STUDY POTENTIAL OF RENEWABLE ENERGY RESOURCES IN IRAQ KURDISTAN WITH A FOCUS ON SOLAR ENERGY

2023
MASTER THESIS
MECHANICAL ENGINEERING

Tareq Aziz Dawood ALMAZROAY

Thesis Advisors
Assist. Prof. Dr. Abdulrazzak Ahmed Saleh AKROOT
Prof. Dr. Ramzi Raphael Ibraheem BARWARI

STUDY POTENTIAL OF RENEWABLE ENERGY RESOURCES IN IRAQ KURDISTAN WITH A FOCUS ON SOLAR ENERGY

Tareq Aziz Dawood ALMAZROAY

Thesis Advisors
Assist. Prof. Dr. Abdulrazzak Ahmed Saleh AKROOT
Prof. Dr. Ramzi Raphael Ibraheem BARWARI

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

KARABUK
June 2023

I certify that in my opinion the presented thesis that has been submitted by Tareq Aziz Dawood ALMAZROAY titled "STUDY POTENTIAL OF RENEWABLE ENERGY RESOURCES IN IRAQ KURDISTAN WITH A FOCUS ON SOLAR ENERGY" is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

Assist. Prof. Dr. Abdulrazzak Ahmed Saleh AKROOT ....
Thesis Advisor, Department of Mechanical Engineering

Prof. Dr. Ramzi Raphael Ibraheem BARWARI ....
Thesis Co-Advisor, Department of Mechanical Engineering Salahaddin University-Erbil

This thesis is accepted by examining committee with the unanimous vote in the Dept. of Mechanical Engineering as Master of Science thesis. June 15, 2023.

<u>Examining Committee Members (Institutions)</u>		<u>Signature</u>
Chairman	: Assoc. Prof. Dr. Daver ALİ (KBU)	....
Member	: Assist. Prof. Dr. Abdulrazzak Ahmed Saleh AKROOT (KBU)	....
Member	: Prof. Dr. Ramzi Raphael Ibraheem BARWARI (SUE)	....
Member	: Assoc. Prof. Dr. Rizgar Bakr WELİ (SUE)	....
Member	: Assist. Prof. Dr. Khaled M.N. CHAHROUR (KBU)	....

The degree of Master of Science by the thesis that has been submitted was approved by the Administrative Board of Institute of Graduate Programs, Karabuk University.

Prof. Dr. Müslüm KUZU ....

Director of the Institute of Graduate Program

"I declare that all the information that has been presented in this thesis was gathered and presented in accordance with ethical principles and academic regulations and I have according to requirements of those regulations and principles that were cited all those which don’t originate in this work too."

Tareq Aziz Dawood ALMAZROAY

ÖZET

Yüksek Lisans Tezi

IRAK KÜRDİSTAN BÖLGESİNDE GÜNEŞ ENERJİSİ KAYNAKLARININ KULLANIM POTANSİYELİNİN İNCELENMESİ

Tarek Aziz Dawood ALMAZROAY

Karabük Üniversitesi
Lisansüstü Eğitim Enstitüsü
Makine Mühendisliği Anabilim Dalı

Tez Danışmanları:
Dr. Öğr. Üyesi Abdulrazzak Ahmed Saleh AKROOT
Prof. Dr. Ramzi Raphael Ibraheem BARWARI
June 2023, 103 sayfa

Bu araştırmada fosil yakıtlara alternatif olabilmesi, çevreyi kirleticilerden koruyabilmesi ve elektrik fiyatlarının yüksek olması sonucunda elektrik enerjisi üretiminde kullanılabilecek yenilenebilir enerji türleri incelenmiştir. fosil malzemeler ve düşüşleri. Bu araştırmanın odak noktası, güneş enerjisini fosil yakıtlara alternatif olarak ele almaktır. Güneş panellerinin üzerine düşen güneş ışınımı miktarının bilinmesi, bu panellerin verimlerinin bilinmesi ve bunları etkileyen faktörlerin incelenmesi için bir çalışma yapılmıştır. Bir yüzeyi suya batırmanın ve yağmurlu bir günde performans verimliliğini incelemenin yanı sıra, en iyi verimliliğin (hava açık ve paneller temizken) %11,25 olduğu bulundu. Panellerin bir miktar toz veya yağmura maruz kaldıklarında verimlerinin düştüğü gözlemlenmiştir. Bu nedenle güneş panellerinin sağlıklı çalışması için önemli faktörlerden biri de bu panellerin temizliğini sağlamaktır. Güneş radyasyonu üzerine yapılan bu çalışma, Irak

Kürdistanı ve Erbil bölgesinin güneş enerjisi santralleri kurmaya yetecek kadar güneş radyasyonuna maruz kaldığı sonucuna varmıştır. Son olarak, bu çalışma genel olarak yenilenebilir enerji kaynaklarının, özellikle de güneş enerjisinin kullanımını desteklemek için Kürdistan hükümetinin - Irak'ta - benimseyebileceği girişimler önermektedir.

MATLAB betiği, güneş pillerinin performansını etkileyen çeşitli değişkenleri analiz etmek için Simulink modelini kullanır. İlk kod parçacığı burada bulunur. Panellerin çıkışını elde etmek için komut dosyası toz katsayısını, voltajı, şebeke akımını ve şebeke gücünü kullanır. Daha sonra senaryo, çeşitli radyasyon ve sıcaklık değerleri için sonuçlar çizerek bu değişkenlerin güneş panelleri üzerindeki etkisini göstermektedir. Zaman içindeki güneş radyasyonu değerlerinin 3 boyutlu bir şerit grafiği, bir Excel dosyasından veri içeren ikinci bir kod parçacığı tarafından oluşturulur. Grafikte, X ekseni günü, Y ekseni zamanı ve Z ekseni güneş ışınımının değerlerini gösterir. Fotoğrafta X ekseninin onay işaretleri de var, tarih" MM / DG" biçiminde gösteriliyor.

Son olarak, bu araştırma Irak'taki Kürdistan hükümetinin genel olarak yenilenebilir enerji kaynaklarının, özellikle de güneş enerjisinin kullanımını desteklemek için neler yapabileceğine işaret ediyor. Çalışma, güneş panelleri üzerinde meydana gelen güneş radyasyonu miktarının, panellerin performansını ve verimliliğini etkileyen değişkenlerini incelemiştir. Araştırma ayrıca toz ve yağmurun güneş panellerinin verimliliğini nasıl etkilediğini inceledi ve panellerin temiz kalması gerektiğini keşfetti.Temmuz. Çalışmanın sonuçları, Irak'ın Erbil bölgesi ve Kürdistan Bölgesi'nin güneş enerjisi santralleri inşa etmek için yeterli güneş radyasyonu aldığını gösteriyor. Son olarak araştırma, Kürdistan hükümetinin yenilenebilir enerji kaynaklarının - özellikle güneş enerjisinin - kullanımını teşvik edebileceği eylem planları önerdi.

Anahtar Sözcükler : Güneş Enerjisi, Yenilenebilir Enerji, PV, Enerji Kaynağı, Güneş Kollektörleri, Güneş Pilleri, Güneş Işınımı, Verimlilik

Bilim Kodu : 91408

ABSTRACT

Master. Thesis

STUDY THE POTENTIAL OF RENEWABLE ENERGY RESOURCES IN IRAQ KURDISTAN WITH A FOCUS ON SOLAR ENERGY

Tareq Aziz Dawood ALMAZROAY

Karabük University
Institute of Graduate Programs
Department of Mechanical Engineering

Thesis Advisor:
Assist. Prof. Dr. Abdulrazzak Ahmed Saleh AKROOT
Prof. Dr. Ramzi Raphael Ibraheem BARWARI
June 2023, 103 pages

In this research, the types of renewable energies that can be used in the production of electrical energy were studied to be an alternative to fossil fuels, to preserve the environment from pollutants, as well as a result of the high prices of fossil materials and their decline. The focus of this research is on solar energy to take it as an alternative to fossil fuels. A study was made to know the amount of solar radiation falling on the solar panels, the efficiency of these panels, and the study of the factors affecting them. As well as submerging a surface with water and studying the performance efficiency on a rainy day, it was found that the best efficiency (when the weather is clear and the panels are clean) was 11.25%. It has been observed that the panels' efficiency decreases when they are exposed to a quantity of dust or rain. Therefore, one of the important factors in keeping the solar panels working well is to maintain the cleanliness of these panels. This study of solar radiation concluded that

Iraqi Kurdistan and the Erbil region are exposed to sufficient solar radiation that qualifies them to establish solar power plants.

The first code snippet is a MATLAB script that implements a Simulink model to analyze different factors affecting the performance of solar cells. The script takes in irradiation and temperature values and uses a dust coefficient to obtain the outputs of the panels, including grid current, grid voltage, and grid power. The script then plots the results for different irradiance and temperature values, showing these factors' effect on the solar panels' performance. The second code snippet imports data from an Excel file and creates a 3D ribbon plot of solar irradiance values over time. The plot shows the solar irradiance values for different days and times, with the x-axis representing the day, the y-axis representing the time, and the z-axis representing the solar irradiance values. The plot also includes tick labels for the x-axis, showing the date in the format "mmmm/dd".

Finally, this study proposes initiatives that the government of Kurdistan can adopt-Iraqi- to support the use of renewable energy resources in general, particularly solar energy. The study included an analysis of the amount of solar radiation falling on solar panels, the efficiency of these panels, and the factors that affect their performance. The research also examined the impact of dust and rain on the efficiency of solar panels and found that maintaining the cleanliness of the panels is crucial for optimal performance. The study concluded that Iraqi Kurdistan and the Erbil region receive sufficient solar radiation to establish solar power plants. Finally, the research proposed initiatives that the government of Kurdistan can adopt to support the use of renewable energy resources, particularly solar energy.

Key Word **:** Solar Energy, Renewable Energy, PV, Energy Source, Solar Collectors, Solar Cells, Solar Irradiation, Efficiency

Science Code: 91408

ACKNOWLEDGMENT

All thanks to God Almighty for blessing, guiding me, and providing me with health while preparing my thesis. I would like to express my gratitude to my supervisor, Assistant Professor Dr. Abdulrazzak AKROOT, for his academic supervision, continuous support, invaluable advice, and constant encouragement in achieving my goals.

As well as to my secondary supervisor Prof. Eng. Dr. Ramzi R. Ibraheem BARWARI, special thanks for their efforts and interesting suggestions in completing the search.

I would also like to thank my professors at Karabuk University for their dedication and contributions to my academic success. In addition, I would like to convey my heartfelt appreciation to my family, especially my father, mother, brothers, and my beloved wife, for their encouragement and material and moral support for me throughout my studies. Finally, I thank all my friends who supported me in completing this academic literary work.

CONTENTS

<u>Page</u>

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

SYMBOLS AND ABBREVITIONS INDEX

SYMBOLS

δ : Solar declination angle

η : The Efficiency

φ : latitude of the location

ω : Hour angle

d : Number of days

θ : Azimuth angle

Ipv : Current of photovoltaic cell

Isc : Short-circuit current

Ac : Area of a solar cell unit

GB,β : Direct solar radiation

β : Angle of PV panel with ground

$\omega_{ss,sr}$: Sunrise and sunset hour angles

i : Terminal current (A)

i_d : Diode current

i_{sh} : Shunt current

v_t : Thermal voltage

n : Ideality factor

V_{oc} : Open-circuit voltage

I_{mp} : Maximum power current

GD,β : Diffused solar radiation

G_R : Reflected solar radiation

R_{sh} : Shunt resistor

R_s : Series resistance

G : Irradiance

T : Temperature

P_{pv} : Power of photovoltaic cell

V_{pv} : Voltage of photovoltaic cell

Iph : pv cell photo current

Io : saturation current of the diode

q : Electron charge

ρ : Ground aAledo

L : Longitude

K : Boltzmann constant

R_R : Factor of reflected solar energy on a tilted surface.

R_B : Ratio between global solar energy on a horizontal surface and global solar energy on a tilted surface

R_D : Ratio between diffuse solar energy on a horizontal surface and diffuse solar energy on a tilted surface

ABBREVITIONS

LST : Local solar time

LT : Local time

LSTM : Local standard time meridian

EOT : Equation of time

TC : Time correction factor

AST : Apparent solar time

LMT : Local meridian time

LOG : Longitude

MPP : Maximum power point

PART 1

INTRODUCTION

Renewable energy is a natural resource that can replace itself quickly and reliably. It has many abundant and sustainable sources. It is also environmentally friendly and has made the planet's inhabitants a great choice. It is the opposite of the energy that got from using the fuel [1]. It is distinguished from others because its sources cannot be implemented, is renewed permanently and are not affected by the amount of use, while the energy generated from fuels [2] such as oil, coal and others will have a specific life and are implemented, while renewable energy is its sources standing [3]. The most widespread definition states that renewable energy consists of energy that is replaced in a short time by a distinct cycle; for example, energy comes via the sun or wind, and most types of energy do not run out, unlike geothermal energy and flowing energy that ultimately consists of the sun. Some structures exclude sun-dependent energy, such as rain and wind-based energy, seen as short-term solar energy. Nevertheless, the energy accumulates in biomass over months, such as in straw or over many years, as in wood.

However, this cannot be obtained from the energy that is environmentally friendly through plants, creatures and people, which leads to the depletion of resources over time, although non-renewable energy sources do not run out, assuming this is forever. However, its continuous use at specific rates will be exhausted in the present or the future. Renewable energy sources can be utilized directly or alternative forms of energy that are more suitable can be created.

There are many direct energies uses, such as furnaces that operate on solar energy and thermal heating from the ground, water and windmills. There are also indirect uses, such as generating electric power through wind engines or photovoltaic cells.

.

1.2. KINDS OF RENEWABLE ENERGY

There are different types of renewable energy. Most of them are based on sunlight in some manner or another [4]. Hydroelectric energy and wind are direct results of heating wind energy. Hydroelectric power is produced by generating electricity from the energy of falling water. This is typically done by building a dam on a river to create a reservoir of water. When the water is released from the dam, it flows through turbines that spin generators to produce electricity. Hydroelectric power is a renewable energy source that does not produce greenhouse gas emissions, making it a clean and sustainable option for generating electricity, other renewable forms of energy besides sunlight, such as geothermal energy, are produced in the crust near the original location of the earth's accumulation. The main types of renewable energy are as follows:

1.2.1. Solar Energy

Solar energy is the heat and light that the sun provides that man has used for his advantage and service from ancient times, using technological means that have developed continuously over time. Humans have benefited from solar energy directly by using it for many purposes, such as heating in a cold climate and cooking. The sun continues to support human societies, and it was a significant and effective factor in the development of life [5,6].

In ancient times, humans have been harnessing the power of the sun for various purposes, such as drying crops and heating water. However, it was not until the early 20th century that American Engineer F. Schumann developed the first solar-powered hydraulic pump, marking the first significant use of solar energy. As the availability of oil and natural gas increased and became more affordable, solar energy was largely overlooked for energy production from 1915 to 1950. It was not until 1949 when an American organization sparked an interest in the Future Energy section of Washington, D.C., where future potential and economic issues were discussed. However, it was not until the 1973 oil embargo that widespread discussion of solar energy began to take place. As a systems engineer, it is important to recognize the historical context of solar energy development and continue to explore and optimize its potential for sustainable energy production [7].

Figure 1.1. A solar cell system in generating electric power [8].

1.2.2. Wind Energy

Wind energy is one of the renewable and clean energies. It is extracted from wind using modern turbines and energy conversion systems in well-established industries. This is with capacities ranging from 10 watts to several megawatts and diameters from about one meter to more than a hundred meters. Previously, traditional mechanical machines were developed only for pumping water. Still, the prevailing trade at present is to generate electric power, such as "wind turbine generators", as it has become accepted as "Main generation" utility networks in many countries with wind energy potential, Europe, the USA and some parts of India and China. Small wind turbine generators are common for energy production. Figure 1.2 shows the rapid growth in the world's capacity to generate electric power from wind turbines.

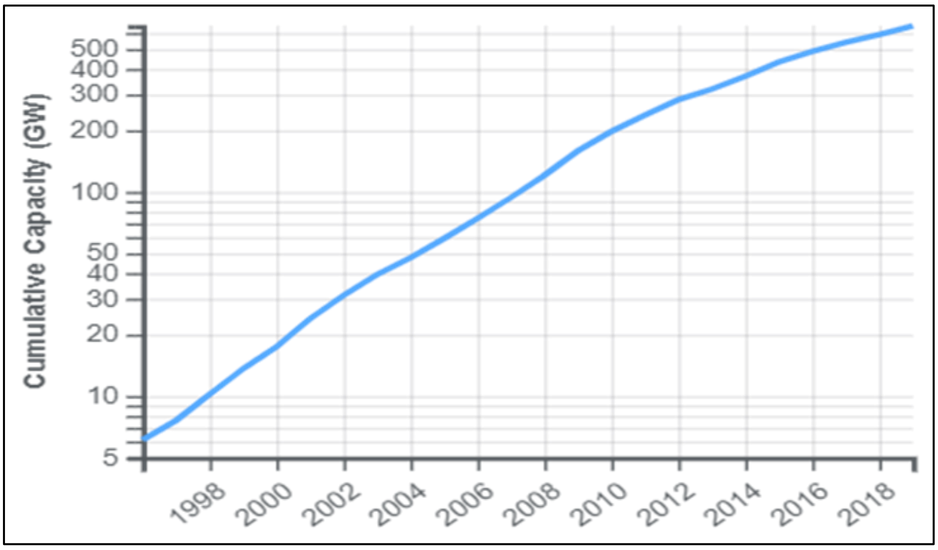


Figure 1.2. The growth in the capacity of world wind turbines / GWatt [9].

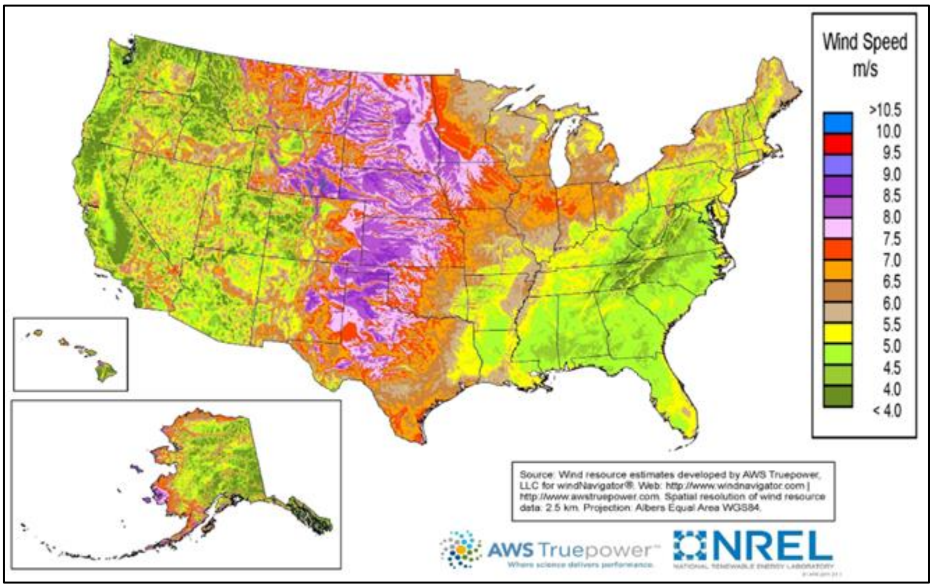


Figure 1.3. The most important annual wind energy resources and their categories [10].

1.2.3. Bioenergy

Bioenergy is the most widespread energy source in the world, accounting for around 70% of the entire renewable energy source [11,12]. Bioenergy differs from other renewable and conventional energy systems [13,14] since biomass systems are directly linked to farms, forests, and ecosystems that produce raw materials [15]. After less than decades, biofuels or bioenergy have turned into traditional fuels from a politically and socially acceptable alternative to one of the controversial solutions [16].

Allegations of land grabs and the loss of victories emerged to undermine the rationale for sustainability that originally motivated its adoption [17]. One of the early controversies surrounding biofuels was food versus fuel. One of the most frequently discussed matters for bioenergy sustainability is land use. There are many discussions about bioenergy as the most widespread energy source in the world. It accounts for about 70% of all renewable energy [18]. In contrast to other conventional and renewable energy systems, biomass systems are directly linked to farms, forests and ecosystems from which raw materials are derived [19].

Nevertheless, biomass production can also positively affect soils, as many permanent energy crops can be raised in soil unsuitable for food production or livestock. So, it returned to production and treatment where water and soil stability and diversity can be stored [11,20].

In addition to its environmental and conservation impacts, bioenergy can have a positive socioeconomic effect and improve living conditions. Increasingly, bioenergy is being integrated into farming and forestry systems. For instance, rather than burning crop residues, electricity is generated from waste. As long as the energy is produced on-site, farmers and foresters can earn additional income and access more energy, thus reducing the environmental impact of on-site combustion [21].

1.2.4. Hydropower

Hydropower is by far the most inexhaustible energy source as a renewable electricity source, with more than two times the consolidated commitment as any other sustainable source in 2016**.** Hydropower can give abundant important kinds of assistance to the power network, including recurrence guidance, voltage support, crisis hold, load following, and dark starting assistance, regardless of the power supply. Hydropower is also critical to adjusting other intermittent sustainable power administrations on a network scale energy capacity, for example, wind and sun-based power and repositories of water the executives' administrations, for example, water supply, water system, flood control, and transportation. Even with a 25% utilization of specialized potential, there is still tremendous potential for improvement. With its exceptionally high energy recovery rate and extremely low ozone-harming substance discharges, hydropower is extremely cost-effective compared to other sustainable power sources and nuclear power sources. Numerous examinations predict that hydropower will increase the current value of 4100 TWh annually by at least two by 2050 due to the significant potential surplus, the high level of energy recovery, and the low levels of ozone-depleting substances [22].

1.2.5. Waste Energy

Waste is known as civil raw materials, considering the problem has appeared with cities' expansion and some industries' emergence [23]. Most of the small quantity of waste produced by most villages in remote rural areas can be disposed of by using it as fertilizer in agriculture or dumping it in the open [24,25]. Waste is currently accumulating in large quantities in most industrialized countries, especially countries with high consumption rates accompanied by waste in the use of various materials, whether in human consumption or various industries. Recently, in the UAE, in May 2022, the primary plant at the level of The Middle East for converting waste into energy, as this plant contributed to converting up to 300,000 tons of waste into energy, thus avoiding 450,000 tons of carbon dioxide emissions annually. There are several ways to obtain energy from waste, the most important of which are (direct burning, hydrogenation and Thermal decomposition) [26]. The figure below shows the waste-to-energy process [27], by 2030. In most cities, the individual's negative environmental impact will be reduced by showing particular interest in air quality and waste management for municipalities and others. To achieve this goal by 2030 at the global level, and because cities are expanding at a rate of (5.1) times due to population growth, the report set the Sustainable Development Goals 2018 [27].

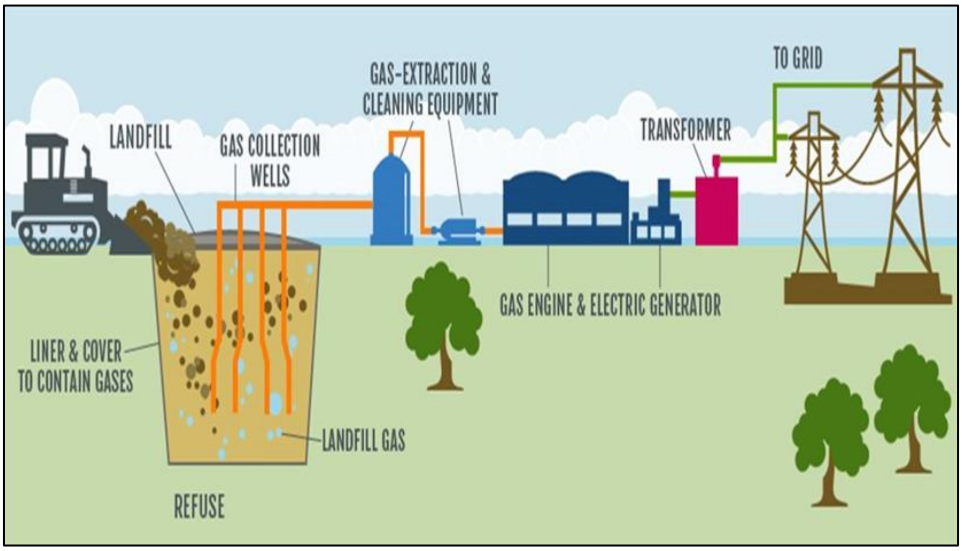


Figure 1.4. Describes the process of converting waste into energy.

1.3. PHOTOVOLTAICS

As a method for converting daylight into electricity, photovoltaics is a fundamentally high-innovation process [28,29]**.** The power is a direct current, and it is possible to be utilized like that, substituting the current or put away for some time in the future. Hypothetically, the photovoltaic device is just a consumable battery, and it is the light that comes from the sun. Basically, a non-nuclear system has no moving portions; climate-friendly activity. Photovoltaic gadgets have heaps of advantages that can be used and are satisfactory to all the globe's inhabitants. Through measured PV frames, the result of its electric power can be reached for all intents and purposes in any application, from the low-controlled purchaser, utilizing wristwatches, adding machines and diminutive chargers for the battery.

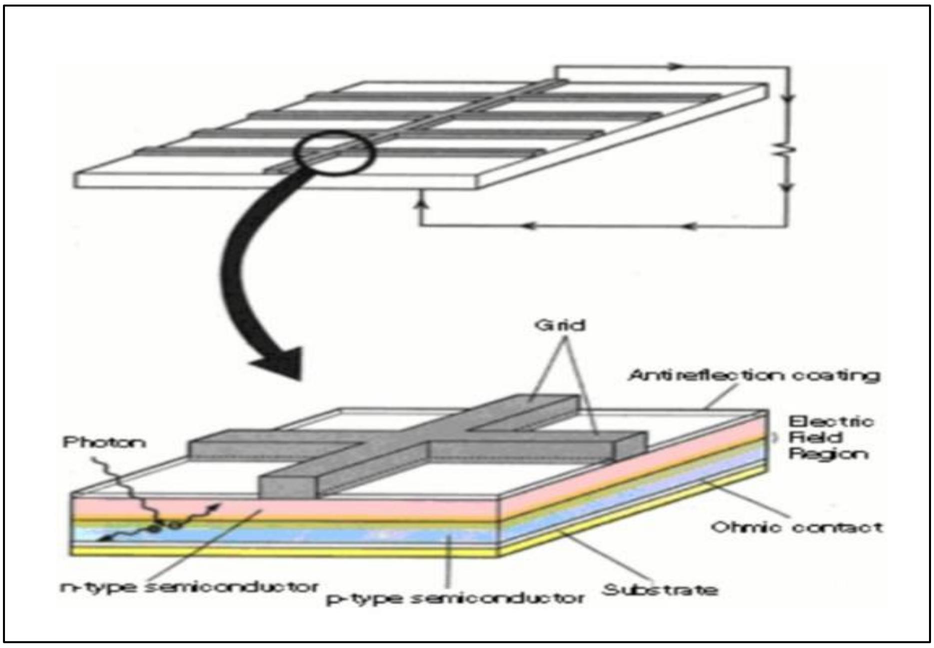


Figure 1.5. PV cell grid contact structure [30].

