear inverse trend, as confirmed by the recorded data. As the temperature decreases, the efficiency of the solar panel increases significantly. At a high temperature of 58.2°C, the efficiency is 13%, while at a lower temperature of 53.3°C, the efficiency rises to 18.576%. This consistent improvement in efficiency with decreasing temperature is due to the reduction in thermal losses, particularly the decline in voltage degradation that typically occurs at elevated temperatures. Intermediate values also support this trend, with efficiency reaching 13.5% at 57.8°C, 14.364% at 55.8°C, and 16.467% at 54.8°C. These findings clearly indicate that high ambient temperatures negatively affect photovoltaic performance, underscoring the importance of effective heat dissipation strategies, especially in hot regions such as Maysan, Iraq.

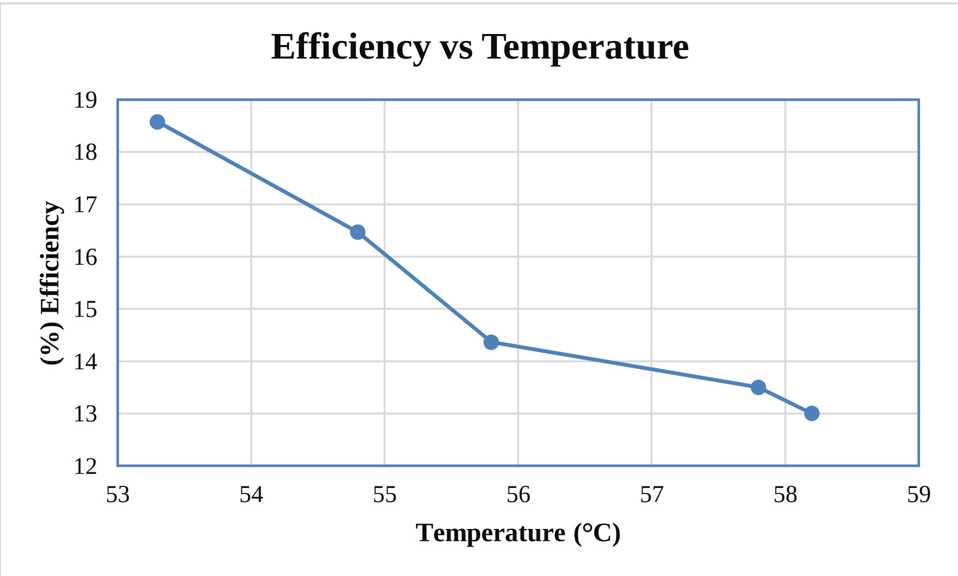


Fig. (5.7): Efficiency vs. Temperature for a moving solar panel (Rotation Angle = 0°).

5.2.8 Effect of Temperature on Current Output

The relationship between temperature and current output for the moving panel at zero rotation degree was analyzed to assess the thermal response of the solar panel under operating conditions. **Figure 5.8** illustrates a clear positive linear correlation between temperature (°C) and current (A). As the fitted trend line shows, the current increases steadily from approximately 1.60 A at 53°C to around 1.75 A at 58°C. This behavior is consistent with the characteristic response of photovoltaic cells, where elevated temperatures increase carrier mobility, thereby slightly enhancing the current output. However, while current rises with temperature, it is important to note that overall efficiency may still decline, as temperature typically causes a reduction in voltage, leading to lower power output. These findings highlight the importance of effective thermal management in solar panel installations, particularly in hot climates such as Maysan, Iraq, to balance current gain against potential efficiency losses.