This figure is taken from reference. Moreover, gradual power needs today are effortlessly given in PV frameworks, unlike more traditional methodologies, for example, fossil or unclear fuels that are demanding, and the economic feasibility of several microphones is possible, the term "several microphones" is not referring to microphones at all, but rather to photovoltaic cells used in solar power systems. The passage explains that these cells come in different structures and that the front grid connection structure allows sunlight to pass through the battery when exposed to sunlight. At the same time, the rear contacts receive the current from the device, completing the circuit. The anti-reflective cover just below the frame is also mentioned as a way to limit the amount of sunlight the device reflects.

Understanding how photovoltaics work is the first step to understanding the many aspects of these devices [31]. Regardless of this, photovoltaic cells come in different structures. The best-known structures are semiconductor materials with vast areas of diodes or junctions. In addition to the front grid connection structure that allows sunlight to pass through the battery when exposed to sunlight, the rear contacts receive the current from the device, completing the circuit. There is an anti-reflective cover just below the frame to limit the amount of sunlight the device reflects in the image below Figure 1.6.

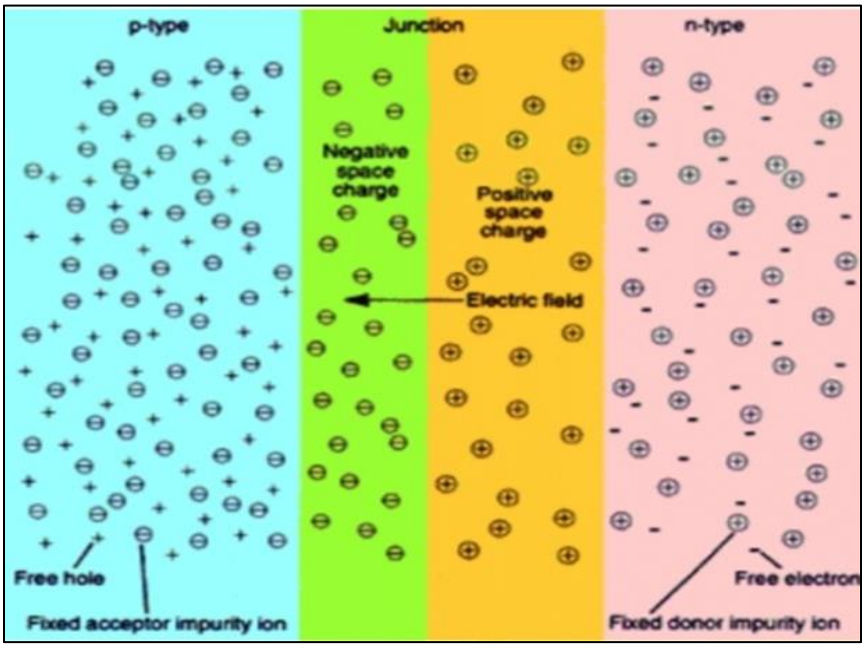


Figure 1.6. Schematic drawing for the significant solar cell characteristics [32].

Although many other types of semiconductors are used by photovoltaic technicians today, silicon crystals represent a convenient solution to this discussion [33].

Silicon represents the crystal structure of a diamond. The nearest four neighbouring atoms are covalently bonded; there are four covalent bonds between silicon atoms, each of which has four valences. The equivalent region contains countries that donate 4 N energy and 4 N valence electrons and fill it. In contrast, at exactly zero, the bars are not filled. Therefore, semiconductors are ideal absolute zero separators. When the temperature of the high-voltage current crosses zero, a transfer of energy occurs between valence electrons so that a certain number of electrons (called intrinsic transporters) are likely to be free to transfer charge in the valence electron conduction band as the energy rises. The energy linking valence and conducting groups is expected to be addressed by covering holes or energy holes, such as B. 1.12 eV for silicon at room temperature. Despite being at temperature of a room, conductivity is low. Intrinsic conductivity is 1.6 x 1010 per cubic centimeter at 300 K; ~1022 scaffolds per cubic meter. Introducing a small amount of adhering impurity into the host material is necessary to adjust the conductivity to a more useful value. The fifth column is phosphorus, arsenic or antimony, and this is across a wide range. In the third column of the covalent bond that loses one electron, the linkage ends from the UE to the outside of the impurity. An electron moving to an unfilled position in the valence band can satisfy the binding condition. As a result, the hole moves because the moving electron leaves the hole behind. It is estimated to require 45-160 meV of energy to put the hole into the valence band in this manner. By altering the admixing impurities thickness, the transition of silicon from the unfortunate power relay to a close metal conveyor can be planned. Silicon doped with tier III components is known as a p-type semiconductor; doped with the components of the V section is called an n-type semiconductor [34].

1.3.1. Photovoltaic cell performance efficiency

Their performance must be accurately measured for photovoltaic devices to be compared and characterized. Earlier, and up to the present time, the results of its efficiency reached controversial results. Measurement of cell efficiency is highly affected by the light source used to illuminate it. It is usual to use a light source with a carefully controlled spectrum. It is necessary to repeat the solar simulator experiment with a high level of accuracy by each category that performs the measurement, or critical correction factors are implemented because it considers many factors that differentiate the spectrum quality from some multiple solar simulators for a single photovoltaic material and the solar simulator that the cells experience it in the actual world below the normal light of the sun. Solar cell usage is crucial to compensate for physical differences. Furthermore, the individual must be sufficiently knowledgeable and able to transfer from measurement to light-intensity measurement. An additional important factor affecting efficiency measurements’ accuracy is the incoming temperature, namely identifying cellular regions. There is much debate about determining the whole area.

1.3.2. Photovoltaic cell materials

Since silicon photovoltaic frameworks have been successfully arranged for space power, silicon has been the decision material for elite performance, exceptionally solid sun cells. Several of today's earthly photovoltaic power structures are glasslike silicon in nature. The necessity to bring down the expense of earthbound photovoltaic power has zeroed in on investigation endeavors on elective materials besides being more affordable. Translucent silicon is produced by developing enormous round and single hollow gems named boules. Wafers are cut from the boules to make photovoltaic gadgets. Cutting is a costly and material-inefficient cycle. Several strategies were conducted to limit the price of the first silicon material and to hinder the development of cutting technology. A more affordable material includes polycrystalline silicon, which avoids costly and energy-intensive gem development. It is rather straightforward to project liquid silicon either onto barrel-shaped or rectangular plates. Polycrystalline materials have an enormous crystallites number isolated via molecule limits. In the material, there is less luck with glasslike qualities, and light-initiated electron-opening matches can re-join at boundaries of grain with no delivering current to the outer circuit.

Albeit polycrystalline materials bring about fewer productive sun-oriented cells than glasslike silicon, and they are adequately less expensive and monetarily suitable. The cast material should, in any case, be cut, prompting a deficiency of about a portion of the material. One more way to deal with delivering less exorbitant materials is to avoid the more significant part of the cutting. Silicon can be produced in sheet form with a few procedures. The principal business achievement was the edge-characterized film-took care of development (EFG) lace procedure, in which a graphite kick-the-bucket process develops polycrystalline silicon by removing solidifying silicon dissolves. This strategy allows it to isolate tiny polycrystalline silicon portions into silicon spaces to produce completed sunlight-based cells with minimal material loss by forming them into numerous strips or polygons. The lace was developed from equal supporting dendrites as an elective methodology.

Almost single-precious stone materials film can be produced by cautiously controlling warm configurations. Different methods, such as strip development and twist projecting, have likewise been illustrated. No matter the methodology, at last, the expense, silicon sun-powered cells will rely upon the beginning material. The least expense approach is to limit the necessary measure of semiconductor material. profoundly mechanized frameworks. Various semiconductor materials can be used to make solar cells that operate on solar energy. Despite its 1.12 eV band gap, silicon is a poor semiconductor. There is a higher hypothetical efficiency for materials with band gaps closer to 1.5 eV, such as CdTe and GaAs. Thin films are less expensive than translucent constructions yet commonly have lower efficiency. Eventually, in any case, meagre movies will be vital for delivering minimal expense power. A primary concern is expense per watt, a higher priority than productivity on the ground.

1.4. SOLAR RADIATION WITHIN THE ATMOSPHERE

Earth's atmosphere wastes part of the external radiation it passes through, which occurs through multiple processes of scattering and absorption by air molecules in the atmosphere as it arrives at the earth's surface only radiation (not diffuse, direct or reflection). Thus, direct radiation will arrive at the surface of the earth without experiencing any interaction with the particles and particles of the atmosphere. Due to Rayleigh scattering, solar radiation is scattered by dust particles, sea salt, pollen, soot and sulfate [35].

Solar radiation undergoes complex processes during its transmission through the atmosphere, changing the spectral distribution flux. For the Earth, this radiation is divided into three parts by the minutes and particles of this atmosphere [36]. The first part is absorbed, while the second half is dispersed, add the third part passes over the atmosphere and reaches the earth's surface [37]. Sun's ultraviolet rays are absorbed by the ozone layer (O_3) in the earth's atmosphere. Simultaneously, some carbon dioxide and water vapor molecules absorb much-infrared radiation. The radiation affects the photoelectric energy significantly, as many researchers have investigated the excitement and influence of factors associated with it, such as the angle of incidence of the site and the angles of inclination of solar cells [38].

1.5 SOLAR ENERGY IN KURDISTAN

In the future, sustainable energy will rely on clean, renewable energy sources such as solar power. The Sun Belt in the scope 34° 42'N to 37° 22'N is where Kurdistan is located, and it is an optimal location for solar power. The Agrometeorological Station of FAO Kurdistan can be used to estimate the solar energy potential of Kurdistan. The estimation showed that:

- The average amount of sunshine per year is 2979.5 hours (8.16 hours/day)
- Mean solar radiation per year of 1803 kWh/m^2/year (4.94 kWh / m^2 / day).

According to Table 1.1, Kurdistan has the potential for solar energy on a monthly basis.

Table 1.1. Kurdistan's average monthly solar [39]

Month Average	Monthly Sunshine (h/month)	Average Monthly Solar Radiation (kwh/m^2/month)
Jan	158.10	77.21
Feb	160.79	91.03
Mar	208.22	134.26
Apr	209.00	154.51
May	303.80	207.53
Jun	375.00	237.22
Jul	360.12	231.50
Aug	360.12	219.73
Sep	301.00	173.06
Nov	255.49	131.97
Oct	175.50	84.31
Dec	112.38	60.78
Total	2979.5 hr/year	1803.09 kWh/m^2/year
Average	8.16 h/day	4.94 kWh/m^2/d

Depending on the geographical region of the agro-meteorological stations, insolation time and solar radiation average are exhibited in Figures 1.7. and 1.8. correspondingly.

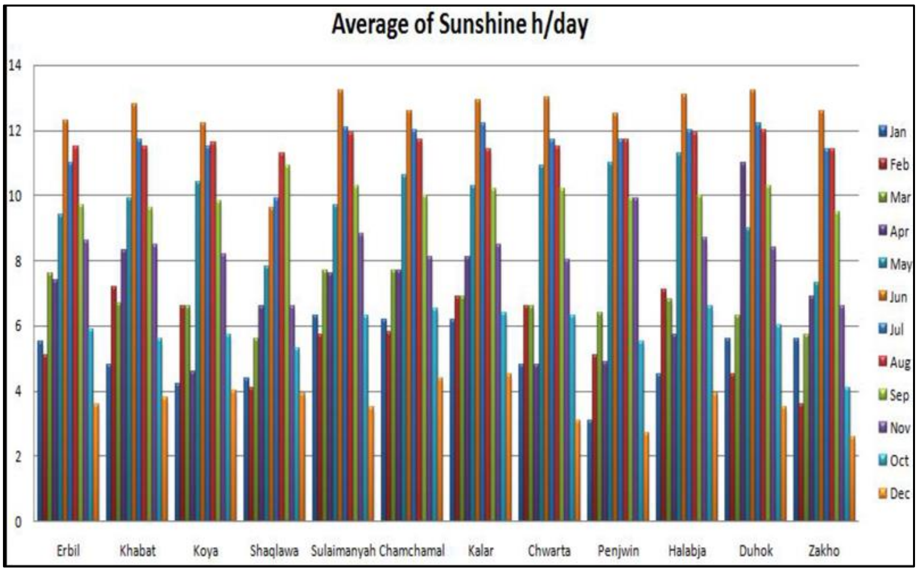


Figure 1.7. Kurdistan sunshine duration by region [39].

Figure 1.8 shows that except for Kurdistan- Iraq, which are situated on the south side of the mountain, where solar irradiance is low, all stations record a similar amount of solar radiation. The shedding factor causes lower solar radiation.

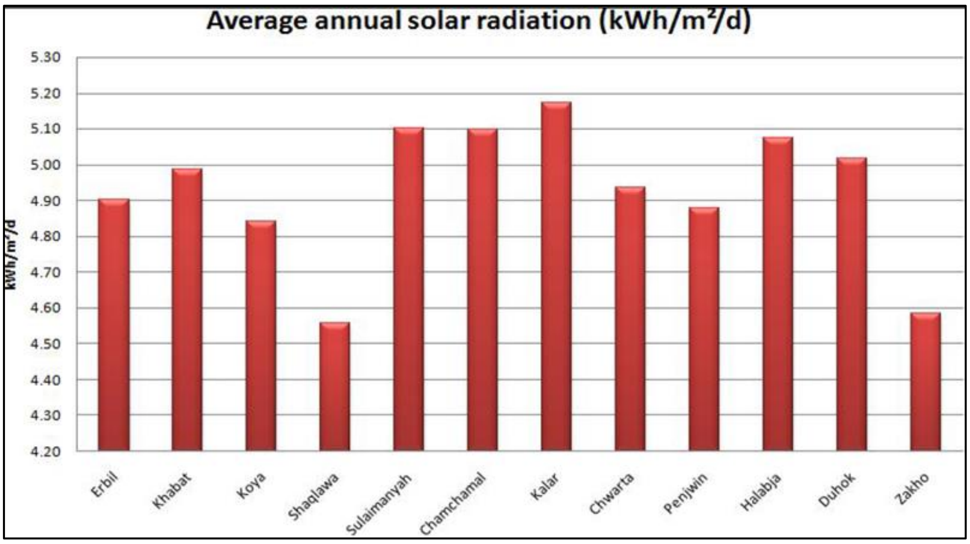


Figure 1.8. Solar radiation averaged over a year [39].

Solar energy is plentiful in Kurdistan with well-dispensed power plants Figure 1.9 however, this abundant energy source has been overlooked in previous years, resulting in extreme energy shortages for the people.

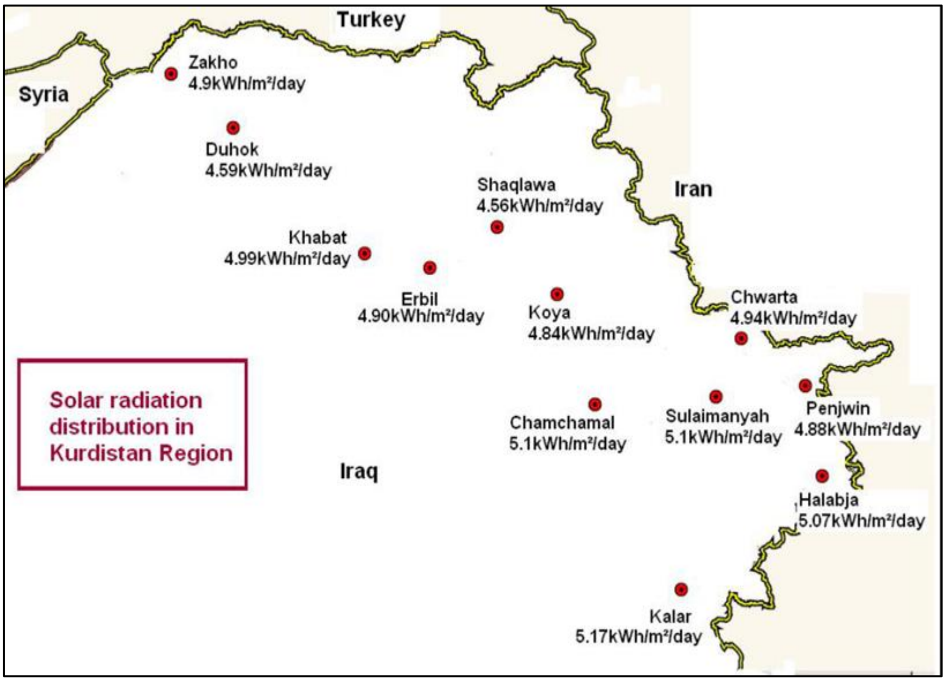


Figure 1.9. Kurdistan solar radiation distribution map [40].

Several solar technologies are applicable in sunny regions such as Kurdistan:

- In villages and big cities, solar water heaters are used. Electricity, LPG, and Kerosene will be less reliant on electricity during the winter when these fuels are scarcer to be obtained,
- In place of conventional fuels, steam can be used to generate electricity.
- In remote mountain areas and rural areas, solar cookers are especially useful.

The use of photovoltaic (PV) systems for the generation of electricity directly, in particular in rural regions. Falling pricing and government incentives in various countries have fueled the fast development of this technology in recent years.

Recently, solar panels are slowly reaching Kurdistan region markets. However, due to the lack of a sensible renewable energy background in normal and solar energy, particularly in the community and the government's reluctance to provide financial incentives, these new technologies are making these new technologies popular.

1.6. DEVELOPMENT OF SOLAR CELLS

In 1941, the first silicon cell with an efficiency of not more than 1% was manufactured. In the year 1954, the American Bell Laboratory succeeded in manufacturing a silicon cell with an efficiency of 4% consisting of a thin layer with a thickness of (3.0 mm) and a diameter of (3-6 cm). It was selected from A mono crystalline type p, or n is a material with two metal electrodes of (Ti-Ag), one of which is connected to the front surface and the other to the back surface [41]. The world's production for the year (2002) of electrical energy was around (900 MW), and that (85%) of this production was only on silicon crystal technology, which has had a stable working efficiency for 20 years [42]. During the past twenty years, despite the great progress made in the field of improving the performance efficiency of solar cells, as shown in the Figure 1.10. the high cost represents a significant factor and an obstacle to the use and spread of solar energy, and research is continuing in this field [43].

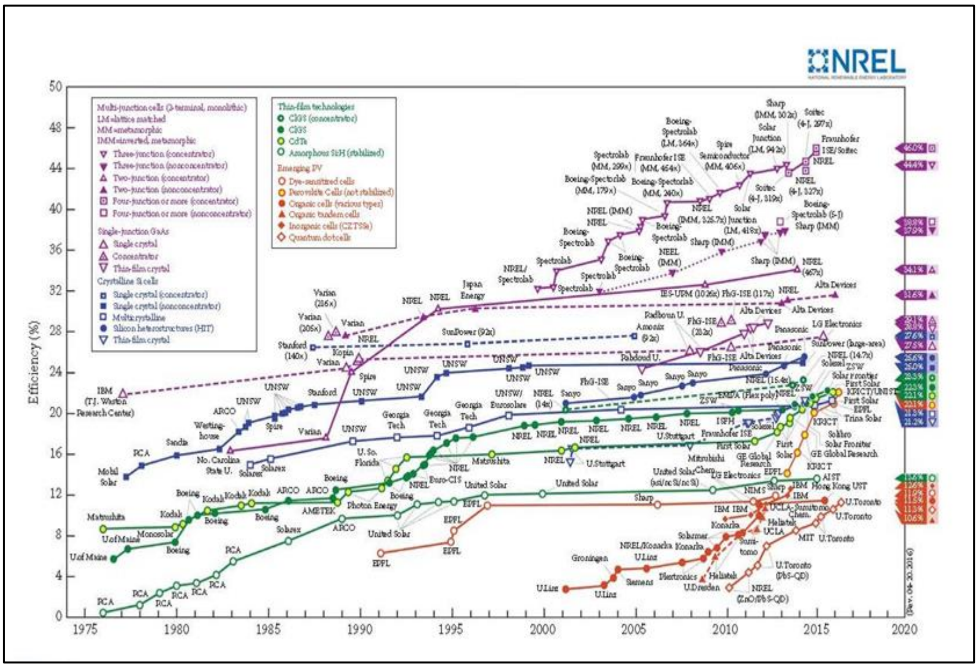


Figure 1.10. Represents the efficiency improvement of solar cells [44].

1.7. FACTORS AFFECTING SOLAR CELLS

1.7.1. Effect Of Temperature and Irradiance Variation

The studies conducted in the countries bordering Iraq have shown that high temperatures and intense solar radiation can significantly impact the performance of photovoltaic energy and solar cells. Iraq experiences hot weather for approximately six months yearly, with the highest temperatures occurring in July and August. During these months, solar radiation and air temperature are particularly elevated, which can further exacerbate the effects of high temperatures on solar energy systems. The operating temperatures and surrounding environmental conditions can affect the physical properties of the materials used in solar cells. This can lead to a decrease in the efficiency of solar cells and a reduction in the overall performance of solar energy systems.

Therefore, it is essential for solar engineers to consider the effects of temperature and other environmental factors when designing and implementing solar energy systems in Iraq and other regions with similar climatic conditions. By taking into account the unique environmental conditions of a particular region, solar engineers can design solar energy systems that are optimized for maximum efficiency and performance. This can help to ensure that solar energy remains a viable and sustainable source of energy in regions with hot and arid climates, such as Iraq [45,46]. Photovoltaic solar cells are devices that convert sunlight into electrical energy. The efficiency of these cells is affected by various factors, including ambient temperature and wind speed. Studies have shown that there is a moderate positive correlation between the efficiency of the cell and wind speed. However, the temperature can have a negative impact on the performance of photovoltaic devices. This is because solar cells rely heavily on solar radiation to produce electrical energy, and high temperatures can cause the cells to overheat, reducing their efficiency. This phenomenon has been observed for a long time and is a well-known issue in the field of photovoltaics. Therefore, it is important to consider the effects of temperature and wind speed when designing and installing photovoltaic systems to ensure optimal performance and efficiency [47], The performance efficiency of photovoltaic solar cells is directly related to the amount of solar radiation they receive. However, it is important to note that only a small percentage of the solar radiation is actually converted into electrical energy, typically around 15%. The remaining 85% is converted into heat, which can negatively impact the performance of the solar cell. High temperatures can cause a solar panel to absorb more heat, which can further reduce its efficiency. The temperature of the photovoltaic cells themselves also plays a critical role in the efficiency of the solar panel. As the temperature of the cells increases, their output capacity and voltage decrease, leading to a decrease in overall performance efficiency. It is important to note that this decrease in performance efficiency is not a linear relationship. As the temperature continues to rise, the decrease in performance efficiency becomes more significant. Therefore, it is crucial to consider the effects of temperature on photovoltaic systems and take steps to mitigate the negative impact of high temperatures on their performance [48].

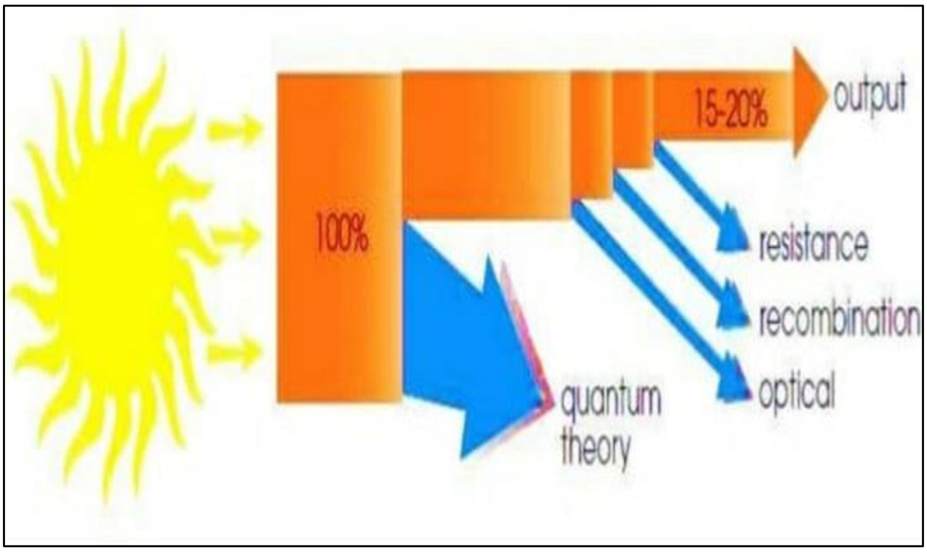


Figure 1.11. A diagram showing the losses of the solar cell as a result of solar radiation [49].

The main problem of solar cells is their low efficiency due to high temperature, as shown in Figure 1.11. despite the availability of a commercial PV system on a large scale, however, there is a need for more research and development to improve its efficiency and reduce costs. Therefore, it is necessary to understand the origin of the loss in ideal solar cells to increase their efficiency [50].

Increasing cell temperature would increase the dark saturation current, and thus (Voc) is lessened [51]. This means that if the temperature of the cell increases, the PV cell (Voc) lessens, as presented in Equation (1-1) can be deduced by solving (Voc) from Equation (3-16) which gives a linear relation between temperature and (Voc) [52].

$$V_{oc} = \frac{nKT}{q} \ln \frac{I_{ph}}{I_O} \tag{1.1}$$

1.7.2. Humidity Effect

In most cities with high humidity, where the average ranges between (40-78%), about 30% of the total solar energy emitted by the sun is reflected or absorbed by clouds and land masses. Energy losses (absorption and reflection) occur when solar energy hits the solar cell, and these losses are in the range of (15-30 %) of the energy [53], as humidity causes a decrease in the solar energy used by about (55-60%). Only 70% of the total energy is used [54].

This difference appears to be non-linear, and this effect will lead to a slight difference in the value of the open circuit voltage (VOC) and a large variation in the short circuit current (ISC).

As the effect of humidity on radiation and (ISC) is clear, this in turn, will lead to a decrease in performance efficiency according to the following equation:

$$\eta = \frac{V_{oc}C_{max} \cdot ISC_{max}}{AC(irradince\ level)} \tag{1.2}$$

Even though three types of photovoltaic cells were tested to determine the effect of relative humidity on their performance: (Silicon), Monocrystalline, Polycrystalline and Amorphous).

The results show that as the relative humidity decreases, the generated current, voltage and energy all increase, and then as the relative humidity has a low value, the power efficiency of the solar cell will be large. The relative humidity reduction generally increases the solar energy Power Efficiency of cells or Photovoltaic Systems [55,56].

1.7.3. Effect of Dust Accumulation

Researchers and workers in the field of solar panels have to contend with dust as one of the most significant problems, such as dust deposition on solar panels and the density of dust in the atmosphere, which play an essential role in the deployment of electric power plants that use solar cells, particularly in Iraq. The increased dust, due to its density in the atmosphere, reduces the arrival of amounts of sunlight to the surfaces of these cells, and this, in turn will lead to a lessening in their performance efficiency [57], while some of the effects of dust storms have been studied on most of the total rate of solar radiation from Through many Iraqi researchers for the cities of Kurdistan. A study was conducted on a dust storm that occurred in Iraq, and the effect was significant on the rate of solar radiation. This storm severely reduced solar radiation levels compared to usual, negatively impacting solar cells' performance efficiency [58,59].

When dust particles accumulate on solar cells, they block light by scattering, absorption and reflection. Moreover, it relies on their density, type, size, and positioning time [60]. Dust particles fall due to gravity, static charges, rain or dust storms. Dust in the air is everywhere, but the size and composition of its particles depend on the area. In Kuwait, dust is present 27% of the time during the day between May to August, which reduces vision, as illustrated in Figure 1.12. [61].

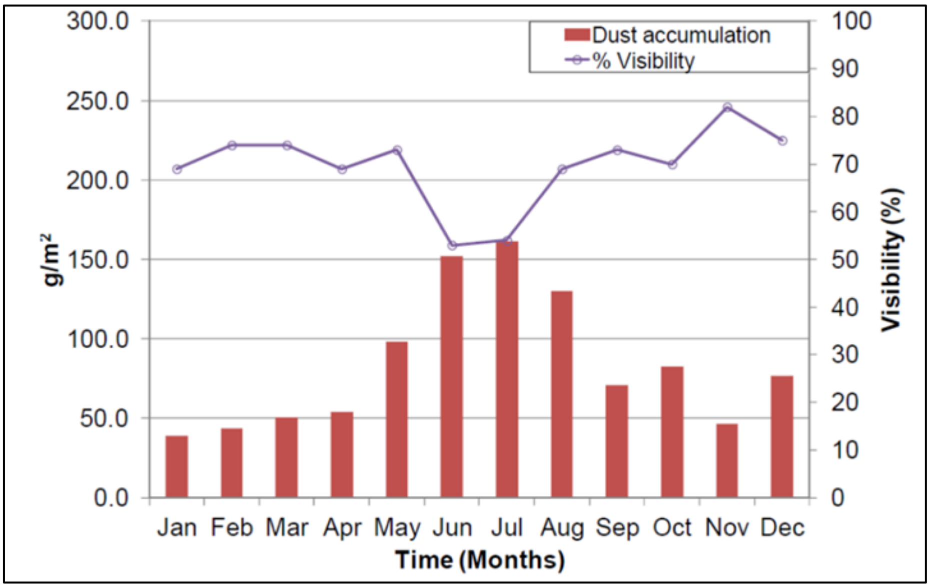


Figure 1.12. Kuwait's monthly mean dust dropping and visibility in 2013 [59].

Many variables control the positioning of dust particles on surfaces, the most important of which is shown in Figure 1.13. [62,63]. The irregular positioning of dust particles on solar cells leads to irregular layers of dust. These layers have different thicknesses and positions, which leads to different light transmittance into the PV cell. It is clear that the process of positioning dust particles is very complex because many different parameters control it.

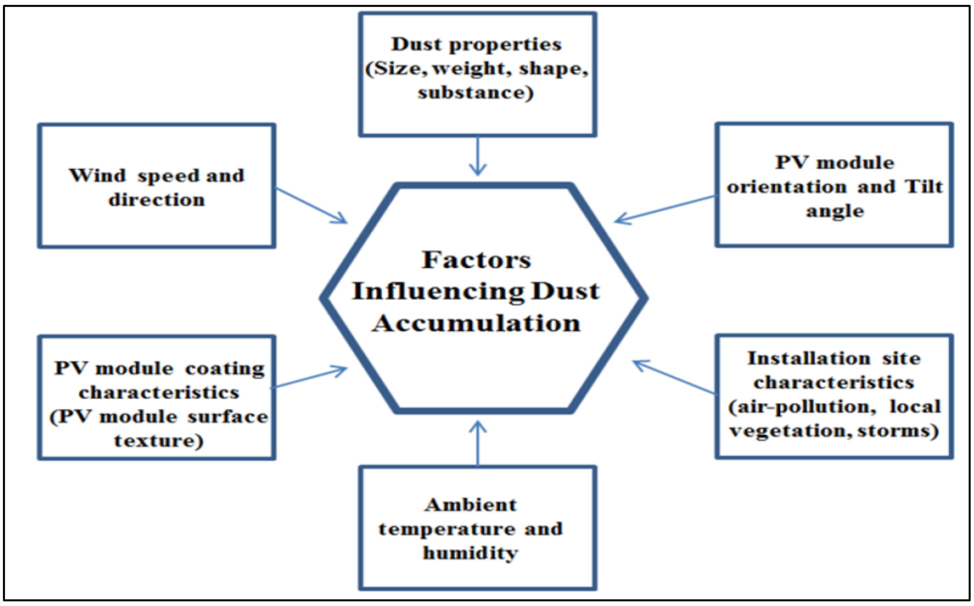


Figure 1.13. Dust accumulation changing factors [64].

The output efficiency of an operational solar power plant depends on the type and texture of the soil in that area. Suppose there are two solar power plants, each one megawatt, built on the same design, same azimuth, and designed by the same company. A solar power plant is installed next to a very busy road with much traffic, so obviously, much soiling will be there. Dust will be accumulated on the solar power plant Figure 1.14. Site A. The other solar power plant, which is again of the same technology and same capacity same direction, is near a thermal power plant Figure 1.14. Site B.

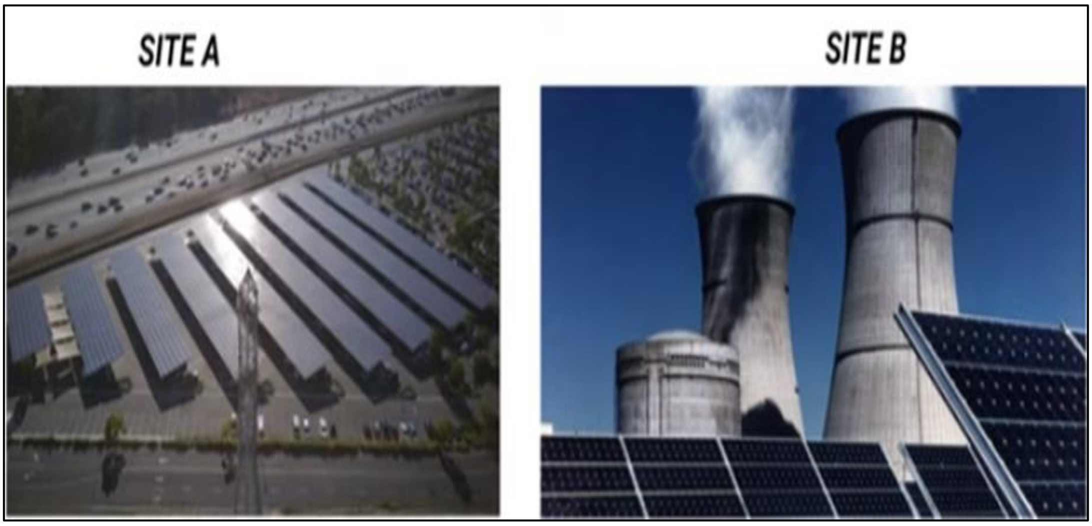


Figure 1.14. 1 MW same technology, same developer, same direction/azimuth [61].

Among both plants, which plant will give a higher output, higher efficiency, and a higher generation at the end of the month?

Silicon cell efficiency with respect to the type and texture of soil falling over it, the very reliable (PVsyst) simulation software which is used to simulate the solar power plant's output behavior for annual performance, does not have this feature to select the type and the texture of soil which is going to be present around that plant. A highly reliable software fails to predict the solar PV plant's performance. As a solar photovoltaic design engineer, considering a two percent or five percent generation loss in the PV Panel due to soiling in a particular area creates confusion and conflict later.

An experiment was conducted to assess the loss of performance efficiency caused by industrial dust deposition on polycrystalline silicon solar modules obtained from fertilizer, gypsum, aggregate, and coal mining industries (see Figure 1.15.[65]. An outdoor experiment was conducted to measure the performance of polycrystalline modules.

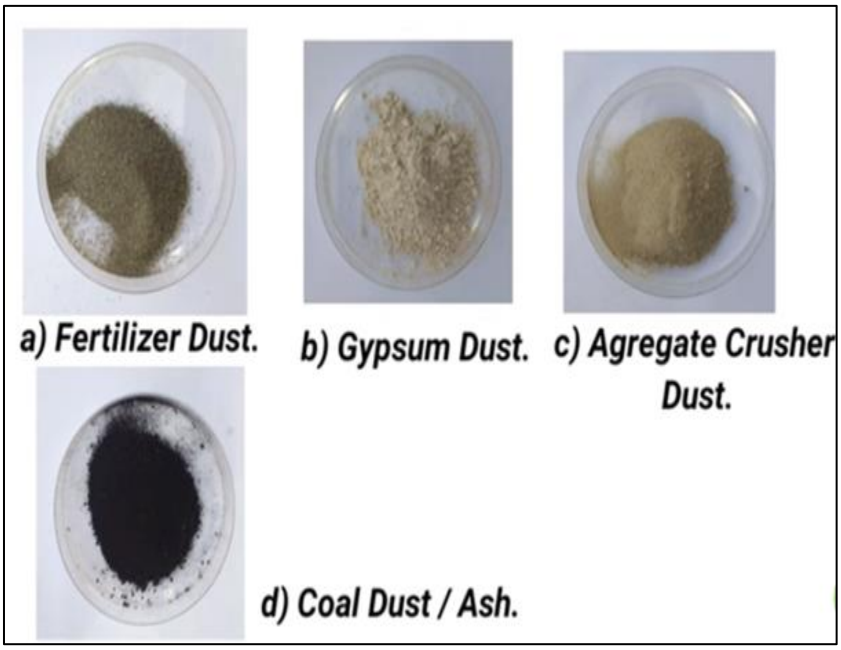


Figure 1.15. Different types of dust [65].

By measuring operating parameters like the IV curve and the PV characteristic curves of similar modules subjected to operational conditions like solar radiation and air or ambient temperature, while one module was covered in dust and the other was kept clean for output comparison, the influence of dust deposition was determined.

Among the polycrystalline modules, coal dust had an efficiency loss of 64 percent, aggregates had a loss of 42 percent, gypsum had a loss of 30 percent, and organic fertilizer dust had a loss of 29 percent. Therefore, as coal dust has the highest absorption capacity and, thus lowest transmittance among the four dust samples, it is the most affecting sample.

Comparing finer dust particles with larger ones, the study showed that finer particles reduced performance efficiency more. It was elucidated that dust accumulation over the glass and its surrounding environment reduced PV module performance as the temperature rose, owing to heat dissipation.

The ambient heat absorption by any material depends on the color and texture of the object or material, so among all the types of soil, coal dust, because of its dark texture, absorbs more heat, dissipating more heat to the module body and hence directs its efficiency. So, the performance efficiency of the solar plant near the coal plant slash thermal plant will be more affected just because of the type and texture of the soiling that is the coal dust.

1.7.4. Wind Effect

Alternative technologies to generate wind electricity are becoming increasingly popular worldwide, but wind speed also affects photovoltaic systems. Indirectly, the sun is similarly responsible for wind energy and its result on the efficiency of the performance of photovoltaic cells [66]. PV modules and systems are exposed to environmental influences, especially wind, throughout the day, as the effect of wind on photovoltaic cells is on multi-variable types .

The effort to force the wind can cause significant structural damage to the photovoltaic panel. It has been found that if the wind speed is reduced to a maximum of 20%, this will reduce the value of the structural costs of the solar cells by about 20%. However, reducing the wind speed will affect the system's performance and should be carefully considered. As mentioned previously, limiting airflow may limit panel cooling, which reduces the performance of photovoltaic cells.

Irritation of sand and dust in the air by wind, which can settle and accumulate on the surfaces of photovoltaic cells, and thus this cumulative effect leads to a decrease in performance efficiency [62,63].

The wind’s direct or indirect effect on the rendition of the photovoltaic regulator and related to the heat transfer of solar panels installed on the roofs in areas with high temperatures. Solar cells become more efficient when wind speeds increase to 5 m/s, as opposed to wind speeds greater than 5 m/sec [64].

1.8 Subject of the research

Solar energy is derived by capturing radiant energy from sunlight and converting it into heat, electricity, or hot water. Photovoltaic PV systems can convert direct sunlight into electricity through solar cells. One of the benefits of solar energy is that sunlight is functionally endless. With the technology to harvest it, there is a limitless supply of solar energy, meaning it could render fossil fuels obsolete by relying on solar energy rather than fossil fuels. It also helps to improve public health and environmental conditions. In the long term, solar energy could also eliminate energy costs while reducing energy bills in the short term. The current limitations: solar energy will save money in the long run. It tends to be a high upfront cost and an unrealistic expense for most households. For personal homes, homeowners also need ample sunlight in space to arrange their solar panels, limiting who can realistically adopt this technology at the individual level.

The installed global capacity of solar cells has increased year on year for the past decade, fueled by the plummeting prices and rising efficiency of solar cells forcing fossil fuel producers out of the market through technological advances. At the end of 2019, the total installed capacity of photovoltaic cells exceeded 630 000 megawatts. An astounding figure that is going to continue to rise in the coming decades. However, in 40 years, solar cells have been used. There has been a mystery flaw that has been sapping away potential electricity from the photovoltaic cells. Upon testing in the laboratory, newly manufactured solar cells display an efficiency of about twenty percent. They can convert twenty percent of the incoming energy from sunlight into electric current. However, within hours of operation, that efficiency would drop to eighteen. A 10% drop in total electric generation. Losing 10% of 630 000 megawatts of power is no small problem. That is equivalent to about 30 nuclear power plants worth of power capacity if the solar panels could operate all day, which they cannot. There is much potential electricity being lost. It is no wonder that scientists and engineers have been hunting down the cause of this problem.

The photovoltaic effect depends on the weather. When the Sun goes down, the PV modules stop producing electricity. Light conditions are decisive factors in the amount of electricity generated by PV. In addition, there is also the operating temperature of the modules, which impacts the amount of electricity generated. High or low temperatures can cause a reduction in photovoltaic conversion efficiency. So, what are the effects of different weather conditions on PV modules?

One , In continuous rainy or foggy weather with low solar radiation illumination, the PV system will not work if the operating voltage of the inverter does not reach the starting voltage. Especially on flat roofs, when there is too much rain, there is a risk that the solar panels will be soaked by rainwater because of the relatively low mounting of the flat roofs. In order to prevent excessive water accumulation on flat roofs and the formation of small ponds, an additional set of drainage systems can be installed before the onset of heavy rainfall to drain water effectively and as long as the water does not accumulate too deeply, the impact on the panels will be minimal.

Two, thunder and lightning: the DC bus bar, inverter, and other equipment lines in the PV system are protected against lightning and overlord. In the event of lightning strikes, leakage, and other abnormal voltages, they are automatically switched off and disconnected, so there is no safety problem. Moreover, the metal edges and supports on the roof are grounded to ensure safety in lightning weather. Secondly, the surfaces of the PV modules are made of ultra-impact resistance toughened glass, which has been subjected to harsh tests during EU certification, making it difficult for lightning to damage the PV panels. In general, installing a lightning protection system is an important basis for the success of lightning protection measures, which are generally considered by the installer during the power station installation.

Three: high or low temperatures, PV modules extract energy from light rather than heat. So cold weather has nothing to do with how much PV power is generated. Energy will be generated in areas prone to freezing temperatures as long as sunlight shines on the modules. Cold temperatures may make PV modules perform even better. Due to the temperature coefficient, high temperatures can instead trigger module power degradation as the PV module becomes hotter. The standard operating temperature of a PV module for normal operation is 25 degrees Celsius for the cells. Under operating conditions greater than 25 degrees Celsius, each degree of temperature rise will cause a corresponding attenuation in the module's output power, at which point the PV module's power output is affected by the module's temperature coefficient. Typically, for every 1-degree Celsius increase in the cell temperature, the output power of the PV module is reduced by 0.42 percent of the reference value; Maysun solar modules have a temperature coefficient of minus 0.34 percent.

Four, Snow accumulation: PV modules and snow can co-exist, and the amount of electricity generated by a PV module when covered with snow depends on the quality of the PV module and how it is installed. PV modules are manufactured to undergo thermal cycling tests to cope with extreme temperature changes in hot and cold climates. In TC tests, modules are subject to external temperature changes. The PV modules under test are placed in an environmental chamber where the temperature is cooled to -40 degrees Celsius, heated to 85 degrees Celsius, and then held again. The modules are also subjected to maximum power currents as the temperature rises, and the process is cycled 200 times. Choose a black framed or full black module with better heat absorption; it will melt snow faster than a normal module. Living in a very snowy area necessitates regular snow cleaning from the modules.

Five, Hailstones: solar panels might be smashed by high-speed ice balls. However, the glass on the surface of PV modules is rigorously tested. Qualified modules in a PV grid-connected system must pass stringent tests such as a maximum static load (wind and snow load) of 5400Pa on the front, 2400 Pa on the back, and a hailstone of 25 millimeters in diameter hitting at 23 meters per second. Hailstones are not harmful to PV Power Systems except in extreme hailstorms. When egg-sized hail particles hit the PV panels, the PV plant is likely to suffer.

Six, Typhoon: Modules are subjected to wind, snow, and ice loads outdoors and to surface static pressures such as stacking and stepping. These can be tested using the experimental method of mechanical loading. According to IEC 61215 PV, modules should have a gust safety factor of 2400 Pa, corresponding to 130 kilometers per hour wind speed. According to the typhoon rating, the module product should withstand typhoons of magnitude 12 or above. To withstand extreme weather, choose scientifically designed, high-quality modules, mounts, and solar PV panels that meet the specifications for household PV plants. In the event of a drop in power generation or other abnormalities following extreme weather, prompt contact should be made with after-sales staff to arrange a home visit for system inspection and replacement.

Seven, dust the major problem that contributes to solar PV efficiency is dust accumulation. Dust accumulation on solar panels is inevitable, and it prevents the sunlight from reaching the solar cell, which in turn reduces the performance of the solar panels. The accumulation of dust depends on the region. The transmission of sunlight varies from 10% to 100%. Different types of falling dust affect the PV panel differently.

1.9 AIMS OF THE STUDY

The study aims to determine whether solar energy in the Kurdistan region of Iraq is profitable for generating electricity. Encouraging the Iraqi Kurdistan government is recommended to provide numerous initiatives to support and encourage using renewable energy sources. The following are the most noteworthy suggestions. Establish open markets and competitions that allow diverse participation to ensure the sustainability of renewable adoption. -Perform market functions efficiently to ensure the diversity of resources.

1.10 METHOD OF THE RESEARCH

1- Recognize the problems in the Kurdistan-Iraq region's power generation sector.
2- Establish methods of collecting recorded climate data .
3- Estimate the potential of renewable energy in Kurdistan, Iraq by assessing, classifying , and reprocessing the recorded data.
4- Understand the possible impact of renewable energy by the calculation results of wind and solar map of the Kurdistan- Iraq region.

1.11 SCOPE AND LIMITATION

This research proposed a study of the effect of different climatic factors and their impact on the efficiency of solar cells in the Kurdistan region, Iraq. This improves solar energy performance if used sufficiently in the Kurdistan, Iraq region. Furthermore, this region has sunny weather on many days of the year, as the intensity of the average daily solar radiation ranges from 2000 kWh/m^2 to 2500 kWh/m^2. It is also possible to benefit from this energy in thermal form, with an estimated guarantee of 0.23 US cents/kWh. In this research, a MATLAB modeling of data collected from the Kurdistan region of the factors that affect the efficiency of solar cells was presented.

Finally, this study suggests initiatives the Kurdistan government could adopt to support renewable energy sources in general and solar energy in particular.

.

PART 2

LITERATURE REVIEW

This chapter shows the origins and developments of updraft energy. Then, it reviews the proposed projects over various periods up to the present. Stations for electricity production have been constructed. Throughout this period, many researchers have focused their attention on the. They have attempted to investigate the system's variables by examining the factors that affect performance, increase efficiency, and reduce construction costs. Much attention has been paid to some work to investigate the effect of the geometrical variables and the possibility of improving the system's performance.

Olawale et al. [67] showed that the 4.5 kW solar PV system installed in Oke-Agunla village is underutilized due to inadequate maintenance, insufficient technical understanding, insufficient training and inexperienced project managers resulting in breakdowns or deteriorating performance. The assessment has unquestionably improved the familiarity with a wide range of factors that should be included in solar PV installation and scaling, particularly in rural areas. It is strongly believed that Solar and PV systems will greatly improve their efficiency. Of course, in areas without connection to the national grid, solar PV systems will be a gateway for dependable electricity delivery.

Jawed [68] offered equations using Parameters (I_{SC}, V_{OC}, η, FF) that are a function of temperature, and V_{OC} decreases with the increase in temperature. The maximum volatilization of organic compounds is 663.9 mV at 20 °C and its lowest value. The value is 545.2mV at 80˚C, while the ISC increases slightly with the increase in temperature. The minimum I_{SC} is 37.49mA at 20˚C, and the maximum I_{SC}

is 37.56mA at 80˚C. The final efficiency disappears with increasing temperature and the maximum. The efficiency at 20 °C is 18.34%, while the minimum efficiency at 80 °C is 13.71%.

Shaharin et al. [69] studied the effect of gathering dust, dirt, sand and water algae on photovoltaic solar panels, as these factors play a major role in the loss of photovoltaic energy and prevent it from reaching the solar cells. This problem is enormous because the materials that prevent the light from reaching the solar cells constitute an external resistance that reduces the solar photovoltaic performance. These experiments were carried out on two plates, one clean and the other with dirt, sand, and algae, for light irradiation of 310 W/m^2, under controlled conditions. The output energy from solar panels was between 9% and 31% due to traces of talc powder, between 60% and 70% due to dust, between 70% and 80% due to sand, and between 77% and 83% due to algae. The study concluded that external influences reduce the performance of photovoltaic cells by about 85%. The study found that opaque molecules greatly affect solar energy photovoltaic energy efficiency, and the study recommended that in order to overcome these problems, regular maintenance should be very important. Dust and sand can be removed naturally through the rain as they will be washed away, yet it is necessary to remove accumulated algae. The study also found that rain does not significantly affect the performance of solar panels.

Kanchan and Gargi [70].improved the solar panel's performance by analyzing its shading pattern. The shadows cast on the top of the solar panel are one of the main factors that cause disturbances to the solar panel, and the clouds cause the shading. Solar panels may become more efficient due to this.

Chikate and Sadawarte [71] conducted a study on many environmental conditions, such as exposure to the sun, high temperatures, dust and dirt, which affect the efficiency of the photovoltaic system. One of the ways to be effectively efficient and to improve its performance is to reduce the operating surface temperatures, and this method is done by cooling the units and reducing the stored heat during the operation of the photovoltaic cell. The battery is the open circuit voltage, which is directly proportional to the battery temperature, so as the temperature decreases, the open circuit voltage decreases, with a slight increase in the short circuit current, which reduces the performance of the battery. The open circuit voltage increases with the increase of solar radiation in logarithmic increments, and the short circuit current increases linearly, which leads to an increase in the output power. The other environmental factor is dust, which, when it accumulates on the solar cells' surfaces, forms darkness and blocks some sunlight, thus reducing its performance.

Boyle et al. [72] studies the accumulation of dust on solar panels and photovoltaic cells leads to the failure to achieve the performance in which they work. Dust naturally collects on the cover of photovoltaic panels from two sides of the front in Colorado. The overall pooling rate was measured, as was the light transmission drop. It was found that the rate of mass collection somewhere on the solar panel was estimated to be about 1 and 50 mg/ m^2/day and varied seasonally and regionally, and the point of order was seen in absolute mass groups up to 2 g/ m^2 after 1-5 week arrangements. It was found that the decrease in transmission reached 11%. The transmission differed directly with the mass of the accumulated residues, and the point of occurrence of the radiation approach does not affect it, not even the point of arrangement of the plate or the area from which the transmitter is received. A direct regression of the information has proven that the direct information is sufficient and appropriate, thus establishing this relationship.

Abd-Elhady et al. [73] promoted another way to augment the solar panel's efficiency. The strategy is implemented by coating the front of the solar panel with a thin layer of oil to determine the amount of light transmitted to the panel and its effectiveness. It was concluded from this:

1. Applying a thin layer of Labovac oil to the PV panels increased the power output by more than 20% compared to uncoated panels if the panel temperature was kept constant.
2. Labovac oil builds up solar energy transfer to the PV panel, which increases the current efficiency of the PV panel, although it overheats the PV panel, compensating for the increase in current efficiency.

3. A layer of Lapovac oil should be applied to the photovoltaic panels in cold countries, yet not in hot and bright places, to avoid heating effects that reduce the current output of the photovoltaic panels.
4. The improvement in productivity due to coating the photovoltaic panels with different oils, such as Mobil oil, Abro oil, and Sunflower oil, is not different from Labovac oil.
5. Olive oil reduces the performance of solar panels, which is different from the state of impermeability and lack of coverage.

Al-Dour and Abed [74] conducted a study in Iraq, Baghdad, receiving>3000 h of solar radiance annually. 5,6 Hourly solar intensity varies between 4.836 kJ/m^2 in January and 9.686 kJ/m^2 in June. The qualities of sunlight-based Radiation in Iraq are summarized in the following matters:

1. In the northern regions, incidental varieties accounted for 300%, increasing from 7MJ/ m^2 in December and January to 23MJ/m^2 in June. In the South, the variety is 200%, increasing from 13 MJ/m^2 in December and January to 27 MJ/m^2 in June and July. In key areas, the diversity is 250%, and north-south can be deemed normal.
2. Solar radiation increases from north to south, sharply contrasting summer and winter. It can be seen that the radiation distribution across Iraq is more uniform in summer (June-August).
3. The decrease in solar energy from east to west is slight and prone to evaluation errors.
4. The solar-based radiation assessment is based on the linkage of information obtained from weather stations in urban and large cities. Considering the effects of pollution, compared to their environmental factors, these places experience less radiation, so the actual radiation levels are higher than expected.
5. Due to the widespread radiation that operates on solar energy in Iraq, photoelectric discovery is the most appropriate in all aspects.

Fardila et al. [75] explored and examined various changeable and immutable elements that might affect a PV module's efficiency, with dust being one of the site-dependent environmental factors that belong to the category of immutable parameters. By physically damaging the photovoltaic panel, dust might reduce its efficiency, reducing the intensity of the radiation coming from the sun and raising the temperature, which leads to changes in the electrical properties of the solar panel. The extent of the reduction is controlled by numerous parameters, but especially by the density of the deposition. The accretion of dust (20 g /m^2) on the photovoltaic panel works to reduce the current of the circuit Short circuit and voltage as well as efficiency in the open circuit by up to (15-21%, 2-6%, and 15-35%) respectively.