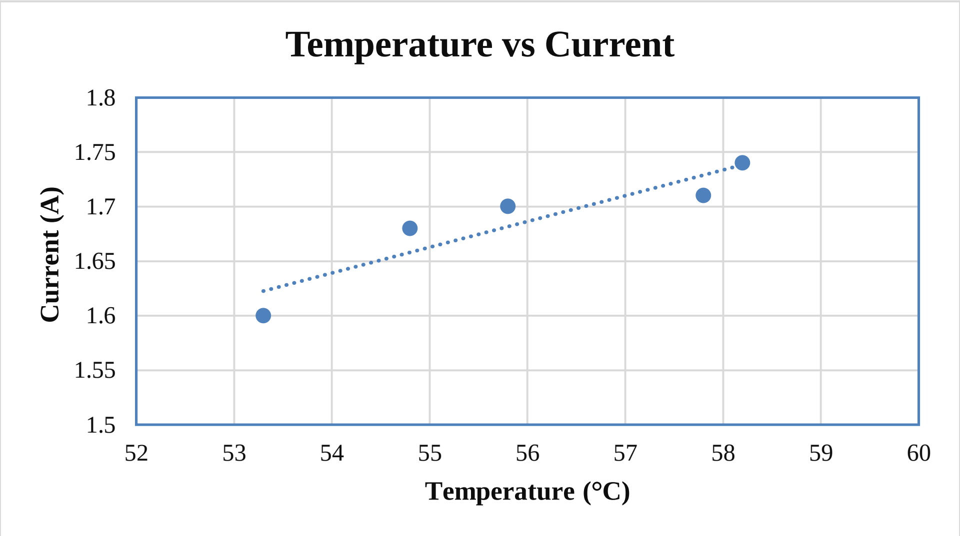


Fig. (5.8): Current vs. Temperature for a moving solar panel (Rotation Angle = 0°).

5.2.9 Effect of Temperature on Voltage Output

The analysis of temperature effects on voltage output as shown in **Figure 5.9** reveals a clear inverse relationship, as shown in Figure X. As temperature increases from 53°C to 58°C, the voltage output of the solar panel decreases from approximately 20.3 V to 20.0 V. This negative linear trend is consistent with the known behavior of photovoltaic cells, where rising temperatures lead to a reduction in the open-circuit voltage due to increased intrinsic carrier concentration and reduced bandgap. Although the current may increase slightly with temperature, the decline in voltage typically dominates, resulting in reduced overall power output and efficiency. These results underscore the importance of thermal regulation in photovoltaic systems, especially in hot climates such as Maysan, Iraq, where elevated temperatures can significantly impact system performance.

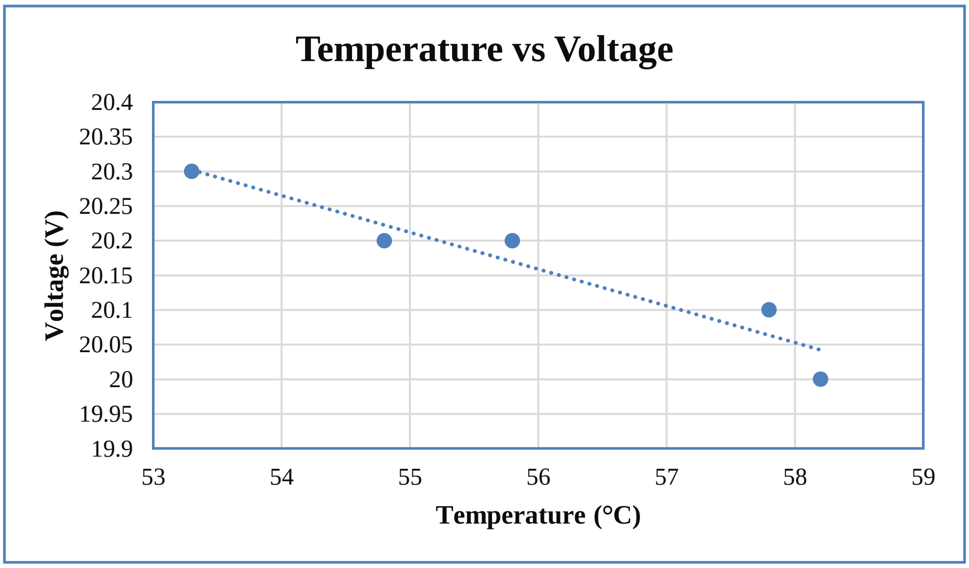


Fig. (5.9): Voltage vs. Temperature for a moving solar panel (Rotation Angle = 0°).