Taziwa et al. [76] investigated the long-term (February-August) focus on 3.8kWp frame-connected PV frames in South Africa, showing that frames perform better in cooler seasons than in summer, despite higher summer sunlight. The maximum performance ratio (PR) was 30% in May with an ambient temperature of 16 °C, compared to a baseline of 14% in February with an ambient temperature of 20 °C, the most extreme reference income, exhibition income, and the last of 5.5 h/d in February Yield, July 2, 9 h/d and April were 1.3 h/d. The largest fishing incident occurred in February at 3.5 hours/day, as the most notable normal ambient temperature for the month was 20˚C. The most notable cluster capacity in May was 12%.

Himanshu et al. [77] analyzed the effect of dust particles and shading on solar panels' efficiency using the MATLAB program. The results were compared with experimental values where images containing black lines were used to block the light in the modeling.

Zhang [78] analyzed the impact of numerous environmental conditions through the MATLAB program. The effect of heat, humidity and radiation intensity on the efficiency of solar panels was considered.

Rashel [79] modelled solar cells using the MATLAB program, taking into account real weather conditions. In which different factors and their impact on the performance of the solar cell were modeled. The program has been provided with the intensity of solar radiation, temperature and wind speed. The concept of the obstacle was also introduced as a generalization of the concept of the shadow, especially dust.

Rahmatmand et al. [80] investigated the primary circumstances for the huge scope execution of sun-based photovoltaic (PV) boards in cold and far-off regions and showed how to manage snow and ice-gathering impacts on the boards' surfaces. In this review, a warm technique was used to eliminate snow from Photovoltaic sunlight-based chargers nine sun-powered chargers was introduced on bended points at tilt angles (30°, 45°, and 55°) separately, with three boards at each corner. A radiator was inserted between the surface of one of the boards, and a back layer of protection was at each corner. In order to serve as reference cases, the other two gatherings remained undisturbed. Various conditions of snowfall were experienced during tests conducted outside. Additionally, every test estimated Sun-based radiation, relative stickiness, encompassing temperature, and wind speed. Results revealed that the snow cover did not slide off the sheets due to the casing at their base edges. Also, it has been seen that the whole plate surface expects heat to eliminate snow on the grounds that the warm conductivity of the board was not adequate to direct hotness to unheated regions. To avoid these issues, the lower edge of one of the reference boards was eliminated at a 45-degree tendency, and the board was warmed utilizing a counter current. For most tests with this plate, the snow cap sneaked off the plate in under 30 minutes [80].

Hussein et al. [81] stated that this white paper presented the performance evaluation and characterization of grid-connected photovoltaic systems relying on test outcomes. In order to reduce Oman's vulnerability, a numerical model is suggested utilizing estimates of its climate throughout the year. Furthermore, it is improved by considering the effect of residue formation on the fabrication of skeletons in different techniques. The suggested model outcomes contrast the target outcomes for IV, PI and PV quality. It has been detected that conscious results surround the suggested model. Similarly, near the power point (MPP), the numerical model results departed most from the experimental results. In addition, the observed model uncertainties RMSE, MSE, and MAE are 0.078, 0.0313, and 1.711, respectively, and the precision R2 is 0.896. Moreover, the research shows that experimental and suggested model findings were precisely related. From the outcomes obtained, it can be seen that the grid-connected photovoltiaic (GCPV) execution rate was 64.92%, whereas the most extreme inverter and PV efficiencies were 94.00% and 10.80%, correspondingly. In addition, the curtailment factor and normal production were also 19.64 % and 141.39 kWh / kWp, respectively. The conclusion is that the GCPV framework's performance is cost-effective and within the projected speed. In the present study, prospective work will focus on developing a generalized photovoltaic current model that considers the cumulative mass and the elemental composition of dust load. The new model aims to predict the effect of dust on PV power generation at any site in light of dust composition knowledge.

Shevchenko et al. [82] conducted research to improve solar cell performance. They created a MATLAB program that utilizes statistical methods in a mathematical model. The program accurately calculates the amount of dust formed on the cell surface and assesses the cell's efficiency. The code is based on the Bouguer-Lambert-Behr law, modified to consider air humidity.

Previous studies have addressed the impact of gathering dust, dirt, sand and water algae on photovoltaic solar panels, as these factors play a major role in the loss of photovoltaic energy and prevent it from reaching the solar cells. This problem is very big because the materials that prevent the light from reaching the solar cells constitute an external resistance that reduces the solar photovoltaic performance. The study found that opaque molecules greatly affect the efficiency of solar energy photovoltaic energy, and the studies recommended that in order to overcome these problems, regular maintenance should be very important, as shown by Olawale S. I et al. in their study. Dust and sand can be removed naturally through the rain as they will be washed away, yet it is necessary to remove accumulated algae. The studies also found that rain does not significantly affect the performance of solar panels. However, by scrutinizing the study of Abdelhady et al. [73] it was noticed that oil was used on the front layers of the boards, which may lead to an increase in heat in the board and thus, a decrease in the efficiency of the board, especially when using olive oil.

2.1. OBJECTIVE OF THE WORK

Several studies were conducted to increase performance and efficiency. Studies differed according to the type of improvement discussed, such as that the panels' efficiency decreases when exposed to dust or rain. Mistakes might stop the renewables, need repairs, and in certain circumstances, even call for revamps and the equipment of modernized systems. Overall, numerous researchers are trying to improve the performance of PV panels by changing some sort of design of it. The information presented will be valuable for new research in this area. Through this study of solar radiation, it was concluded that Iraqi Kurdistan and the Erbil region are exposed to a sufficient amount of solar radiation that qualifies them to establish solar power plants, Hence the importance of the study.

The results have been examined from technical, economic, and social viewpoints. Conclusions have been drawn about local, small-scale energy supply and, more generally, for the whole of Kurdistan, Iraq. Furthermore, seeing what is available in the markets in Kurdistan-Iraq.

PART 3

THEORETICAL BACKGROUND

3.1. INTRODUCTION

The sun is one of the most important and most important sources of fuel in the world of renewable energy, and research and studies have started to zero in on sustainable power, particularly sun-oriented energy, to address customary energy issues and supplant it with a clean and harmless to the ecosystem choice. The energy from the sun is one of the main sorts of energy humans can contribute. Extremely durable energy does not need the utilization of gases or side-effects unsafe to the climate contrasted with different sources, as solar panels produce electrical energy through individual photovoltaic units connected in the form of chains. This form of energy collection can be applied in most regions of the world because of the abundance of the sun, and it can also be used in isolated or remote areas and in homes to cover the high cost of electricity. Solar cells capture photons from the sun's rays to convert the sun's energy into electrical energy, forming free electrons that flow through the solar cells to produce electrical current [82,83].

3.2. BASIC FORMULAS OF SOLAR RADIATION

3.2.1. Solar Declination

$$\delta = 23.45^{\circ} \sin\left[360\,\frac{n+284}{365}\right] \tag{3.1}$$

Where n is the number of days in the year counted from 1 January.

3.2.2. Solar altitude

$$\sin\alpha = \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\cos(\omega) \quad (3.2)$$

Where φ is the location's latitude, δ is the deflection angle, and ω is the angle of the hour.

3.2.3. Hour Angle

A local solar time (LST) is converted to the number of degrees during which the sun moves within the sky using the Hour Angle**.** Solar noon is characterized by an Hour Angle of 0°. Every hour away from solar noon corresponds to an angular movement of 15° of the sun in the sky due to the Earth's rotation of 15° per hour. There is a negative hour angle in the morning and a positive hour angle in the afternoon [84].

$$\omega = 15^{\circ}(\mathrm{LST} - 12) \quad (3.3)$$

3.2.4. Local Solar Time (LST) and Local Time (LT)

Local solar time (LST) defines the time when the sun is at the top of the sky at twelve noon local solar time**.** Earth's orbit eccentricity and adaptations of humans, like the time zone and saving time for daylight, can cause local time (LT) to differ from LST.

3.2.5. Local Standard Time Meridian (LSTM)

Like the Prime Meridian used for Greenwich Mean Time, the Local Standard Time Meridian (LSTM) is a reference for a particular time zone. Based on the equation below, (LSTM) is calculated:

$$\mathrm{LSTM} = 15^{\circ}\Delta T_{\mathrm{GMT}} \quad (3.4)$$

Where the hourly difference between local time (LT) and universal coordinate time (UTC) is denoted by the symbol ΔT_{GMT}. The time zone is also equal to ΔT_{GMT}. 15°=

360°/24 hours. It is 150 °E of the Meridian of Local Standard Time for Sydney, Australia, since its GMT is +10. LSTM is 105°W for Phoenix, USA, which is GMT -7; Erbil, Iraq is GMT +3; and LSTM is 45°E.

3.2.6. Equation of Time (EoT)

The equation of time (EOT) (in minutes) is an empirical equation that corrects for the eccentricity of the Earth's orbit and the Earth's axial tilt. EOT is given by [84].

$$EOT = 9.87 \sin 2B - 7.53 \cos B - 1.5 \sin B \quad (3.5)$$

Where:

$$B = \frac{360}{365}(d - 81) \quad (3.6)$$

In degrees and d is the number of days since the start of the year. The time correction EOT is plotted in Figure 3.1.

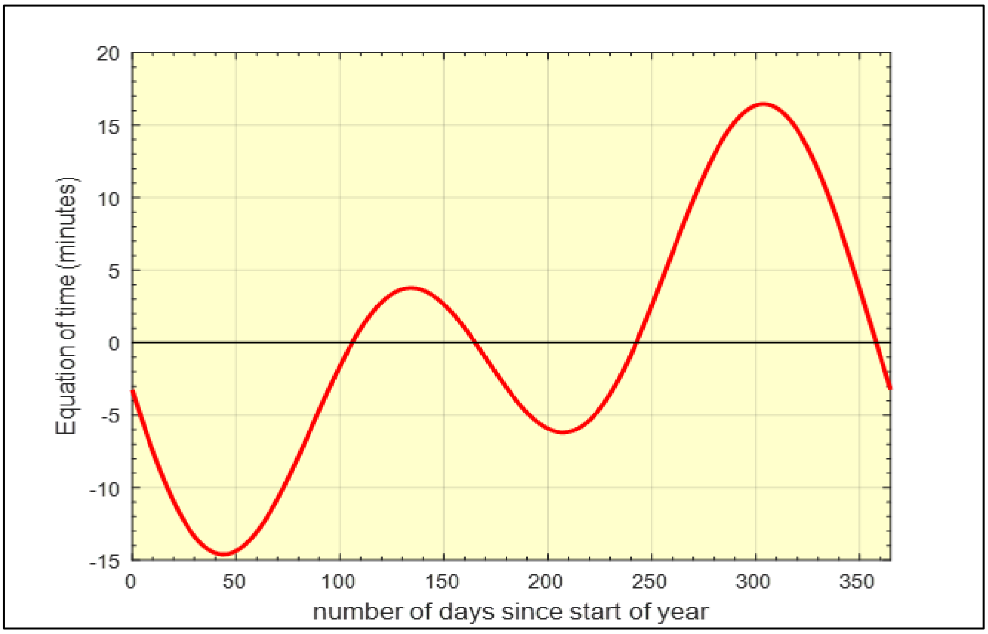


Figure 3.1. The time correction EoT [85].

3.2.7. Time Correction Factor (TC)

As a result of longitude variations within a particular time zone, the overall Time Correction Factor (in minutes) simulates variations in Local Solar Time (LST) within that particular time zone as well as incorporating the EOT Equation (3-5) within its calculation [54].

$$TC = 4(Longitude - LSTM) + EOT) \qquad (3.7)$$

Since the Earth rotates once every 4 minutes, the factor of 4 minutes is based on that.

3.2.8. Local Solar Time (LST)

Using the two corrections described above to adjust the local time (LT), it is possible to determine the Local Solar Time (LST).

$$LST = LT + \frac{TC}{60} \qquad (3.8)$$

Alternatively, the angle of azimuth, which is possible to be observed in Figure 3.2. this angle is related to the Sun's reference line being offset from its axis. It is possible to be estimated via the equation:

$$\sin\theta = \frac{\cos(\delta)\sin(\omega)}{\cos\alpha} \qquad (3.9)$$

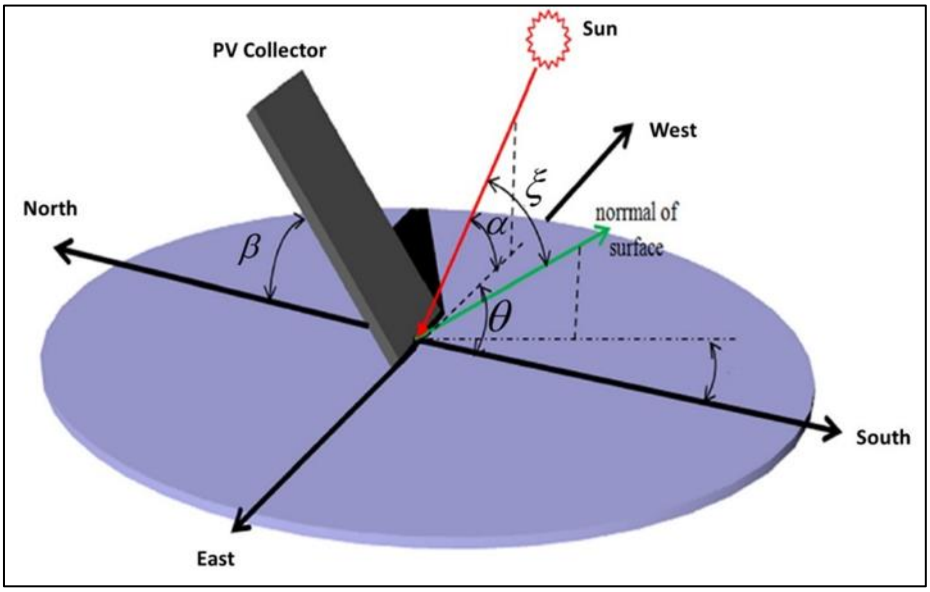


Figure 3.2. Photovoltaic thermal collector [86].

If the azimuth angle was calculated for the location of Erbil on the date 20/3/2022 at the time 13:00, it was founded that θ=19.3741°.

3.2.9. Sunrise/Sunset Hour Angle

The time interval between sunrise and sunset is known as a solar day. This means that from sunrise until sunset, the azimuth and altitude angles must be determined for every hour. The sunset and sunrise hour angles may be deemed equal and computed as [87].

$$\omega_{SS,Sr} = \cos^{-1}(-\tan(\varphi)\tan(\delta)) \tag{3.10}$$

Where δ is the angle between a plane perpendicular to a line between the earth and the sun and the earth's axis, and φ is the latitude (given in degrees). As a result, Equation 3.1 can be rewritten as follows to calculate the solar time of each hour angle:

$$\frac{\omega_{SS,Sr}}{15^{\circ}} \pm 12 = AST_{Sr,SS} \tag{3.11}$$

To determine the time of sunrise, a negative sign is required for Equation (3-11), whereas a positive sign is needed to calculate the time of sunset. Observed or real solar time (AST) is determined by the apparent everyday motion of the observed or true Sun. The ostensible solar day is the basis of the AST. This is the interval between the

Sun's two consecutive returns over the local meridian. A solar apparent's time can be calculated by [84]:

$$AST = LMT + EOT \pm 4^{\circ}/(LSMT - LOD) \tag{3.12}$$

LMT denotes the local Meridian time, while LOD indicates the longitudinal.

3.3. THEORETICAL MODEL

In the case of the tilted PV panel, the components of incident global solar radiation on a tilted surface are shown in Figure (3-3). The direct (GB, β), diffuse (GD, β) solar radiation, and reflected solar radiation (GR). The relation expresses these terms:

$$G_{T,\beta} = G_{B,\beta} + G_{D,\beta} + G_R \tag{3.13}$$

Equation (3-13) can be rewritten in terms of solar energy components on a horizontal surface as follows:

$$G_{T,\beta} = G_B R_B + G_D R_D + G_T \rho R_R \tag{3.14}$$

Where RB, RD, and RR are coefficients, and ρ is ground Aledo. RB is the ratio between global solar energy on a horizontal surface and global solar energy on a tilted surface. RD is the ratio between diffuse solar energy on a horizontal surface and diffuse solar energy on a tilted surface, and RR is the factor of reflected solar energy on a tilted surface.

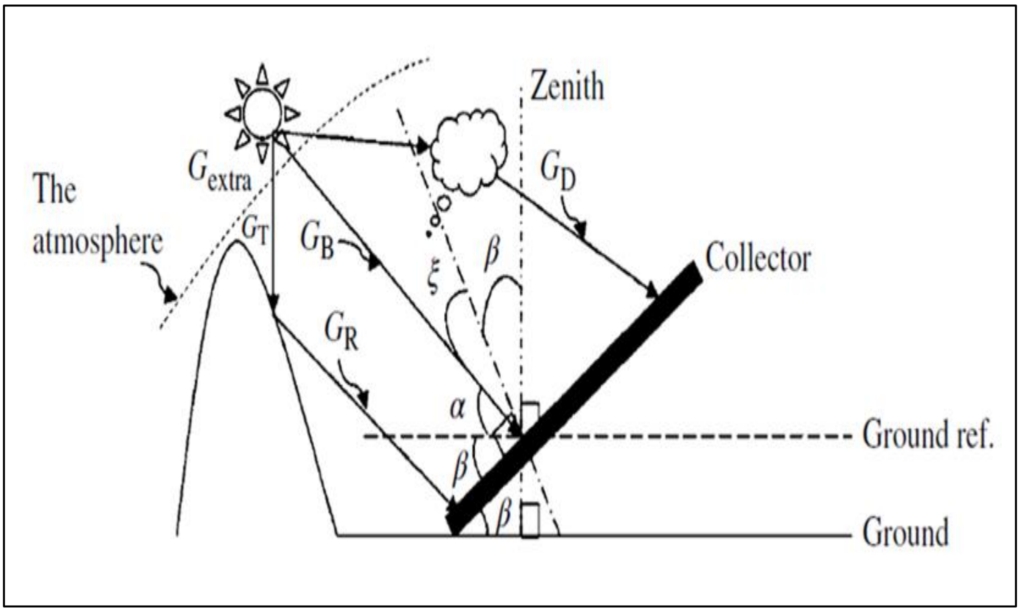


Figure 3.3. Solar radiation component on a tilted surface [88].

From Equation (3-14), it is clear that the key to finding solar energy components on a tilted surface is to estimate the coefficients RB, RD, and RR. The most often used model for calculating RB is the Liu and Jordan model [89], which defines RB as:

$$R_B = \frac{\cos(L-\beta)\cos\delta\sin\omega_{SS} + \omega_{SS}\sin(L-\beta)\sin\delta}{\cos L\cos\delta\sin\omega_{SS} + \omega_{SS}\sin L\sin\delta} \tag{3.15}$$

The most recommended equation for RR is given by:

$$R_R = \frac{1-\cos\beta}{2} \tag{3.16}$$

Isotropic solar models have based on the premise that the isotropic radiation has the same intensity regardless of the measurement direction and that the isotropic field exerts the same action regardless of how the test particle is oriented. One of the most used isotropic diffuse solar models is the Liu and Jordan model, with RD being formulated as follows:

$$R_D = \frac{1+\cos\beta}{2} \tag{3.17}$$

3.3.1. PV Cell Equivalent Circuit Model

The photovoltaic cell equivalent circuit model is illustrated in Figure 3.4. In general, the amount of incident solar power is directly proportionate to the photocurrent i_p, and this is primarily the source. All other parameters are sink dissipators. The terminal current i can be deduced from the equivalent circuit using Kirchhoff's current and voltage laws as described in Equation (3-18).

$$i = i_p - I_O\left(e^{\frac{v+iR_S}{nV_T}} - 1\right) - \frac{v+iR_S}{R_{sh}} \quad (3.18)$$

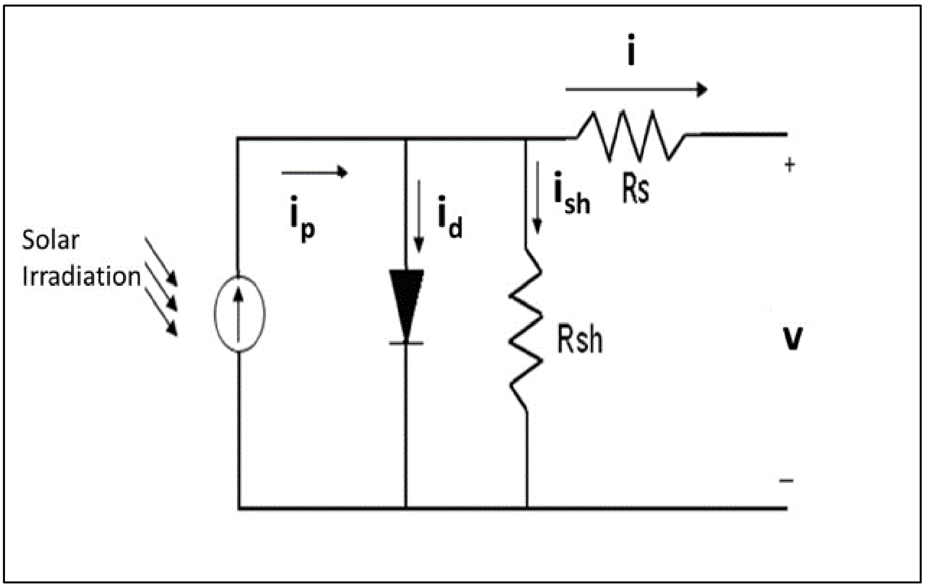


Figure 3.4. Ideal PV cell

Where i_d the diode current, ish is the shunt current, i is the terminal current, is the diode saturation current, v_T thermal voltage, n quality factor, R_{sh} shunt resistance and R_s series resistance.

Figure 3.5. Simulink model of a PV cell shows the MATLAB/Simulink model, where the inputs are the PV voltage V_pv, temperature T, and the solar irradiance G, while the outputs are the power P_pv and the PV current Ipv.

Table 3.1. Simulated in MATLAB. The circle indicates the maximum power point (MPP), where the PV gives its maximum power. The PV open-circuit voltage is V_{OC}, and the voltage as the current through the PV is zero and labelled the same as [86]. When the PV voltage is zero, the current is known as the short-circuit current (ISC).

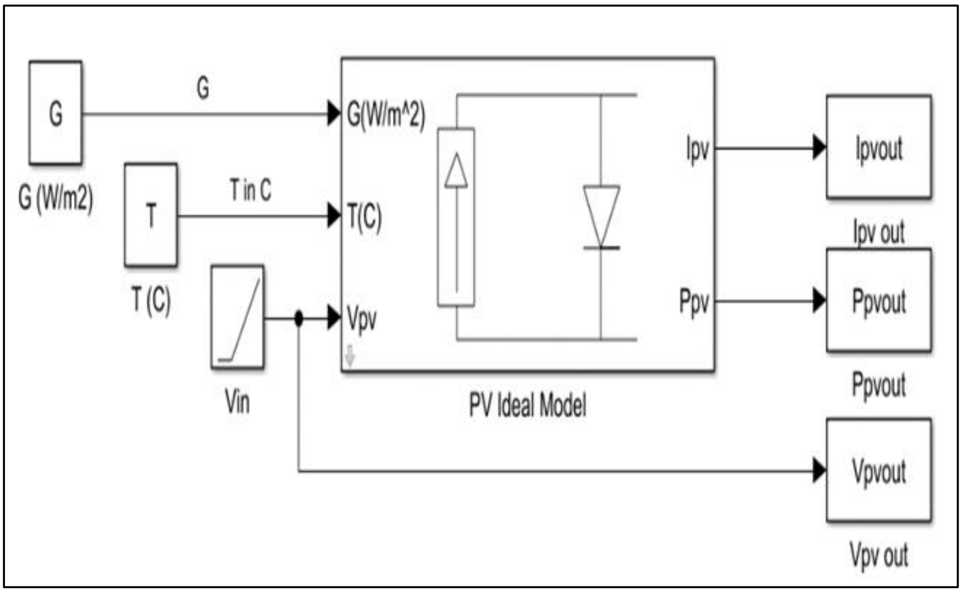


Figure 3.5. Simulink model of a PV cell.

Table 3.1. Properties of the PV panel used.

Rated Maximum Power at STC	450 Watt
Maximum Power Voltage (Vmp)	41.4 V
Maximum Power Current (I_{mp})	10.86 A
Open Circuit Voltage (V_{OC})	49.2V
Short Circuit Current (I_{SC})	11.58 A
No. of Cells	144 (18×9)

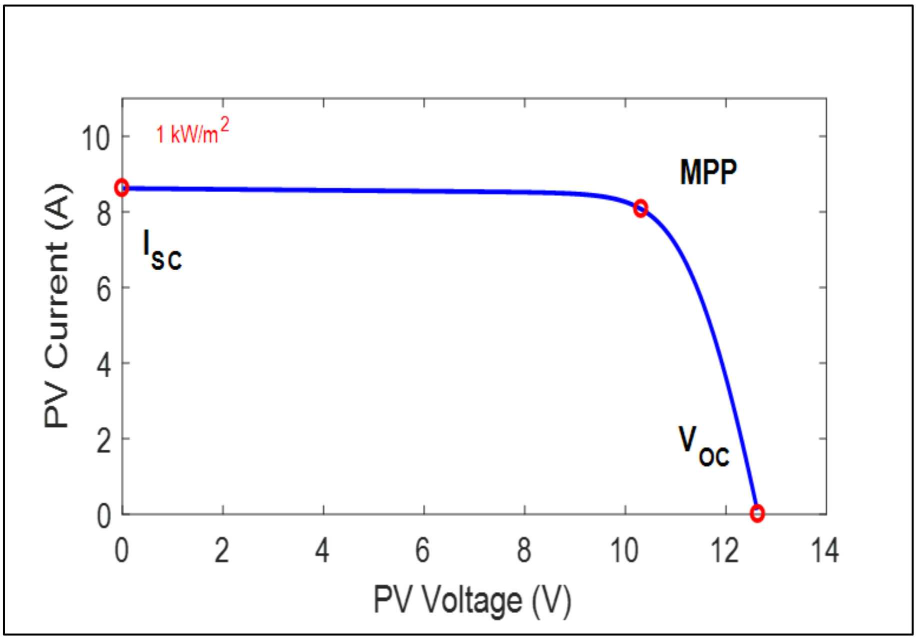


Figure 3.6. PV cell I–V curve (G = 1000 W/m² and T = 25 °C).

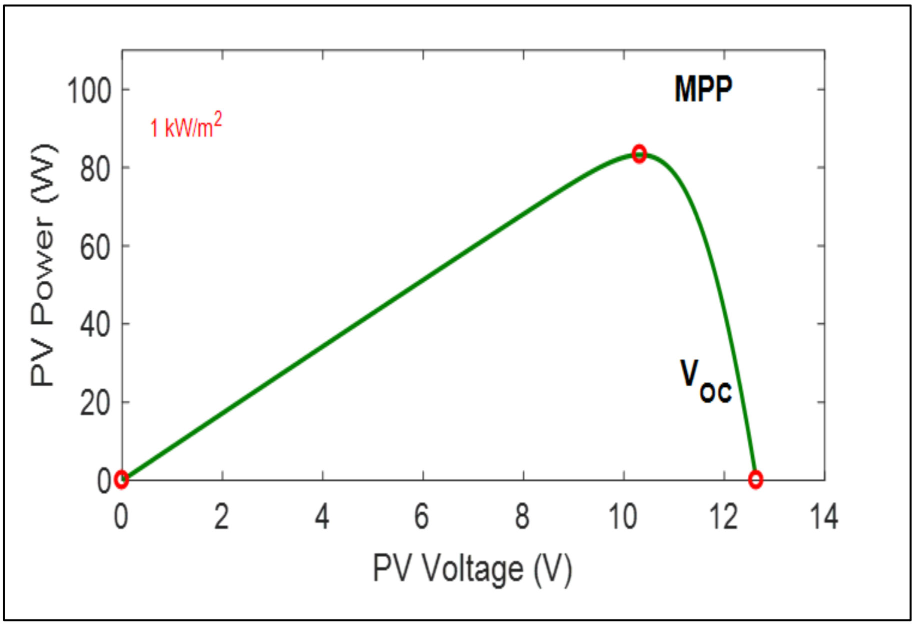
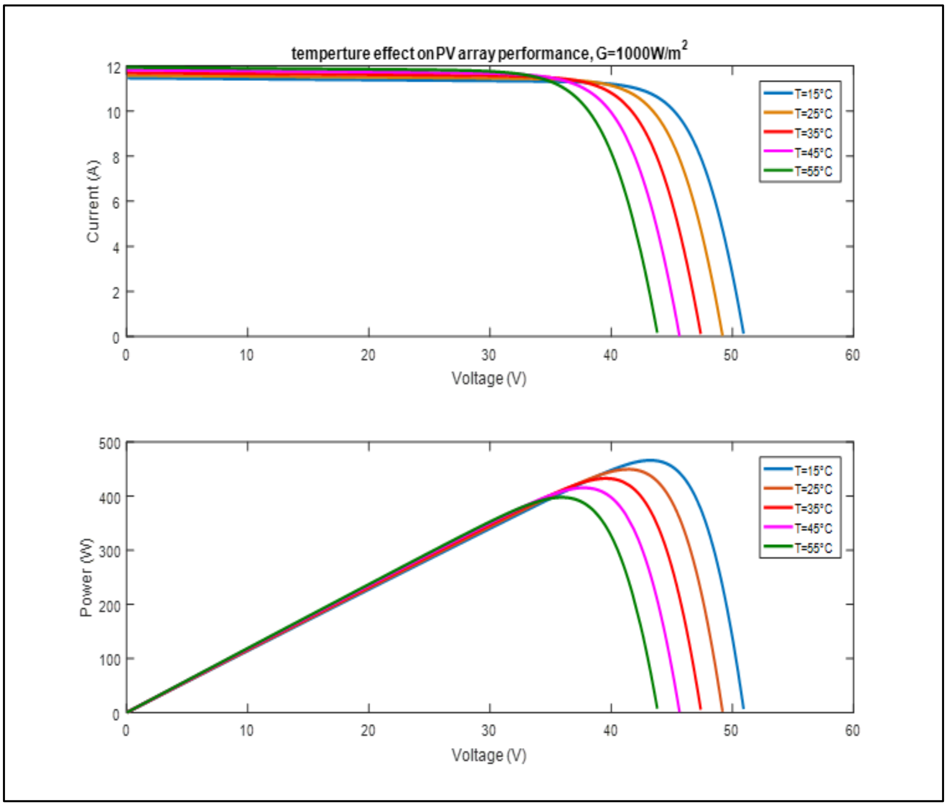


Figure 3.7. The PV cell's power-voltage graph with a fixed temperature and irradiance of T = 25 °C and G = 1000 W/m^2.

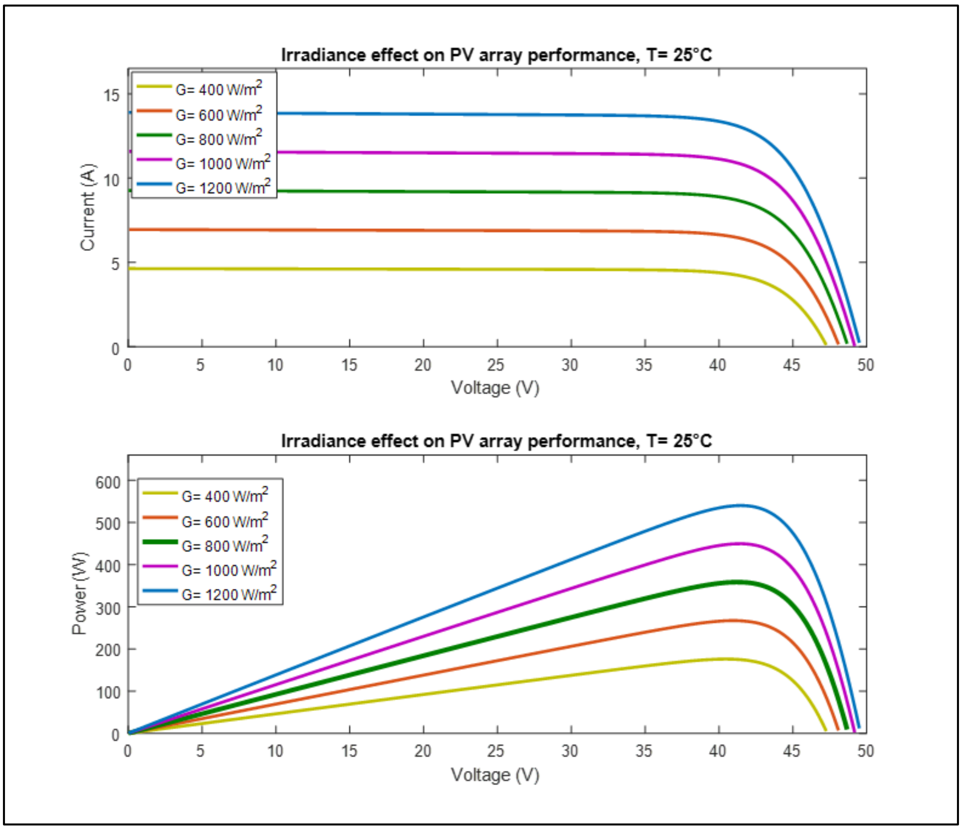
The power-voltage curve for a PV cell or panel may be determined from its associated I-V curve. Figure 3.6. shows the power-voltage curve for the I–V curve shown in Figure 3.7. with the circle indicating the curve's maximum point. The (I–V) and power–voltage curves are shown for specific irradiance and temperature conditions.

Temperature and radiation change throughout the day, sometimes slowly, sometimes rapidly, for example, when clouds move.

Figure 3.8. portrays multiple values of irradiance and multiple values of temperature. Twenty-five simulations have been done with multiple parameter changes. The standard behavior of the photovoltaic array was detected. As the irradiance increases (the amount of light), the power output increases, and as the temperature rises, the power output decreases. Therefore, this trade is something that must be taken into account. The more light that hits the PV panel will give more power, which means more current will be produced, which will heat the PV panel, so its performance will degrade. Undoubtedly, there is a balance that optimizes all these parameters, enabling maximum power generation for different levels of irradiance. It is also noticeable that the voltage at maximum power varies with different irradiances.



(A)



(B)

Figure 3.8. Effect of multiple parameters on the performance of the PV cell.

3.3.2. Calculation of The Theoretical Efficiency of The Solar Panel

The theoretical efficiency of any solar cell is calculated by knowing the theoretical values of the cell, which are (power, total cell area) as standard conditions (AM = 1.5, IS =1000W/m^2).

3.3.3. Numerical Simulation For The Dust Impact on The PV Panel

The PV panel properties in Table 3.2 are taken into account in all the numerical simulations.

Table 3.2. The theoretical efficiency of the solar panel used.

Power	450 watt
Solar radiation	1000 W/m^2
Width of one cell	0.09 m
Length of one cell	0.18m
Number of cells	144
Total area	2.33 m^2
Efficiency	20.5

Firstly, the fitting equation of the solar irradiation is required to be implemented in the Simulink model. It was taken on the day of 20 .3. 2022 as a sample. Two terms of the Fourier have been taken as a fitting equation:

$$I_r = a_0 + a_1 \cos \omega t + b_1 \sin \omega t + a_2 \cos 2\omega t + b_2 \sin 2\omega t \quad (3.19)$$

The following coefficients have been found:

$\boldsymbol{a_0}$	380.7
$\boldsymbol{a_1}$	135.5
$\boldsymbol{b_1}$	205.1
$\boldsymbol{a_2}$	-22.71
$\boldsymbol{b_2}$	-18.97
$\boldsymbol{\omega}$	0.5679

The correlation coefficient between the data and the analytical function is 0.9955. (3-19) Figure 3.9. Solar irradiance fitted with equation Shows the experimental data and the fitting curve.

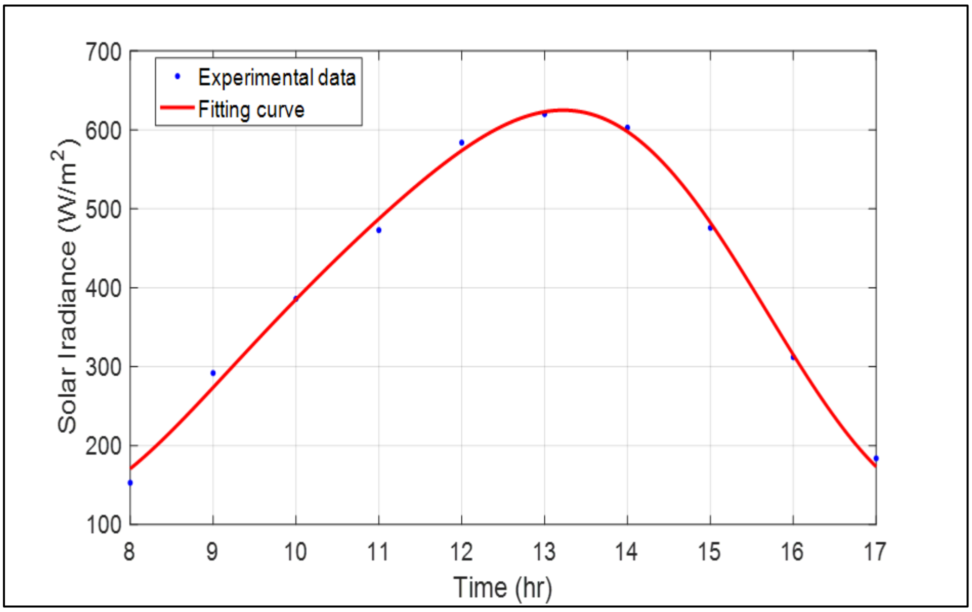


Figure 3.9. Solar irradiance fitted with equation (3-19).

Equation (3-19) used in the following Simulink model Figure 3.10. which calculates the effect of dust accumulation. The linear accumulation of dust over the PV panel was proposed.

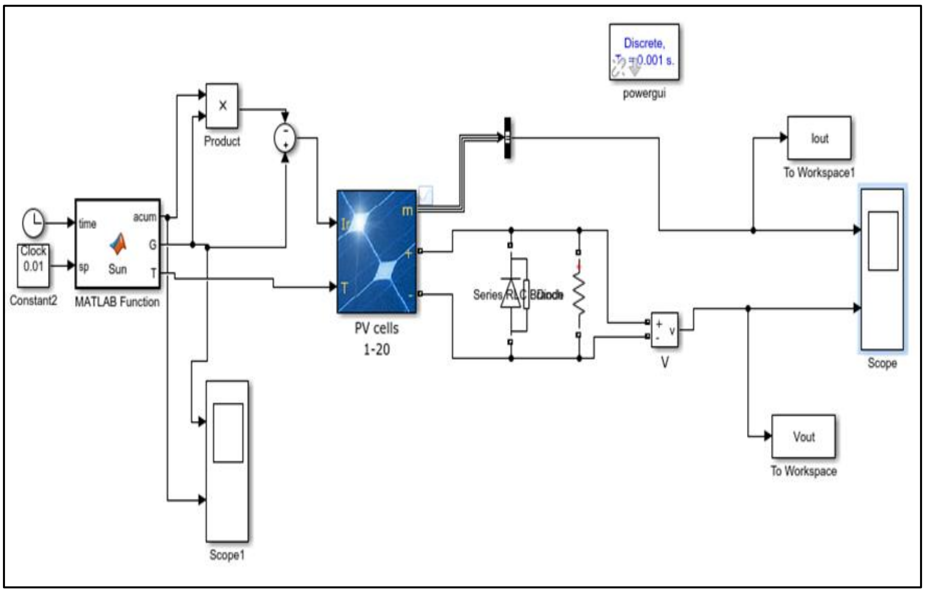


Figure 3.10. The Matlab Simulink model for analysis of different dust accumulation speeds on PV panels.

Figure 3.11. shows the voltage versus time curves for the dusty and the reference PV panel. For the accumulation speed of dust 0.01, When compared to the output voltage

of the PV panel used as a benchmark, it has been determined that the average voltage drop is roughly 14%. A decrease in total wattage capacity between the reference and dusty PV panels has been observed.

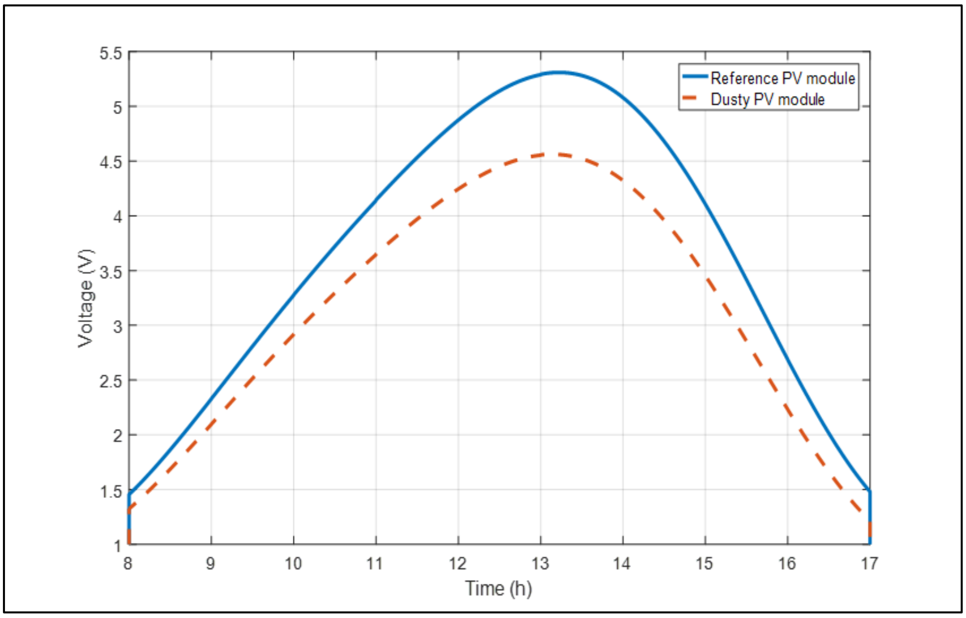


Figure 3.11. PV reference and dusty panel curves.

According to the results obtained from Figure 3.11. voltage and output power have decreased. When dust particles are deposited on the solar cell's surface, its output energy will decrease depending on the accumulated dust masses and their type.

The above experiments show that the cleaner the solar cell, the higher its performance efficiency. Conversely, the greater the amount of dust deposited on it, the lower its performance for it.

PART 4

EXPERIMENTAL METHODOLOGY

4.1. INTRODUCTION

In this chapter, the most important experiments used to examine solar cells were discussed, as well as the measurement devices used in these experiments to measure the solar cell's performance.

4.2. ESTIMATION OF SOLAR RADIATION OVER TIME

Solar radiation was measured in Erbil Governorate, located at 44.00 longitude and 36.20 latitude, using the measuring device (MS206) in units (watts/m^2). By installing it vertically to capture the sun's rays and taking hourly readings consecutively, the measurement begins precisely at eight in the morning and continues until five in the afternoon. On 15.3.2022, the weather will be moderate, but on 3/25/2022, the weather will be uneven as some clouds and intermittent periods in the morning affect the values of solar radiation.

The fall of solar radiation on the solar cell. On day 5 and 10.4.2022, an increase in the value of solar radiation is observed due to clear weather conditions without any clouds scattering the solar radiation. On 20.4.2022, there will be fluctuations in the value of solar radiation due to the presence of clouds and intermittent rainfall.

4.3. THEORETICAL CELL EFFICIENCY OF THE USED BOARD

In this study, a rectangular (Monocrystalline) solar panel was used, model LR5-72HBD-525M, where the dimensions of the panel were (2094 * 1038 mm) divided into small cells, the number of these cells was (144) cells, where the dimensions of one cell were (18 * 9 cm) and the area of one cell It is equal to (0.0162 m^2). As for the total area of the solar panel, it was equal to the product of multiplying the total number of cells by the area of one cell. It was found that it is equal to (2.332 m^2) as shown in Figure 4.1. and Table 4.1, which shows the solar panel's mechanical and electrical properties used, where the theoretical value of the output power from the solar panel (450 watts) was used under standard conditions (Is= 1000 w/m2, T= 25 ^oC, AM = 1.5)

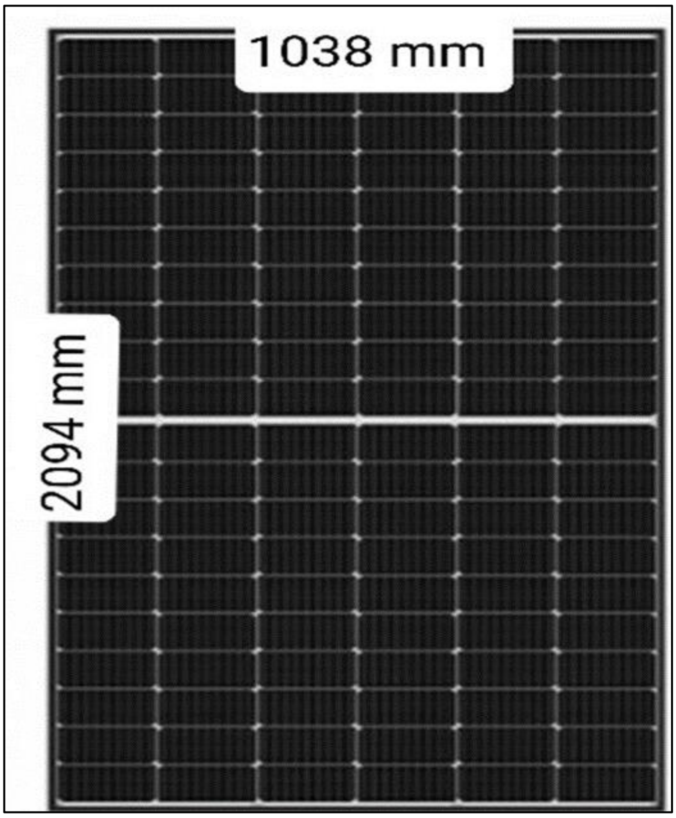


Figure 4.1. Shows the solar cell used.

Table 4.1. Properties of the solar cell used.

Rated Maximum Power at STC	450 watts
Maximum Power Voltage (Vmp)	41.4 V
Maximum Power Current (Imp)	10.86 A
Short Circuit Voltage (Vsc)	49.2 V
Short Circuit Current (Isc)	11.85 A
No. of Cell	144 (24x6)
Wight	23.5 Kg

4.4. MEASURING THE PERFORMANCE EFFICIENCY OF THE SOLAR CELL UNDER DIFFERENT CONDITIONS

The performance efficiency of the solar cell was tested in Erbil Governorate, located at 44.00 longitude and 36.20 latitude in different atmospheric conditions.

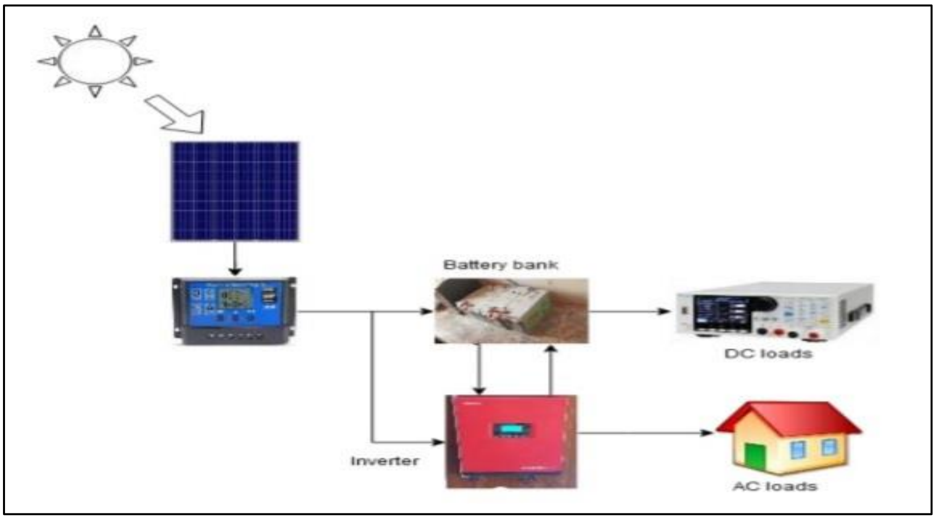


Figure 4.2 Solar system diagram

4.4.1. Measuring the solar cell efficiency when it is dusty

I. Measuring the efficiency of the solar cell when it is clean:
This experiment was conducted on 7.4.2022 when the weather was clear and on a clean solar cell. The solar radiation of the cell and the voltage and current were measured at a rate of reading every half hour from ten in the morning until one and a half in the afternoon. Figure 4.3. shows the solar cell when it is clean.

Figure 4.3. The clean solar cell surface.

II. Measuring the efficiency of the solar cell when the amount of dust is low:

Dust was deposited on the surface of the solar cell with a low density, as shown in Figure 4.4. on 17.4.2022, and then the outputs (current-voltage) were calculated with the calculation of the radiation.

The solar cell was at each reading, as readings were taken from ten in the morning until (13:30) in the afternoon, and then a determination was made of the solar panel's efficiency.

Figure 4.4. A small amount of dust deposits on the solar cell surface.

III. Calculating the efficiency of the solar cell when the amount of dust is high: Dust was deposited on the surface of the solar cell with a high density with the presence of sand, as shown in Figure 4.5. on 23.4.2022. Then the outputs (current-voltage) were calculated with the solar radiation calculated at each reading where readings were taken from the time ten in the morning until (13:30) in the afternoon, and then a determination was made of the solar cell's efficiency.

Figure 4.5. Large amount of dust deposits on the solar cell surface.

4.4.2. Calculating the solar cell efficiency under cloudy weather

The monocrystalline solar cell was tested in cloudy weather on 28.4.2022. The resulting current and voltage are also measured and recorded in the presence of the load, at a rate of half an hour for each reading, from 10:00 until 1:30, with the values of solar radiation recorded for each reading.

4.4.3. Calculating the solar cell Efficiency under rainy weather

The test on 1.5.2022 utilized the same solar panels, connection to the solar cell, and load. Its purpose was to study and calculate the performance efficiency under rainy weather conditions. The current and voltage were also recorded with and without load and solar radiation at a reading rate for every half hour, and the measurement starts from ten o'clock in the morning until one and a half o'clock in the afternoon.

4.4.4. Calculating the solar cell efficiency when it is immersed in water

The solar panel surface used was encompassed with water in clear weather on the date 7.5.2022, as shown in Figure 4.6. and then calculate the output of the solar cell was at a reading rate for every half hour, where the same connection method and the same load were used in previous experiments to calculate the outputs (voltage-current) with the measurement of solar radiation as well.

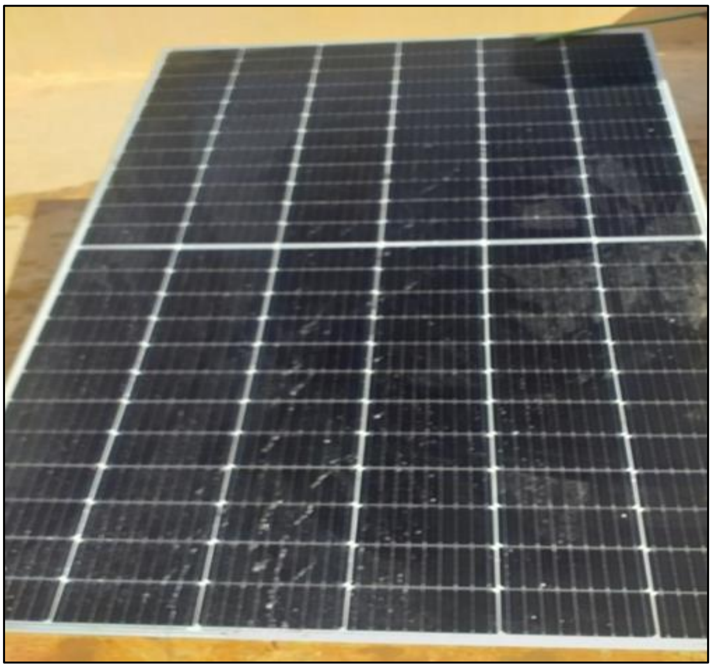


Figure 4.6. A water-immersed solar cell.

4.5. MEASURING DEVICES

4.5.1. Solar power meter

This research used a solar power meter to determine the solar radiation intensity dropping perpendicular to the solar cell. Where it is measured in units (w/m^2), the quality of the device is (SM206), the weight of the device is (325 g), and it has an accuracy of up from (±5 to ±10).

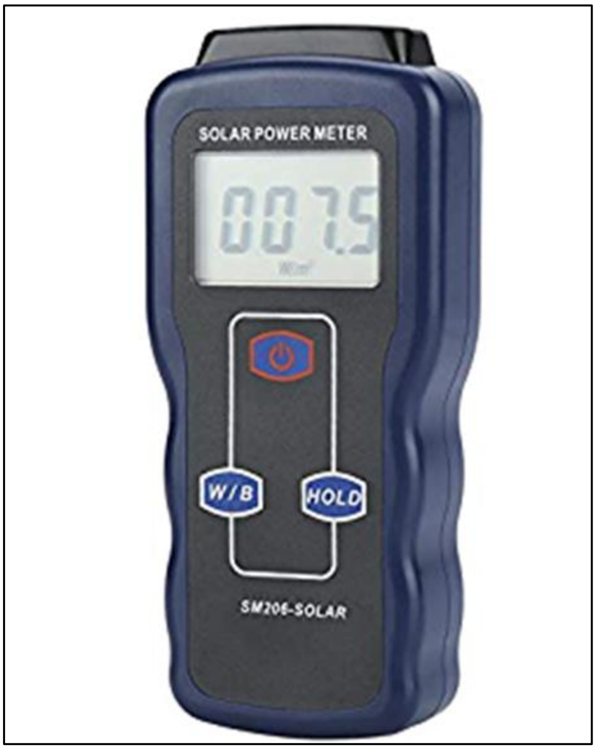


Figure 4.7. The solar radiation intensity device used Akozon.