5.3 SUMMARY

The performance of a moving solar panel in Maysan, Iraq, was evaluated under varying tilt angles, rotation angles, and temperatures. The results show that **efficiency, power output, and fill factor are maximized at lower tilt angles**, particularly around **13°**, due to improved solar irradiance capture. **Rotation angle analysis** revealed that the optimal orientation is at **0°**, with efficiency decreasing symmetrically at ±45°.

Thermal analysis indicated that **as temperature increases**, both **efficiency and voltage output decline**, while **current output slightly increases**. The **fill factor and power output** also demonstrate a **negative correlation with temperature**, highlighting the importance of **thermal regulation**. Overall, the study emphasizes the need for **geometric and thermal optimization** to enhance photovoltaic performance in hot climates like Maysan.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

CHAPTER SIX CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

This chapter presents the key conclusions derived from the experimental study and provides practical recommendations based on the findings.

6.2 CONCLUSION

The This study investigated the performance of a moving solar panel system in Maysan, Iraq, under varying **tilt angles, rotation angles, and temperatures**. The results demonstrated that **solar efficiency, power output, and fill factor** are significantly influenced by these parameters. The **optimal tilt angle** for maximum performance was found to be around **13°**, while the best **rotation angle** was **0°**, aligning the panel directly with the sun. Additionally, **temperature had a negative impact** on both efficiency and voltage, although current output increased slightly with temperature rise. These results confirm that both **geometrical positioning and thermal management** are crucial for enhancing photovoltaic system performance, particularly in hot climates like Maysan.

6.2 RECOMMENDATIONS

Based on the experimental results, the following recommendations are proposed:

- **Install solar panels at a tilt angle of approximately 13°–15°** to optimize irradiance capture and energy output in regions with similar latitudes.
- **Maintain rotation alignment at 0°** or implement sun-tracking systems that keep the panel perpendicular to solar rays throughout the day.
- **Implement cooling or ventilation strategies** to reduce panel temperature and mitigate thermal losses, especially during peak summer months.
- **Use materials and technologies** with low temperature coefficients to reduce voltage and efficiency degradation under high thermal conditions.
- **Conduct seasonal and real-time monitoring** to dynamically adjust tilt or rotation if feasible, improving adaptability to changing environmental conditions.

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الخلاصة:

يتناول هذا المشروع دراسة تجريبية لتأثير زاوية الميل وزاوية الانحراف ±٤٥° على كفاءة الأداء لنظام الألواح الشمسية في مدينة ميسان، العراق. تم تنفيذ تجارب ميدانية لقياس أداء النظام تحت ظروف مختلفة من زاوية الميل والانحراف، بالإضافة إلى درجات الحرارة. أظهرت النتائج أن زاوية الميل والانحراف تؤثران بشكل كبير على كل من الكفاءة، القدرة الكهربائية الخارجة، وعامل الامتلاء. وقد تبين أن زاوية الميل المثلى لتحقيق أعلى كفاءة كانت حوالي ١٣°، بينما كانت زاوية الانحراف المثلى ٠°، حيث تكون الألواح موجهة مباشرة نحو أشعة الشمس.

كما أوضحت الدراسة أن ارتفاع درجات الحرارة يؤثر سلبًا على الكفاءة والفولتية، رغم الزيادة الطفيفة في التيار الكهربائي. تؤكد هذه النتائج أهمية الضبط الهندسي الصحيح للوضعية الجغرافية للألواح الشمسية، إلى جانب إدارة الحرارة بفعالية، من أجل تحسين أداء الأنظمة الكهروضوئية، خصوصًا في المناخات الحارة مثل منطقة ميسان.

استنادًا إلى هذه النتائج، توصي الدراسة بتركيب الألواح الشمسية بزاوية ميل تتراوح بين ١٣° و١٥°، والحفاظ على زاوية انحراف صفرية أو استخدام أنظمة تتبع شمسي. كما توصي باستخدام تقنيات تبريد أو تهوية لتقليل درجة حرارة الألواح، واعتماد مواد ذات معاملات حرارية منخفضة للحد من التدهور في الأداء الناتج عن الحرارة، إلى جانب تنفيذ أنظمة مراقبة دورية لضبط الوضعيات حسب تغير الظروف البيئية.