4.5.2. Surface thermometer

A thermometer was used to measure the temperatures of surfaces and objects (UNI-T UT325). Moreover, its weight is (270 g), and the dimensions of the device are (175 x 85 x30) cm, with an accuracy of (± 0.2 – 0.6 %) and a measurement range of (-200 - 1370 ^{0}C), as this device contains ports used to measure heat after installing the cable on the surface whose temperature is to be measured.

Figure 4.8. The thermometer used.

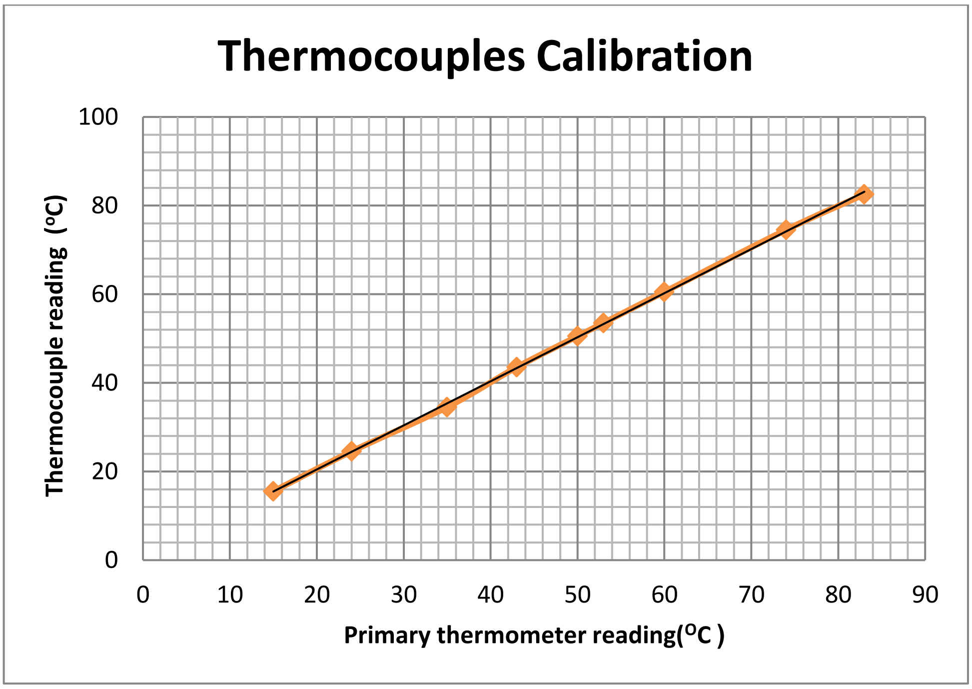


Figure 4.9. Thermocouple calibration curve

4.6. EXPERIMENTAL PROCEDURE

In this section, the steps that were followed in this study will be explained. The experience is divided into two main parts:

1) Dust was placed on the panel to conduct the experiment.

2) The panel is clean and free from dust and dirt.

In the first experiment, dust was placed on the panel, and then the radiation values were taken using a solar radiation intensity device. As for the temperature of the panel, a surface thermometer was used then the energy produced by the panel was measured and compared with the theoretical results. All results are shown in chapter 5.

In the second experiment, the panel was clean and free of dirt. Then using a solar radiation intensity device, radiation values were taken, and as for the panel temperature, a surface thermometer was used. The energy produced by the panel was then measured and compared with the computational results as well, as an increase in the efficiency of the solar panels was observed compared to the first experiment. Readings were taken for both experiments overtime periods, in addition to study the effect of water on those panels. As described in chapter 5 in detail.

Several cases of the panel have been discussed as follows:

1) Measuring performance efficiency when the solar cell is clean.
2) Performance efficiency when the amount of dust is low.
3) Performance efficiency when the dust density is high.
4) In cloudy weather, the solar cell is dry, the weather is cloudy, and the solar cell's surface is flooded with rain.

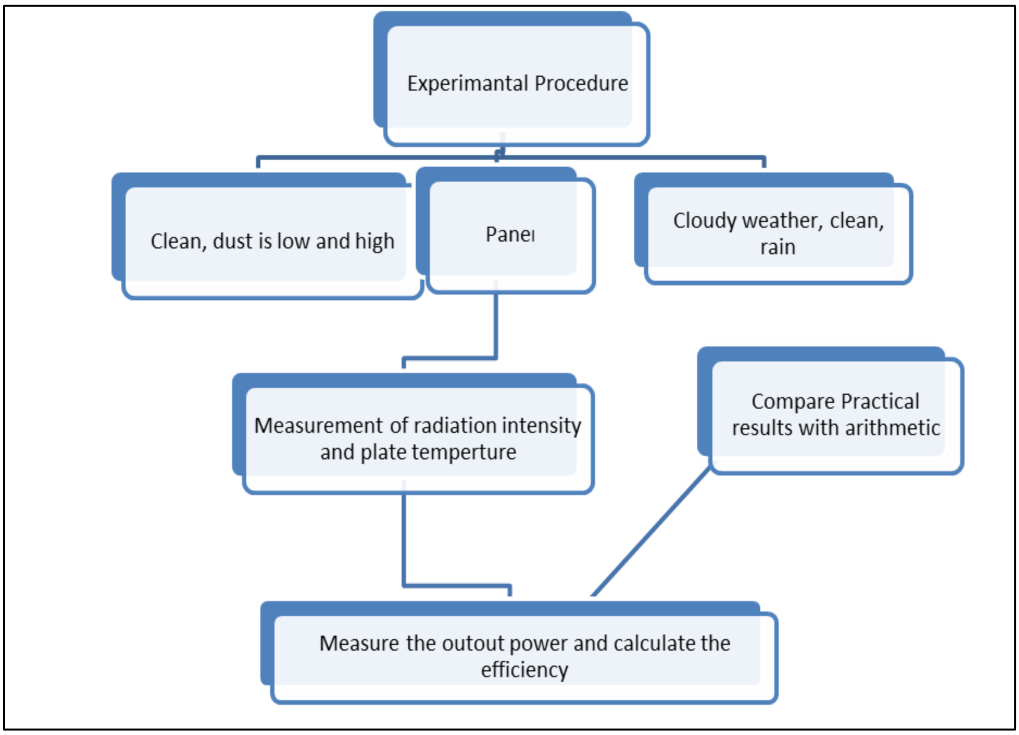


Figure 4.10. Scheme of Experimental Procedure.

PART 5

RESULTS AND DISCUSSION

5.1. INTRODUCTION

Several practical experiments were conducted to know the efficiency of solar panels in different conditions and to inspect the effect of these conditions on the performance and efficiency of solar panels. By measuring solar radiation with time and inset these values in a Matlab model, the solar panel output can be obtained for various dust amounts and the addition of water. Subsequently, the effect of these factors on the efficiency of the panels can be known.

5.2. THE RESULTS OF MEASURING SOLAR RADIATION WITH TIME

Table 5.1 and Figure 5.1 show the solar radiation values falling on a solar panel at different times. A solar radiation intensity meter (SM 206 SOLAR POWER METER) was used. The intensity of solar radiation was measured on 15.3.2022. The measurement began at eight in the morning, with the solar radiation amount recorded as 148 W/m^2. On 20.3.2022, at the same time, at eight in the morning, the solar radiation intensity was measured as 153 W/m^2. As the day progressed, the solar radiation continued to increase, reaching its peak around noon with an intensity of 543 W/m^2. However, on 20.3.2022, the maximum value of solar radiation is expected to occur around one o'clock in the afternoon, reaching approximately 620 W/m^2. Then it gradually decreases to reach the intensity of solar radiation to about (184 Watts / m^2) at five o'clock in the afternoon. On 20.3.2022, while the strength of the solar radiation reaches about (170 Watts/m^2) at five o'clock in the afternoon, the decrease in the value of the solar radiation continues. Until the intensity of solar radiation becomes zero at sunset for both. The reason for the difference in the value of solar radiation for both days is that the Earth is on an elliptical path, and because the angle of the sun with the Earth is constantly changing, the value of the incident solar radiation will vary daily with a different angle of the sun [90].

Table 5.1. Represents the values of solar radiation with time for the months (March – April).

Time (hour)	Solar radiation (w/m^2) in March					Solar radiation (w/m^2) in April		
	15 Mar	20 Mar	25 Mar	30 Mar	5 Apr	10 Apr	20 Apr	25 Apr
8:00 AM	148	153	214	142	270	314	150	330
9:00 AM	270	292	231	193	484	425	98	560
10:00 AM	336	386	175	321	658	536	460	780
11:00 AM	443	473	264	92	731	768	298	810
12:00 AM	543	584	598	219	743	776	397	850
13:00 AM	506	620	535	347	846	872	187	776
14:00 AM	491	603	486	532	642	556	236	634
15:00 AM	410	476	247	483	527	356	429	551
16:00 AM	290	312	201	294	411	380	157	470
17:00 AM	170	184	150	126	322	194	93	329

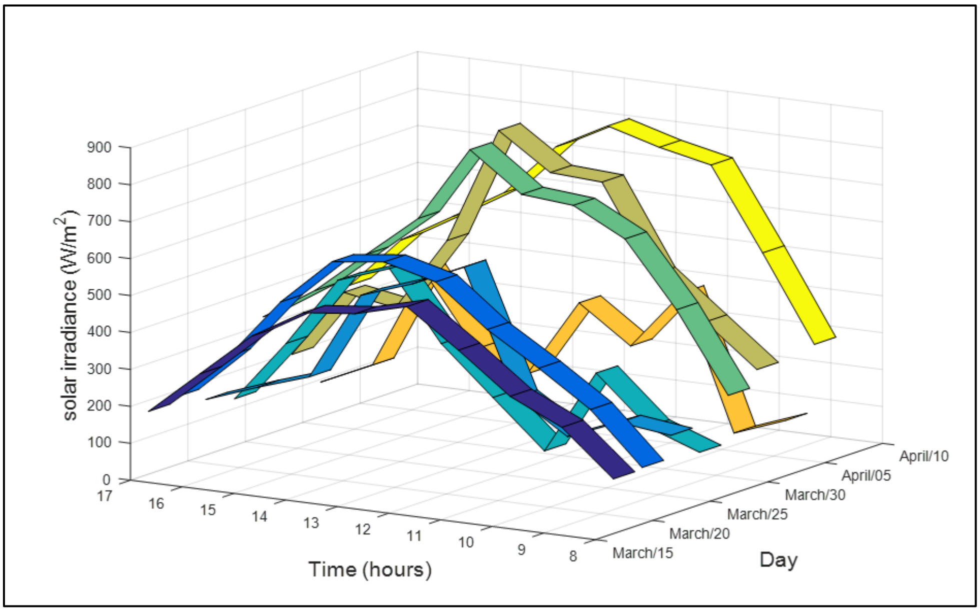


Figure 5.1. The change of solar radiation with time for the day (2022).

Figure 5.1. also shows the change in solar radiation with time for the days 15 and 25.4.2022. The figure shows that the solar radiation on 25.3.2022 exhibits slight

fluctuations, with noticeable rises and falls in its values. These data for the flat collector, also known as a flat-plate collector, is a solar panel that is flat and rectangular in shape. It is typically mounted on a roof or a wall and is designed to absorb sunlight directly. The flat collector is usually made of a dark-colored metal or plastic material that absorbs the sun's energy and converts it into heat. The heat is then transferred to a fluid, such as water or air, which is circulated through the collector and used to heat a building or provide hot water. This reason is the presence of some clouds that affect the intensity of solar radiation, where the highest value of the radiation reaches around one o'clock in the afternoon, and its value is within the limits of (598 w/m^2) and then decreases to zero at sunset. As for the day 30.3.2022, the highest value that the solar radiation reaches is around two o'clock in the afternoon, where its value is about (532 w/m^2) because the sun's rays fall vertically, and there are no clouds at that hour in order to scatter or reflect the solar radiation, as the presence of clouds leads to a decrease in the amount of incoming solar radiation [88].

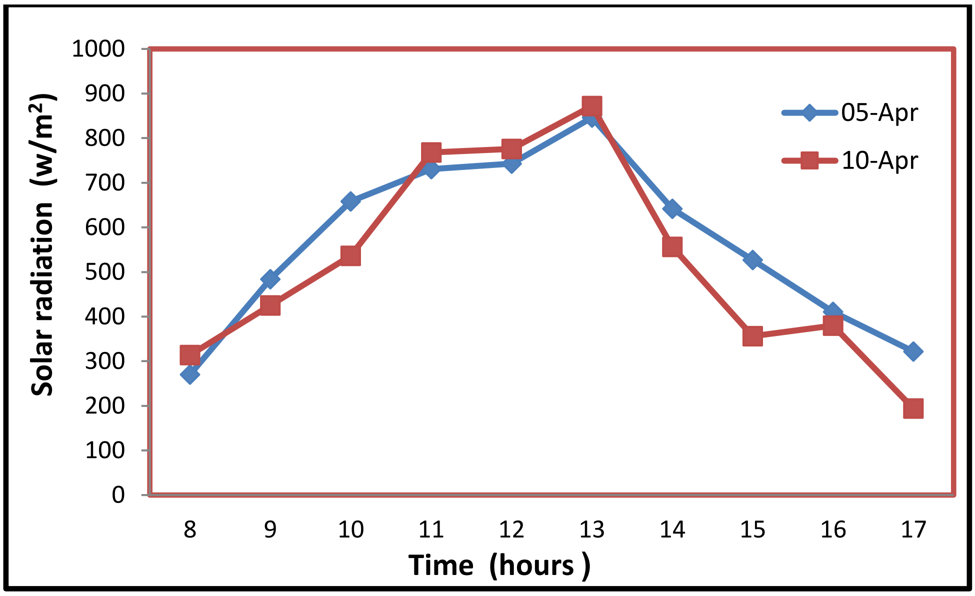


Figure 5.2. The solar radiation change with time for the day 5 and 10.4.2022.

Figure 5.2. shows that solar radiation varies in April and on different days from it. On 5.4.2022, solar radiation begins at about (270 W/m^2), but on 10.4.2022, solar radiation begins with an almost high amount, as it is about (314 w/m^2) at eight o'clock in the morning. The reason is that the weather on these two days is clear. Thus, the solar radiation will arrive directly without suffering any loss in its value, as it is where its

greatest value is about one o'clock in the afternoon and for the two days together, where its value is about (846 w/m^2) on the date of 5.4.2022. However, on the date of 10.4.2022, its value is about (872 w/m^2) and then begins to decline, as shown in the figure below, as the effect of clouds The absorption of solar radiation in the atmosphere depends on the angle of the solar peak and the height of the cloud [89].

On 20.4.2022, Figure 5.3. indicates the presence of clouds and rain, which impact solar radiation. Consequently, there is a fluctuation in the amount of solar radiation, characterized by increases and decreases. The clouds and rain obstruct a significant portion of solar radiation through scattering, absorption, and repeated reflections. This process attenuates the wavelengths of solar radiation as it passes through, eventually reaching zero at sunset.

However, on 25.4.2022, the weather was clear, so there was almost an increase in the amount of incoming solar radiation, as it begins with a high amount of about (330 w/m^2) at eight o'clock in the morning and begins to increase to reach its highest value of about (850 w/m^2) at Twelve o'clock and then start decreasing to become zero at sunset [91].

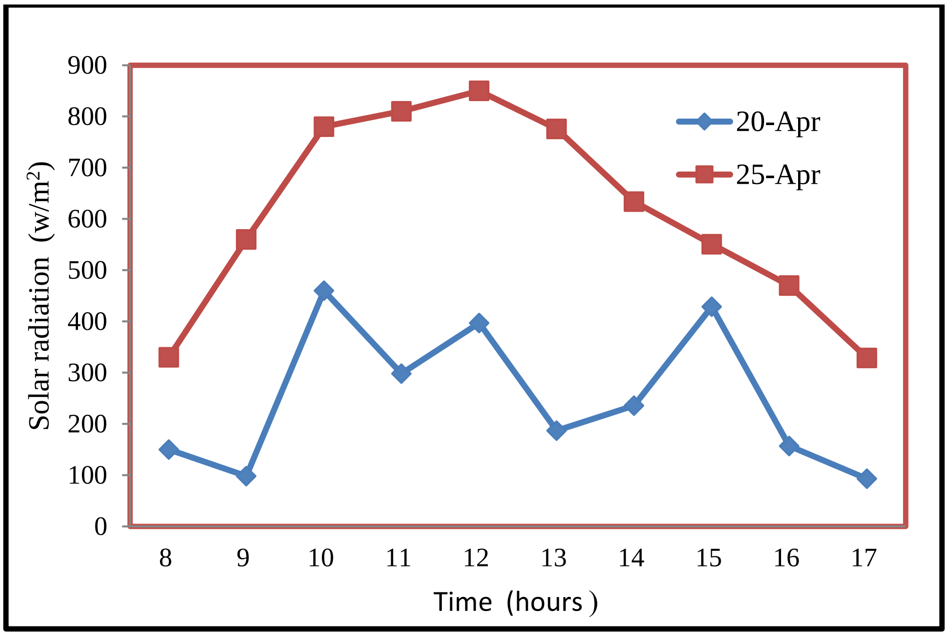


Figure 5.3. The solar radiation change with time for the day 20 and 25.4.2022.

The results in Figure 5.4. were obtained using the theoretical models and the experimental data from Erbil on the horizontal PV cell and clear sky. It was noticed that there is full agreement between the theoretical calculation of the solar irradiance on the tilted surface and the experimental data.

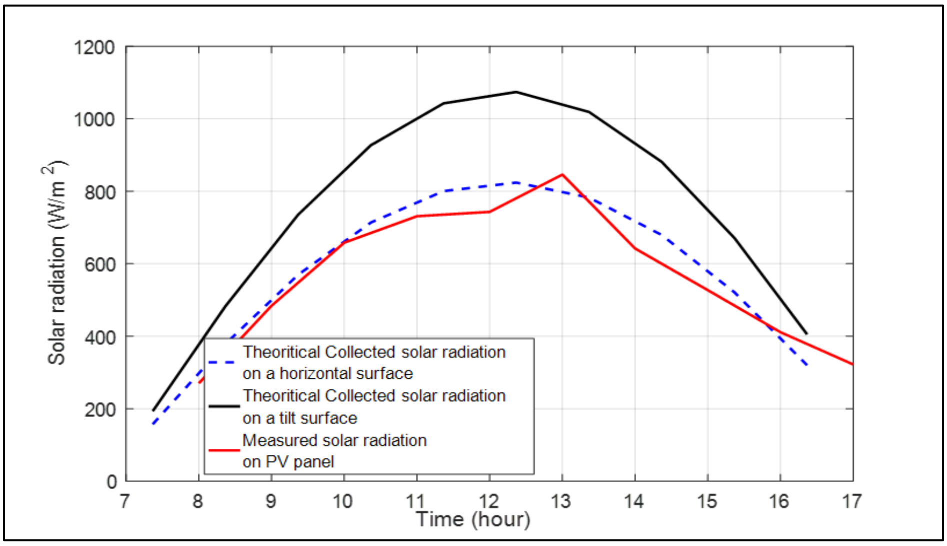


Figure 5.4. Estimation of solar irradiation using Liu and Jordan model.

5.2.1. The results of measuring performance efficiency when the solar cell is clean.

This test was conducted on 17.4.2022, and the output of the solar cell was measured when its surface was clean, and the weather was clear. The results were obtained as shown in the table below:

Table 5.2. The solar cell output when it is clean and the weather is clear.

Time (hr)	**$V_{with\ load}$ (Volt)**	**I (A)**	**P (Watt)**	**I_s (w/m^2)**	**A (m^2)**	**η**	**η%**
10:00	40.6	4.88	198.128	775	2.33	0.1097	10.97
10:30	40.9	4.93	201.637	786	2.33	0.1115	11.15
11:00	41.5	5.0	207.5	791	2.33	0.1125	11.25
11:30	40.7	4.91	199.43	810	2.33	0.1056	10.56
12:00	40.6	4.98	202.188	824	2.33	0.1053	10.53
12:30	40.9	5.0	204.5	828	2.33	0.1060	10.60
13:00	40.5	5.0	202.5	842	2.33	0.1032	10.32
13:30	40	4.9	196	853	2.33	0.0986	9.86

From Figure 5.5. it is noticeable that the performance efficiency and capacity of the solar panel maintain stable values, indicating minimal fluctuations in the curves. This stability is attributed to clear weather conditions, signifying the absence of external factors impacting the solar panel's efficiency and capacity.

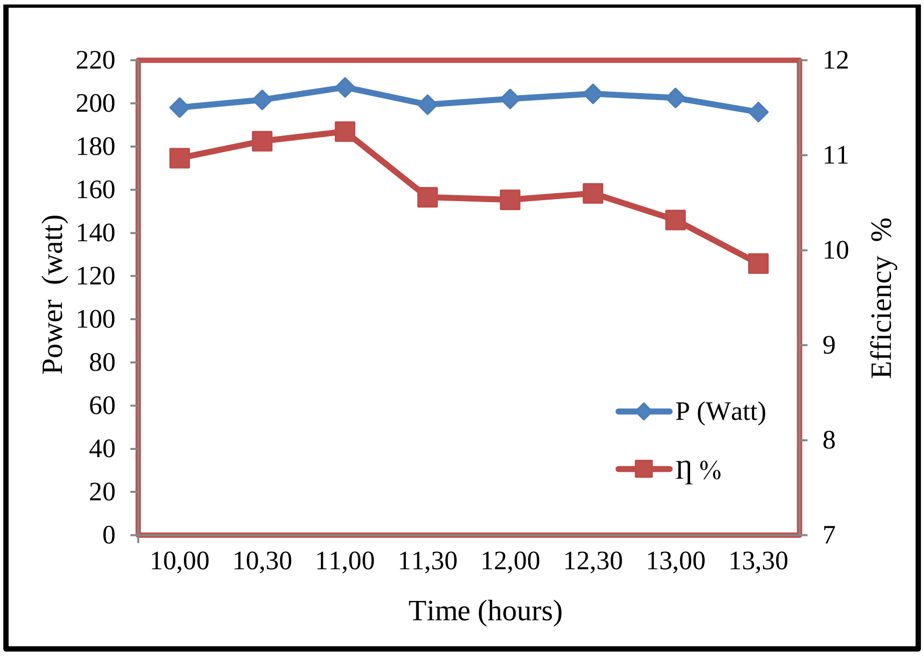


Figure 5.5. The relationship between efficiency and power when the solar cell is clean.

5.2.2. The results of performance efficiency when the amount of dust is low

This test was carried out on 21.4.2022 when the dust density on the solar cell's surface was low, and the weather was clear. The following results were obtained, as shown in Table 5.3.

Table 5.3. The solar cell output when the dust amount is low.

Time (hr)	$V_{with\ load}$ (Volt)	I (A)	P (Watt)	I_s (w/m²)	A (m²)	η	η%
10:00	37.5	4.78	197.25	795	2.33	0.0967	9.67
10:30	37.7	4.8	181.9	830	2.33	0.0940	9.40
11:00	36.7	4.7	172.85	825	2.33	0.0897	8.97
11:30	37.5	4.69	175.87	832	2.33	0.0907	9.07

12:00	37.4	4.62	172.788	815	2.33	0.0909	9.09
12:30	39	4.83	188.37	846	2.33	0.0955	9.55
13:00	38.5	4.64	178.64	835	2.33	0.0918	9.18
13:30	35.4	4.1	145	812	2.33	0.0766	7.66

According to the results obtained from Table, it has been observed that there is a reduction in the output power unit and voltage compared to the results obtained in Table 5.3. When dust particles are deposited on the surface of the solar cell, it will decrease its output energy depending on the accumulated dust masses and their type. Matlab /Simulink model was developed for the case that the dust density on the solar cell surface was low, and the weather was clear.

Figure 5.6 shows that the experimental and theoretical calculations of the solar cell efficiency exhibit a smaller decrease compared to when the cell is clean. Theoretical value refers to the expected or predicted value of a certain parameter or measurement based on a theoretical model or calculation. In the context of the figure you mentioned, the theoretical value of the cell efficiency with time when the amount of dust is low would be the expected efficiency of the cell based on a theoretical model or calculation, without any external factors affecting its performance. This value can be compared to the experimental value, which is the actual efficiency of the cell measured in a real-world setting, to evaluate the accuracy and effectiveness of the theoretical model or calculation. This decrease is attributed to dust particles' deposition and adherence to the solar cell's surface. Therefore, the permeability of the glass surface of the cell will also decrease, which will lead to a decrease in both efficiency and capacity, which is consistent with previous studies in this matter.

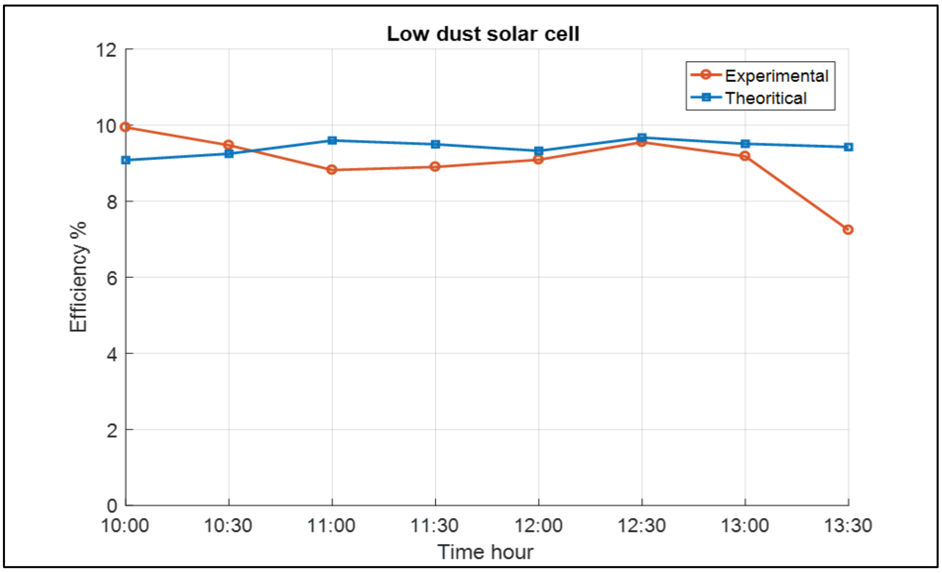


Figure 5.6. Experimental and theoretical of the cell efficiency with time when the amount of dust is low.

5.2.3. The results of performance efficiency when the dust density is high

This test was conducted on 23.4.2022 when the weather was clear, and the results were obtained, as shown in Table 5.4. The solar cell output when the dust amount is high.

Table 5.4. The solar cell output when the dust amount is high.

Time (hr)	$V_{with\ load}$ (Volt)	I (A)	P (Watt)	I_s (w/m^2)	A (m^2)	η	η%
10:00	34.3	2.5	85.75	786	2.33	0.0468	4.68
10:30	34.3	2.49	85.4	815	2.33	0.0449	4.49
11:00	34.5	2.52	86.94	829	2.33	0.0450	4.45
11:30	34	2.43	82.62	827	2.33	0.0428	4.28
12:00	34.2	2.48	84.816	834	2.33	0.0436	4.36
12:30	34.6	2.57	88.922	849	2.33	0.0449	4.49
13:00	34.4	2.49	85.656	842	2.33	0.0436	4.36
13:30	33.5	2.45	82.072	838	2.33	0.0420	4.20

Figure 5.7. shows that the experimental and theoretical efficiency has decreased dramatically, almost to describe their value when the solar cell is clean (i.e., the amount of dust is zero). The reason for this is that the dust density has increased. Thus, the

transmittance will decrease, leading to the blocking of part from solar radiation to the inside of the solar cell, where the greater the dust density, the lower the transmittance of the glass to the passage of sunlight, which was also mentioned in the previous studies.

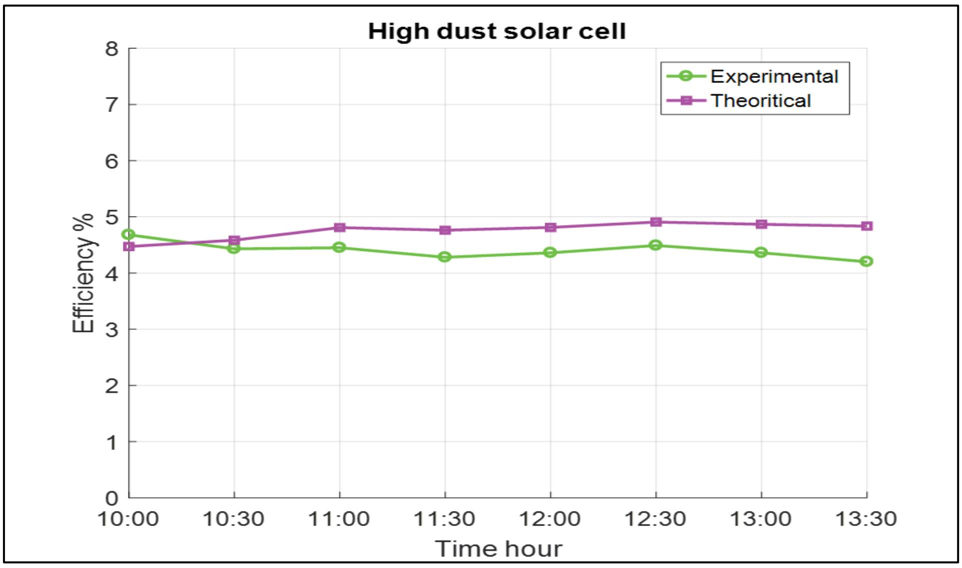


Figure 5.7. The change of experimental and theoretical cell efficiency with time when the amount of dust is high .

As a result of Figure 5.8. and Figure 5.9. if the amount of dust increases and covers the entire surface of the cell in a very high amount, then the efficiency of the cell does not exceed 1%, which is the lowest value, because the high amount of dust prevents the transmittance of radiation completely because the dust formed on the cell surface will scatter and reflect solar radiation.

Based on the above experiments, it is observed that the efficiency of the solar cell's performance increases as the cell becomes cleaner. Conversely, the greater the amount of dust deposited on it, the lower its performance for it.

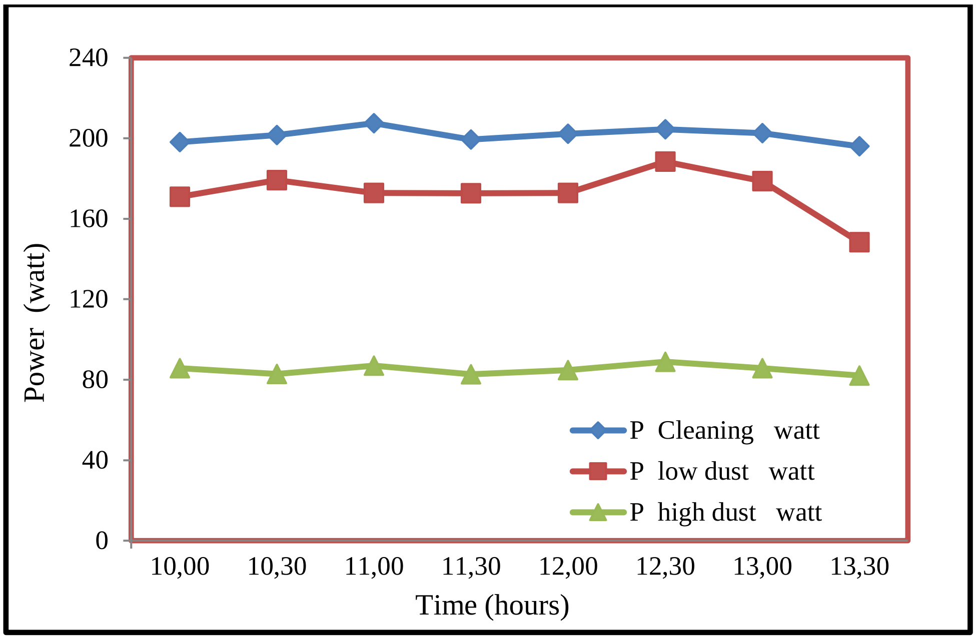


Figure 5.8. The capacity of the solar panel in different conditions.

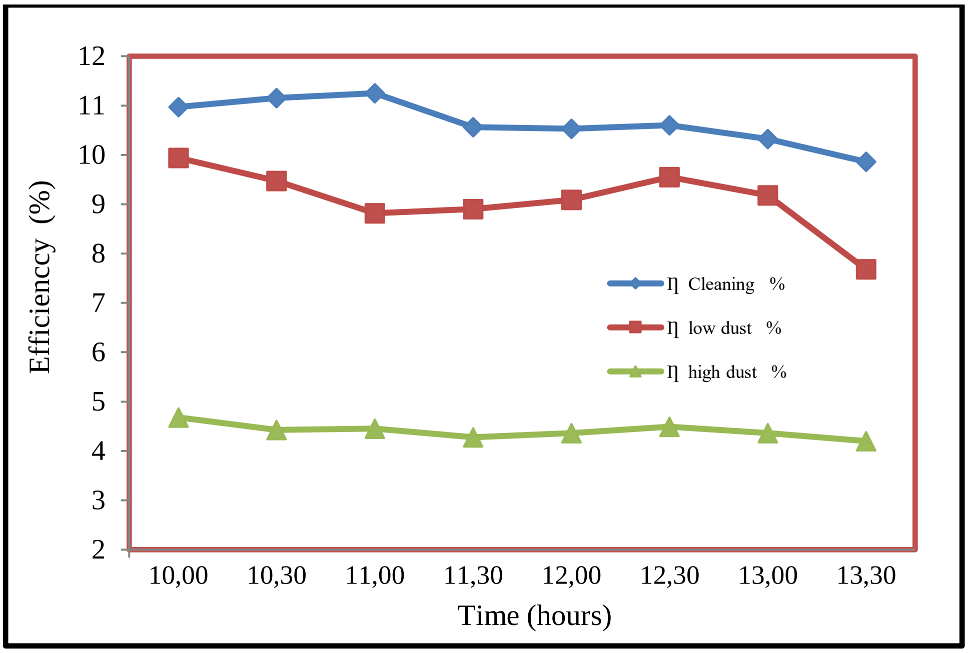


Figure 5.9. The efficiency of the solar panel in different conditions.

5.2.4. Cloudy weather

This test in this part is divided into two parts as follows:

5.2.4.1. The surface of the solar cell is dry

This experiment was conducted on 28.4.2022, where the readings were taken for each solar radiation and voltage in the presence of the load and the current at an average of half an hour for each reading. The results were obtained as shown in Table 5.5 below.

Table 5.5. The solar cell's output when its surface is dry and the weather is cloudy.

Time (hr)	$V_{with\ load}$ (Volt)	I (A)	P (Watt)	I_s (w/m^2)	A (m^2)	η	η%
10:00	15.9	2.37	37.68	272.2	2.33	0.0594	5.94
10:30	14.1	3.03	28.62	237	2.33	0.0518	5.18
11:00	14.3	2.1	30.03	243	2.33	0.0529	5.29
11:30	18.5	2.82	53.17	328	2.33	0.0682	6.82
12:00	12.4	1.5	18.6	189	2.33	0.0422	4.22
12:30	14.3	2.17	31.03	254	2.33	0.0524	5.24
13:00	24.8	3.67	91.96	397	2.33	0.0982	9.82
13:30	15.6	2.25	35.1	266.8	2.33	0.0560	5.6

5.2.4.2. The weather is cloudy, and the surface of solar cell is flooded with rain

This experiment was conducted on 1.5.2022, where the readings of both solar radiation and voltage were taken with and without load and current at a rate of half an hour for each reading. The results were obtained as shown in Table 5.6.

Table 5.6. The solar cell's output when flooded with rainwater and the weather is cloudy.

Time (hr)	$V_{with\ load}$ (Volt)	I (A)	P (Watt)	I_s (w/m^2)	A (m^2)	η	η %
10:00	13.6	1.59	21.62	227.6	2.33	0.0407	4.07
10:30	13.8	1.92	26.49	233.4	2.33	0.0487	4.87
11:00	13.93	1.86	25.90	231	2.33	0.0465	4.81
11:30	15.45	2.03	31.36	295.8	2.33	0.0455	4.55
12:00	17.3	2.18	37.71	306	2.33	0.0528	8.28
12:30	20.4	2.86	58.34	311.7	2.33	0.0803	8.03

13:00	19.94	2.59	51.64	309	2.33	0.0717	7.17
13:30	13.5	1.33	17.95	197	2.33	0.0391	3.91

In Figure 5.10. the highest values for efficiency and capacity are observed when the surface of the panels is immersed in rainwater, with an efficiency of 5.26% and a capacity of 27.89 watts. Conversely, the lowest values are recorded as 3.88% efficiency and 27.46 watts capacity.

Based on the above, the highest efficiency of the solar panel in cloudy weather is achieved when its surface is dry. This dry surface exhibits greater efficiency compared to the maximum efficiency value of the same cell when its surface is flooded with rainwater. This is because rainwater is impure because it contains impurities or atmospheric plankton, which causes them to be deposited on the cell's surface and thus will lead to blocking a large part of the solar rays. In terms of the lowest efficiency value, it is likewise observed in the case of the dry solar panel. The reason for this is the difference in the density of the clouds present, as it is greater for a solar cell with a dry surface than a cell with a dry surface. The surface is flooded with water, so the decrease in solar radiation will be greater as the intensity increases. It will block most of the solar radiation without reaching the solar cell.

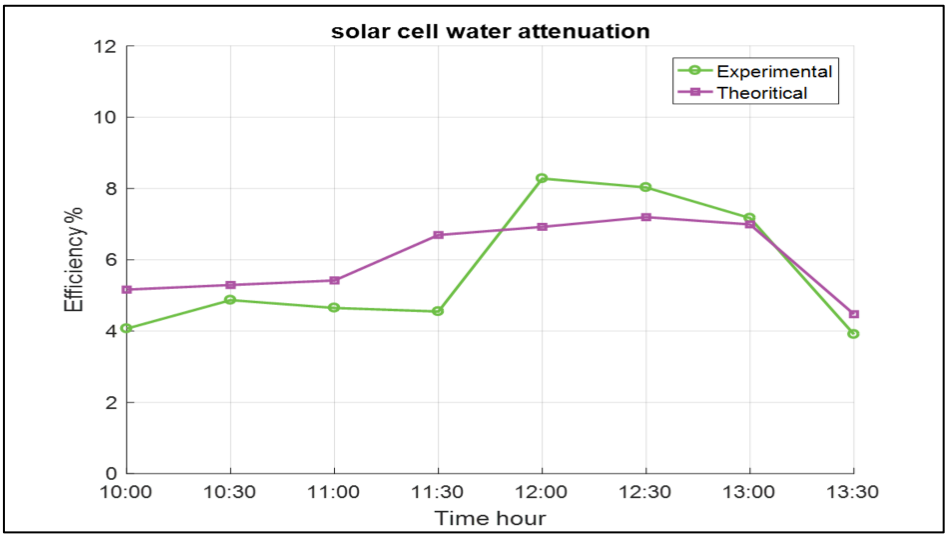


Figure 5.10. The experimental and theoretical change of cell efficiency with time due to rainy and cloudy weather.

5.2.5. Results of the effect of water on the surface of the solar cell

In this test, the solar cell was covered with water, where the same work was used by taking readings of solar radiation and voltage in the presence of the load and the current, and the following results were obtained, as shown in Table below.

Table 5.7. The solar cell's output as its surface is covered with water.

Time (hr)	$V_{with\ load}$ (Volt)	I (A)	P (Watt)	I_s (w/m^2)	A (m^2)	η	η%
10:00	34.8	3.1	107.88	769	2.33	0.0620	6.20
10:30	34.5	3.4	117.30	781	2.33	0.0644	6.44
11:00	34.3	3.7	126.91	803	2.33	0.0678	6.78
11:30	34	3.9	132.6	815	2.33	0.0698	6.98
12:00	34.9	3.8	128.82	817	2.33	0.0676	6.76
12:30	34.7	4.0	138.8	836	2.33	0.0712	7.12
13:00	34.2	3.9	133.38	842	2.33	0.0679	6.79
13:30	34.3	4.09	140.287	851	2.33	0.0707	7.07

When covering the surface of the solar panel with water. Figure 5.11. and Table 5.7. reveal an increase in voltage compared to the clean surface of the cell. However, the absence of water and the current will decrease significantly due to the reduction in the movement of charges, decreasing their kinetic energy. Consequently, the number of electric charges, upon which the current outside the solar cell depends, also decreases. This charge decrease is the reason behind the decline in the output power. Thus, the performance efficiency of the solar cell will decrease, what it would be if it were clean because solar radiation is electromagnetic rays, so it travels at the speed of light, as its speed in the air will differ in the circles of water. The one that covers the solar cell's surface has a coefficient of (1.33). The refractive index of the front glass of the solar cell surface is (1.5) and because of the refraction and reflection processes that are induced during its passage from air to water and then to glass, according to Snell's law thus, the actual solar radiation will decrease As a result of its low speed and because the kinetic energy of solar radiation photons depends on the frequency of solar radiation photons. [92]. Therefore the performance efficiency of the solar panel will decrease whenever the water density on the solar cell's surface is higher.

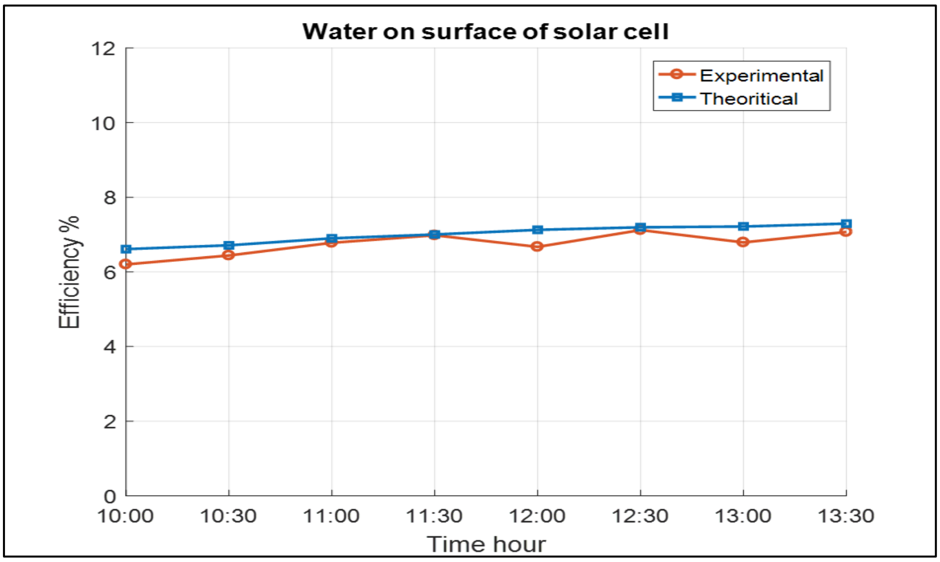


Figure 5.11. The experimental and theoretical change of cell efficiency with time due to water on the PV panel.

5.2.6. Partial shading effects

Stormy weather and moving clouds can cause partial shading caused by nearby tall structures and climatic conditions. It was revealed that unshaded modules generate more power than shaded modules [31]. Cascade connections within a module result in the same current flowing between different modules. Due to this, shaded cells can carry more power than they are rated for in a short circuit. The shaded cells form an opposite polarity voltage as a result. Therefore, the voltage of the system is overall reduced. Adding these cells reduces the power loss and acts as if the system has a new load. As a result of cascaded connections between cells, the current in cascaded connections cannot exceed the current through the shaded cell; since the loss of power in shaded cells will affect neighboring cells negatively. Complete PV arrays fail when shaded cells lose power, resulting in the formation of hotspots.

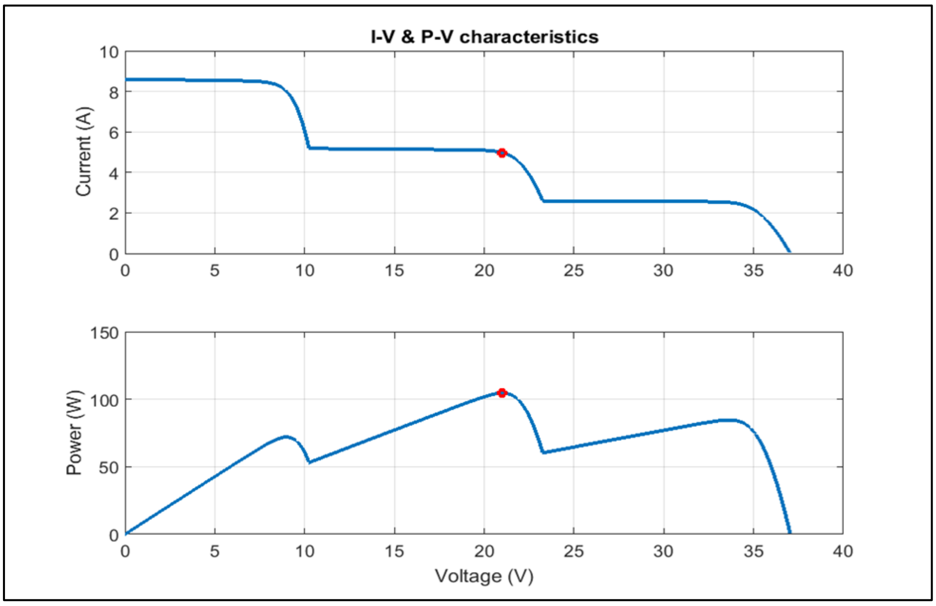


Figure 5.12. PV and VI curves due to partial shading.

Figure 5.12. shows the cascaded solar panel's PV and VI curves, a significant variation in voltage and power resulting from shading or variable sun radiation is evident.

By discussing the above, it is noted that there is a direct relationship between the cleanliness of the panel and the efficiency, as mentioned when there is a small or large amount of dust, which leads to poor yield because the dust absorbs most of the solar radiation coming to the board, in addition to the high temperature in Dust particles, which will negatively affect the temperature of the panel and waste the amount of valuable energy. Likewise, when the weather is cloudy, the incoming speed will be lower, as shown above, which leads to losses in efficiency and waste in economic returns.

Through the study of Jawed [68] offered equations using Parameters (Isc, Voc, η, FF) that are a function of temperature and Voc decreases with the increases in the temperature, the maximum volatilization of organic compounds 663.9 mV at 20 °C and its lowest value. The value is 545.2mV at 80˚C, while the ISC increases slightly with the increase in temperature. The minimum Isc is 37.49mA at 20˚C, and the maximum Isc is 37.56mA at 80˚C. The final efficiency disappears with increasing temperature, and the maximum efficiency at 20 °C is 18.34%, while the minimum efficiency at 80 °C is 13.71%.

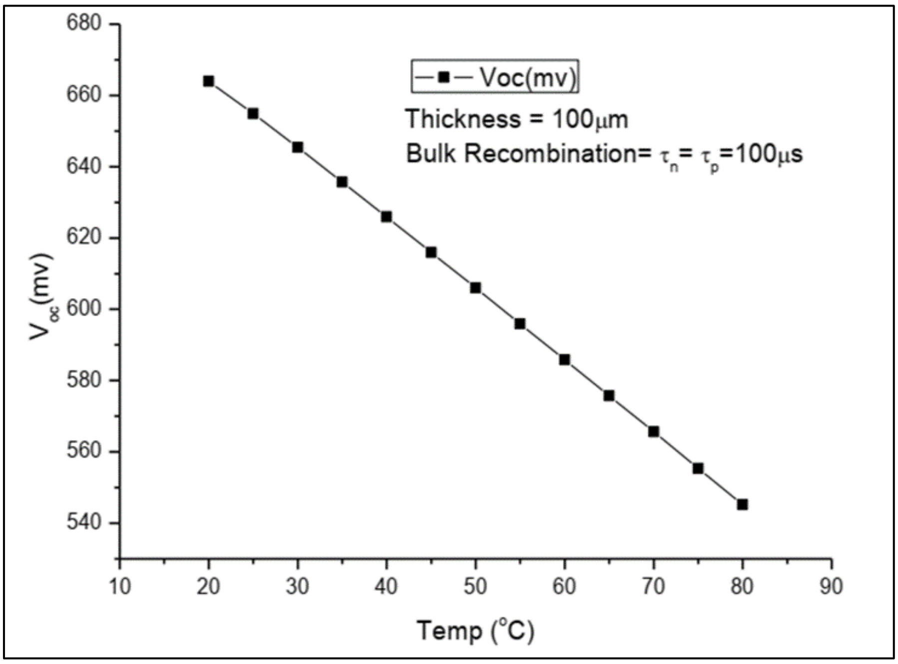


Figure 5.13. Variation of VOC with Temperature [68].

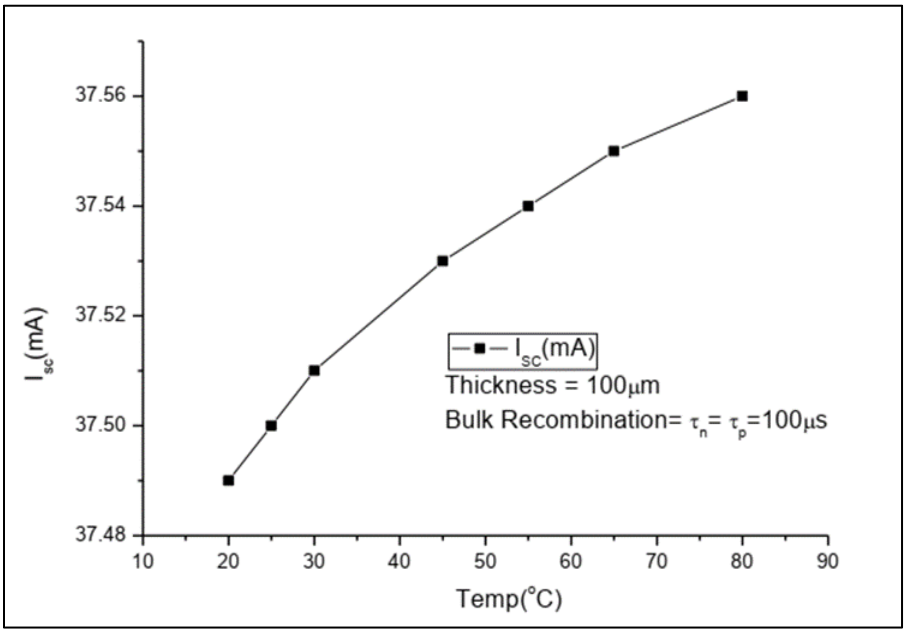


Figure 5.14. Variation of ISC with Temperature [68].

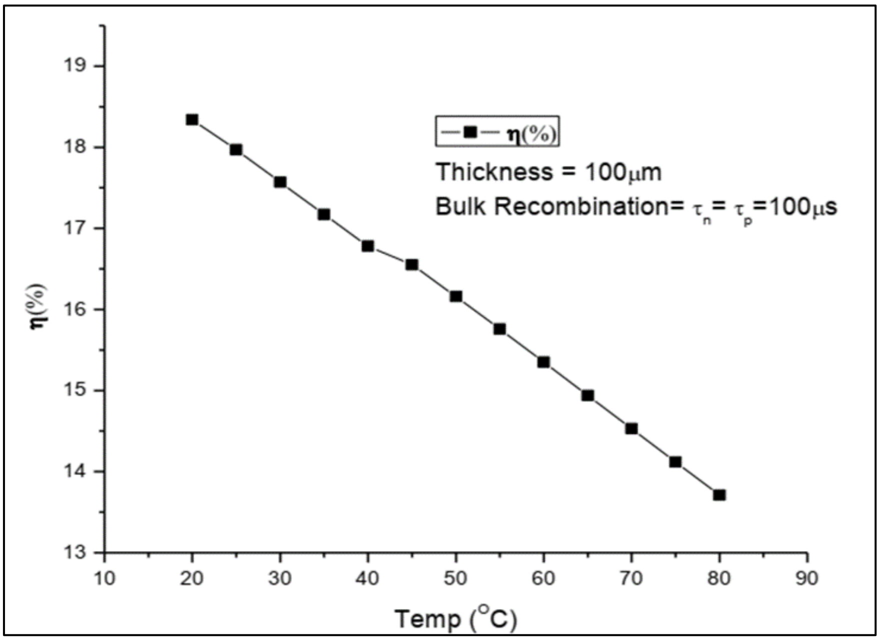


Figure 5.15. Variation of efficiency with Temperature [68].

While Suleiman et al. [69] studied the effect of gathering dust, dirt, sand and water algae on photovoltaic solar panels, as these factors play a major role in the loss of photovoltaic energy and prevent it from reaching the solar cells. These experiments were carried out on two plates, one clean and the other with dirt, sand, and algae for light irradiation of 310 W/m^2 under controlled conditions. The output energy from solar panels was between 9% and 31% due to the presence of traces of talc powder, between 60% and 70% due to dust, between 70% and 80% due to sand, and between 77% and 83% due to algae, The study also found that rain does not significantly affect the performance of solar panels.

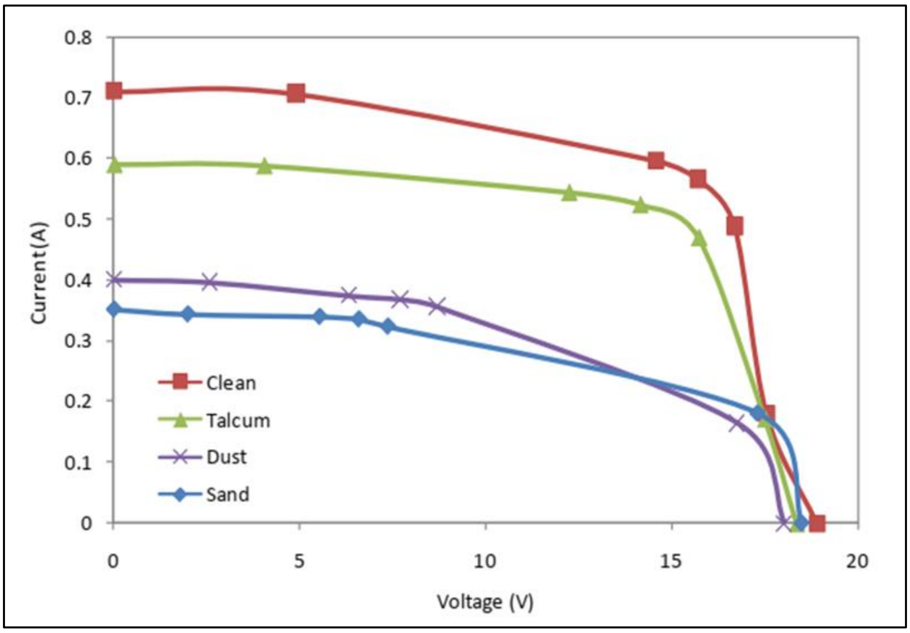


Figure 5.16. I-V characteristic at radiation intensity of 310 W/m² [69].

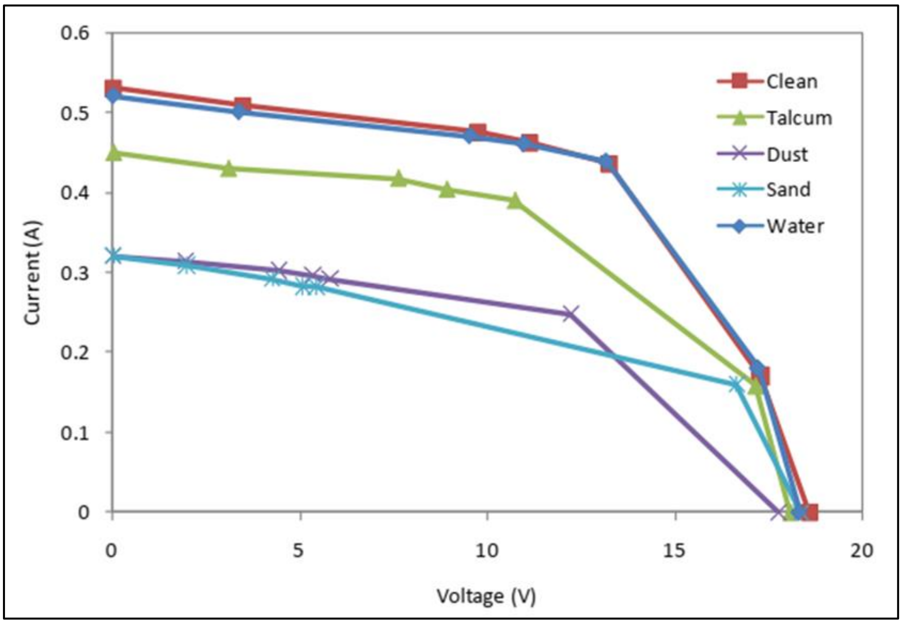


Figure 5.17. I-V characteristic at radiation intensity of 250 W/m² [69].

Some of the studies mentioned also confirm the results and conclusions reached by this study, as they all prove the effect of dust and dirt on the efficiency of the panels and the effect of temperature. As this study agrees with that of Suleiman et al. [68], where the study proved that water and rain do not significantly affect the performance of solar panels, and this corresponds to the figures 5.10. & 5.11.

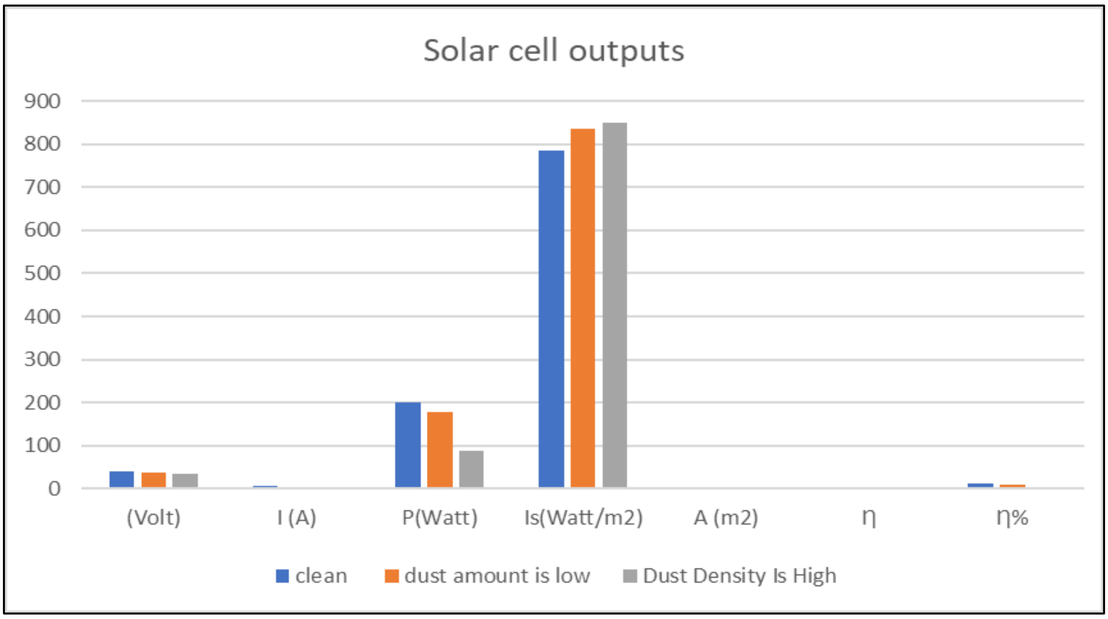


Figure 5.18. comparison between solar sell outputs during different situations and times Represented by the maximum output for each medium.

The given tables show the solar cell output under different conditions. Table 5.2 shows the output when the solar cell is clean and the weather is clear, while Table 5.3 and Table 5.4 show the output when the dust amount is low and high, respectively. Previous studies have shown that the accumulation of dust on the surface of solar panels can reduce their efficiency by up to 30%. The effect of dust on solar panel efficiency varies geographically and depends on the seasonal basis as well. A comparative study of seven different dust samples at three radiation levels of 650, 750, and 850 W/m^2 with different weights has been carried out, and the results are summarized in Tables 3 and 4. The study found that the accumulation of dust particles on solar PV systems blocks the sunlight and hence reduces its power to a large extent. An experimental study has been conducted to study the effect of dust accumulation on the performance of a solar PV panel using two different artificial dust particles. The study found that the performance of the solar panel decreased with the increase in dust accumulation [88].

PART 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

1. Based on this study of solar radiation, the conclusion is drawn that Iraqi Kurdistan and the Erbil region receive adequate solar radiation, making them suitable for establishing solar power plants.
2. Solar panels' efficiency decreases due to dust accumulation on their surface and according to the density of dust. The greater the amount of accumulated dust, the lower the efficiency.
3. Through this study, it was found that the efficiency of solar panels is affected by incoming solar radiation from sunrise to sunset.
4. The efficiency of solar panels is affected by the fall of rain, as it is noticed that it decreases in the presence of rain, and this depends on the intensity of the falling rain and the accompanying atmospheric plankton.
5. The continuous cleaning process of solar panels plays a significant role in improving the system's performance stability.

6.2. RECOMMENDATIONS

1- The study of an integrated solar organization consisting of many solar panels.

2- Working on studying solar panels for a whole year.

3- Working on adding sensors to the system that sense the dust and cleaning the panels themselves.

4- Designing an intelligent system and linking it with the computer.

5- Work to install a water recycling system and a link to the panels to work on cooling it in the summer.

REFERENCES

1. Maka, A. O. M., Salem, S., and Mehmood, M., "Solar photovoltaic (PV) applications in Libya: Challenges, potential, opportunities and future perspectives", ***Cleaner Engineering And Technology***, 5: 100267 (2021).
2. Hamzah, A. H., Akroot, A., and Jaber, J. A., "Analytical Investigation of Biodiesel Mixed Levels and Operation Factors' Effects on Engine Performance by RCM", ***International Journal Of Design And Nature And Ecodynamics***, 17 (6): 863–873 (2022).
3. Abdul-Wahhab, H. A., Al-Kayiem, H. H., A. Aziz, A. R., and Nasif, M. S., "Survey of invest fuel magnetization in developing internal combustion engine characteristics", ***Renewable And Sustainable Energy Reviews***, 79 (March): 1392–1399 (2017).
4. Khafaji, H. Q. A., Abdul Wahhab, H. A., Al-Maliki, W. A. K., Alobaid, F., and Epple, B., "Energy and Exergy Analysis for Single Slope Passive Solar Still with Different Water Depth Located in Baghdad Center", ***Applied Sciences (Switzerland)***, 12 (17): 0–13 (2022).
5. Goswami, D. Y., "Principles of Solar Engineering", ***CRC Press***, (2015).
6. Dawood, T. A., Raphael, R., Barwari, I., and Akroot, A., "Solar Energy and Factors Affecting the Efficiency and Performance of Panels in Erbil / Kurdistan", 41 (2): 304–312 (2023).
7. Palatnik, R., "Real-Time Clouds Motion Analysis and Possibility of Its Application to Solar Engineering", ***Citeseer***, (2007).
8. ACE, B. U. E., "Solar Panels as an Efficient Energy Saving Tool in New Housing Districts in Cairo", .
9. Twidell, J. and Weir, T., "Renewable Energy Resources. by Taylor and Francis", ***Newyork, USA***, (2006).
10. Internet: Wind and Hydropower Technologies Program, "Wind Energy

Resource Potential", .

11. Röder, M., "More than food or fuel. Stakeholder perceptions of anaerobic digestion and land use; a case study from the United Kingdom", ***Energy Policy***, 97: 73–81 (2016).

12. Kareem, A. F., Akroot, A., Wahhab, H. A. A., Talal, W., Ghazal, R. M., and Alfaris, A., "Exergo – Economic and Parametric Analysis of Waste Heat Recovery from Taji Gas Turbines Power Plant Using Rankine Cycle and Organic Rankine Cycle", (2023).

13. Akroot, A. and Namli, L., "Performance assessment of an electrolyte-supported and anode-supported planar solid oxide fuel cells hybrid system", ***J Ther Eng***, 7 (7): 1921–1935 (2021).

14. Akroot, A., "Modelling of Thermal and Water Management in Automotive Polymer Electrolyte Membrane Fuel Cell SystemsOtomotivPolimer MembranElektrolit YakitHücresSistemlerinin Isil Ve YönetimininModelenmesi Abdulrazzak Akroot", (January): (2014).

15. Sikkema, R. and Fiorese, G., "Use of forest based biomass for bioenergy in EU-28", ***Res. Rural. Dev***, 2: 7–13 (2014).

16. Akroot, A., "Effect of Operating Temperatures on the Performance of a SOFCGT Hybrid System", ***International Journal Of Trend In Scientific Research And Development***, Volume-3 (Issue-3): 1512–1515 (2019).

17. DELIBAS, H. M. and ERHAN KAYABASI, "ENERGY, ENVIRONMENT AND ECONOMY ASSESSMENT OF WASTE HEAT RECOVERY TECHNOLOGIES IN MARINE INDUSTRY", ***Materials And Engineering Technology***, 002 (2021): 39–45 (2019).

18. Tomei, J. and Helliwell, R., "Food versus fuel? Going beyond biofuels", ***Land Use Policy***, 56: 320–326 (2016).

19. Rathmann, R., Szklo, A., and Schaeffer, R., "Land use competition for production of food and liquid biofuels: An analysis of the arguments in the current debate", ***Renewable Energy***, 35 (1): 14–22 (2010).

20. Montanaro, G., Xiloyannis, C., Nuzzo, V., and Dichio, B., "Orchard

management, soil organic carbon and ecosystem services in Mediterranean fruit tree crops", ***Scientia Horticulturae***, 217: 92–101 (2017).

21. Röder, M., Stolz, N., and Thornley, P., "Sweet energy–Bioenergy integration pathways for sugarcane residues. A case study of Nkomazi, District of Mpumalanga, South Africa", ***Renewable Energy***, 113: 1302–1310 (2017).

22. Ayyash, S. Y., "Alternative Energy Technology", ***National Council For Culture, Literature And Arts. Kuwait. Arabic Version***, 287 (1981).

23. Tozlu, A., Kayabasi, E., and Ozcan, H., "Thermoeconomic analysis of a low-temperature waste-energy assisted power and hydrogen plant at off-NG grid region", ***Sustainable Energy Technologies And Assessments***, 52 (PA): 102104 (2022).

24. Akroot, A. and Nadeesh, A., "Performance Analysis of Hybrid Solid Oxide Fuel Cell-Gas Turbine Power System", (2021).

25. Assaf, Y. H., Akroot, A., Abdul Wahhab, H. A., Talal, W., Bdaiwi, M., and Nawaf, M. Y., "Impact of Nano Additives in Heat Exchangers with Twisted Tapes and Rings to Increase Efficiency: A Review", ***Sustainability (Switzerland)***, 15 (10): (2023).

26. Ozcan, H. and Kayabasi, E., "Thermodynamic and economic analysis of a synthetic fuel production plant via CO2 hydrogenation using waste heat from an iron-steel facility", ***Energy Conversion And Management***, 236 (February): 114074 (2021).

27. Nations, U., "The Sustainable Development Goals 2016", ***ESocialSciences***, (2016).

28. Khudhur, J., Akroot, A., and Al-samari, A., "Experimental Investigation of Direct Solar Photovoltaics that Drives Absorption Refrigeration System", 1 (1): 116–135 (2023).

29. Tuama, S., Abdulrazzaq, O., Abdulridha, S., and Faiq, N., "Investigating the Impact of Tilt Angle, Orientation, and Configuration on PV System Performance Using PVSyst Software", ***Journal Of Applied Sciences And Nanotechnology***, 1 (3): 73–85 (2021).

30. Capar, S., "Photovoltaic power generation for polycrystalline solar cells and turning sunlight into electricity thesis", ***Engineering Physics, University Of Gaziantep***, (2005).

31. Abdulridha, S. K., Tuma, S. A., and Abdulrazzaq, O. A., "Study of the Partial Shading Effect on the Performance of Silicon PV Panels String", ***Renewable Energy And Environment Research Center/ Corporation Of Research And Industrial Development***, .

32. Messenger, R. and Ventre, J., "Photovoltaic Systems Engineering", ***CRC-Press***, (2000).

33. Green, M. A., "Photovoltaic principles", ***Physica E: Low-Dimensional Systems And Nanostructures***, 14 (1–2): 11–17 (2002).

34. Hermann, A. M., "Polycrystalline thin-film solar cells–a review", ***Solar Energy Materials And Solar Cells***, 55 (1–2): 75–81 (1998).

35. Mousazadeh, H., Keyhani, A., Javadi, A., Mobli, H., Abrinia, K., and Sharifi, A., "A review of principle and sun-tracking methods for maximizing solar systems output", ***Renewable And Sustainable Energy Reviews***, 13 (8): 1800–1818 (2009).

36. Dickinson, E. W., "Solar Energy Technology Handbook", ***CRC Press***, (1980).

37. Gueymard, C. A., "Direct and indirect uncertainties in the prediction of tilted irradiance for solar engineering applications", ***Solar Energy***, 83 (3): 432–444 (2009).

38. Myers, D. R., "Evaluation of the performance of the pvusa rating methodology applied to dual junction pv technology: Preprint (revised)", ***National Renewable Energy Lab.(NREL), Golden, CO (United States)***, (2009).

39. Husami, M. S., "Energy crisis in Kurdistan and the impact of renewable energy", ***University Of Strathclyde. Glasgow***, (2007).

40. Internet: Hassan, D. A., Abdulrahman, Z. A., & Saeed, M. A., "Kurdistan Regional Government-Iraq Ministry of Higher Education and Scientific Research Salahaddin University-Erbil", .

41. Jameel, S. K. and Balawah, B. D., "The Principles of Electro-Optics", ***Ministry***

Of Higher Education And Scientific Research, Baghdad University. Arabic Version., (1991).

42. Jäger-Waldau, A., "Status of PV Research, Solar Cell Production and Market Implementation in Japan, USA and the European Union-September 2002", ***European Commission, Joint Research Centre***, (2002).

43. Profile, S. E. E., "PVNET Workshop on “ RTD Strategies for PV ” Held in Ispra on 30th - 31st May", (2014).

44. Marion, B., Kroposki, B., Emery, K., Myers, D., del Cueto, J., and Osterwald, C., "Validation of a Photovoltaic Module Energy Ratings Procedure at NREL", ***National Renewable Energy Laboratory***, (August): .

45. Gregg, A., Parker, T., and Swenson, R., "A" real world" examination of PV system design and performance", (2005).

46. Talal, W. . and Akroot, A., "Exergoeconomic Analysis of an Integrated Solar Combined Cycle in the Al-Qayara Power Plant in Iraq", ***Processes***, 11, 656.: (2023).

47. Green, M. A., Emery, K., Hishikawa, Y., and Warta, W., "Solar cell efficiency tables (version 36)", ***Progress In Photovoltaics: Research And Applications***, 18 (5): 346 (2010).

48. Skoplaki, E., Boudouvis, A. G., and Palyvos, J. A., "A simple correlation for the operating temperature of photovoltaic modules of arbitrary mounting", ***Solar Energy Materials And Solar Cells***, 92 (11): 1393–1402 (2008).

49. Lynn, P. A., "Electricity from Sunlight: An Introduction to Photovoltaics", ***John Wiley & Sons***, (2011).

50. Hirst, L. C. and Ekins-Daukes, N. J., "Fundamental losses in solar cells", ***Progress In Photovoltaics: Research And Applications***, 19 (3): 286–293 (2011).

51. Hegedus, S. and Luque, A., "Handbook of Photovoltaic Science and Engineering", ***John Wiley & Sons***, (2011).

52. Vergura, S., "A complete and simplified datasheet-based model of pv cells in variable environmental conditions for circuit simulation", ***Energies***, 9 (5): 326

(2016).

53. Han, X., Wang, Y., Zhu, L., Xiang, H., and Zhang, H., "Mechanism study of the electrical performance change of silicon concentrator solar cells immersed in de-ionized water", ***Energy Conversion And Management***, 53 (1): 1–10 (2012).

54. Panjwani, M. K. and Narejo, G. B., "Effect of humidity on the efficiency of solar cell (photovoltaic)", ***International Journal Of Engineering Research And General Science***, 2 (4): 499–503 (2014).

55. Darwish, Z. A., Kazem, H. A., Sopian, K., Alghoul, M. A., and Chaichan, M. T., "Impact of some environmental variables with dust on solar photovoltaic (PV) performance: review and research status", ***International J Of Energy And Environment***, 7 (4): 152–159 (2013).

56. Kazem, H. A., Chaichan, M. T., Al-Shezawi, I. M., Al-Saidi, H. S., Al-Rubkhi, H. S., Al-Sinani, J. K., and Al-Waeli, A. H. A., "Effect of Humidity on the PV Performance in Oman", ***Asian Transactions On Engineering***, 2 (4): 29–32 (2012).

57. Karathanasis, A. D. and Hajek, B. F., "Elemental analysis by X-ray fluorescence spectroscopy", ***Methods Of Soil Analysis: Part 3 Chemical Methods***, 5: 161–223 (1996).

58. Salim Akhter, M. and Madany, I. M., "Heavy metals in street and house dust in Bahrain", ***Water, Air, And Soil Pollution***, 66: 111–119 (1993).

59. Draxler, R. R., Gillette, D. A., Kirkpatrick, J. S., and Heller, J., "Estimating PM10 air concentrations from dust storms in Iraq, Kuwait and Saudi Arabia", ***Atmospheric Environment***, 35 (25): 4315–4330 (2001).

60. Al-Hasan, A. Y., "A new correlation for direct beam solar radiation received by photovoltaic panel with sand dust accumulated on its surface", ***Solar Energy***, 63 (5): 323–333 (1998).

61. Qasem, H., Betts, T. R., Müllejans, H., AlBusairi, H., and Gottschalg, R., "Dust-induced shading on photovoltaic modules", ***Progress In Photovoltaics: Research And Applications***, 22 (2): 218–226 (2014).

62. Hinds, W. C., "Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles", ***Wiley***, (1999).

63. Bony, L., Doig, S., Hart, C., Maurer, E., and Newman, S., "Achieving low-cost solar PV", ***Rocky Mountain Institute (RMI), Snowmass, CO***, (2010).

64. Schwingshackl, C., Petitta, M., Wagner, J. E., Belluardo, G., Moser, D., Castelli, M., Zebisch, M., and Tetzlaff, A., "Wind effect on PV module temperature: Analysis of different techniques for an accurate estimation", ***Energy Procedia***, 40: 77–86 (2013).

65. Andrea, Y., Pogrebnaya, T., and Kichonge, B., "Effect of industrial dust deposition on photovoltaic module performance: Experimental measurements in the tropical region", ***International Journal Of Photoenergy***, 2019: 1–10 (2019).

66. Ettah, E. B., Eno, E. E., and Udoimuk, A. B., "The effects of Solar panel temperature on the power output efficiency in Calabar, Nigeria", ***The Effects Of Solar Panel Temperature On The Power Output Efficiency In Calabar, Nigeria***, 23: 1–7 (2009).

67. Ismail, O. S., Ajide, O. O., and Akingbesote, F., "Performance assessment of installed solar PV system: A case study of Oke-Agunla in Nigeria", (2012).

68. Javed, A., "The effect of temperatures on the silicon solar cell", ***Int. J. Emerg. Technol. Comput. Appl. Sci.(IJETCAS)***, 9: 305–308 (2014).

69. Sulaiman, S. A., Singh, A. K., Mokhtar, M. M. M., and Bou-Rabee, M. A., "Influence of dirt accumulation on performance of PV panels", ***Energy Procedia***, 50: 50–56 (2014).

70. Sarkar, G. and Bakade, K., "Analysis of shading pattern of solar panels", ***Int. J. Res. Eng. Technol***, 3 (02): 594–599 (2014).

71. Chikate, B. V, Sadawarte, Y., and Sewagram, B., "The factors affecting the performance of solar cell", ***International Journal Of Computer Applications***, 1 (1): 975–8887 (2015).

72. Boyle, L., Flinchpaugh, H., and Hannigan, M. P., "Natural soiling of photovoltaic cover plates and the impact on transmission", ***Renewable Energy***,

77: 166–173 (2015).

73. Abd-Elhady, M. S., Fouad, M. M., and Khalil, T., "Improving the efficiency of photovoltaic (PV) panels by oil coating", ***Energy Conversion And Management***, 115: 1–7 (2016).

74. Al-Douri, Y. and Abed, F. M., "Solar energy status in Iraq: Abundant or not—Steps forward", ***Journal Of Renewable And Sustainable Energy***, 8 (2): 25905 (2016).

75. Zaihidee, F. M., Mekhilef, S., Seyedmahmoudian, M., and Horan, B., "Dust as an unalterable deteriorative factor affecting PV panel's efficiency: Why and how", ***Renewable And Sustainable Energy Reviews***, 65: 1267–1278 (2016).

76. Meyer, E. L., Buma, C. L., and Taziwa, R. T., "Performance parameters of an off-grid building integrated photovoltaic system in South Africa", (2017).

77. Srivastava, H. K., Chauhan, A. S., and Saraswat, & R., "ANALYSIS & MODELING OF DUST AND SHADING EFFECTS ON THE PERFORMANCE OF SOLAR PHOTOVOLTAIC SYSTEM UNDER VARIOUS WEATHER CONDITIONS", ***International Journal OF Engineering Sciences & Management Research***, (2017).

78. Zhang, Z., "Influence of Special Weather on Output of PV System", ***IOP Conference Series: Earth And Environmental Science***, 108 (5): 052063 (2018).

79. Rashel, M. R., "Modeling Photovoltaic Panels Under Variable Internal and Environmental Conditions With Non-Constant Load", ***University of Évora***, (2018).

80. Rahmatmand, A., Harrison, S. J., and Oosthuizen, P. H., "An experimental investigation of snow removal from photovoltaic solar panels by electrical heating", ***Solar Energy***, 171: 811–826 (2018).

81. Kazem, H. A., Chaichan, M. T., Al-Waeli, A. H. A., and Sopian, K., "A novel model and experimental validation of dust impact on grid-connected photovoltaic system performance in Northern Oman", ***Solar Energy***, 206: 564–578 (2020).

82. Shevchenko, S. Y., Danylchenko, D. O., Bilyk, S. Y., Potryvai, A. E., and Kovtun, G. A., "Considering the effect of dustiness of a photovoltaic module surfaces on solar power generation by matlab software", ***Electrical Engineering And Power Engineering***, (4): 28–35 (2021).

83. Bollinger, J. D., "Applications of solar energy to power stand-alone area and street lighting", (2007).

84. Khatib, T., Mohamed, A., Mahmoud, M., and Sopian, K., "Modeling of daily solar energy on a horizontal surface for five main sites in Malaysia", ***International Journal Of Green Energy***, 8 (8): 795–819 (2011).

85. Liu, B. Y. H. and Jordan, R. C., "The interrelationship and characteristic distribution of direct, diffuse and total solar radiation", ***Solar Energy***, 4 (3): 1–19 (1960).

86. Serna, R. J., Pierquet, B. J., Santiago, J., and Pilawa-Podgurski, R. C. N., "Field measurements of transient effects in photovoltaic panels and its importance in the design of maximum power point trackers", (2013).

87. Matius, M. E., Ismail, M. A., Farm, Y. Y., Amaludin, A. E., Radzali, M. A., Fazlizan, A., and Muzammil, W. K., "On the optimal tilt angle and orientation of an on-site solar photovoltaic energy generation system for Sabah's rural electrification", ***Sustainability***, 13 (10): 5730 (2021).

88. Chou, M., Arking, A., Otterman, J., and Ridgway, W. L., "The effect of clouds on atmospheric absorption of solar radiation", ***Geophysical Research Letters***, 22 (14): 1885–1888 (1995).

89. Budiyanto, M. A. and Shinoda, T., "The effect of solar radiation on the energy consumption of refrigerated container", ***Case Studies In Thermal Engineering***, 12: 687–695 (2018).

90. Stine, W. B. and Geyer, M., "Power from the Sun, 2001", ***Available Online: Powerfromthesun. Net (Accessed On 23 April 2020)***, (2006).

91. Khatib, T., Kazem, H., Sopian, K., Buttinger, F., Elmenreich, W., and Albusaidi, A. S., "Effect of dust deposition on the performance of multi-crystalline photovoltaic modules based on experimental measurements",

International Journal Of Renewable Energy Research, 3 (4): 850–853 (2013).

92. De Greve, B., "Reflections and refractions in ray tracing", ***Retrived Oct***, 16: 2014 (2006).

93. Lira, I., "Evaluating the Measurement Uncertainty: Fundamentals and Practical Guidance", ***CRC Press***, (2002).

94. Holman, J. P., "Experimental Methods for Engineers EIGHTH EDITION", (2021).

APPENDIX A

An in-series PV module with 60 cells is partially shaded in Figure (A-1). For measuring the PV module's I-V and P-V characteristics, a variable DC voltage source is used. A model of the device involves three strings of 20 series-connected cells in parallel connected to bypass diodes to provide current flow when cells are damaged or shaded. The first string of 20 cells receives a standard irradiance of 1000 W/m^2, while strings 2 (cells 21-40) and 3 (cells 41-60) receive partial shading resulting in irradiances of 300 W/m^2 and 600 W/m^2, respectively.

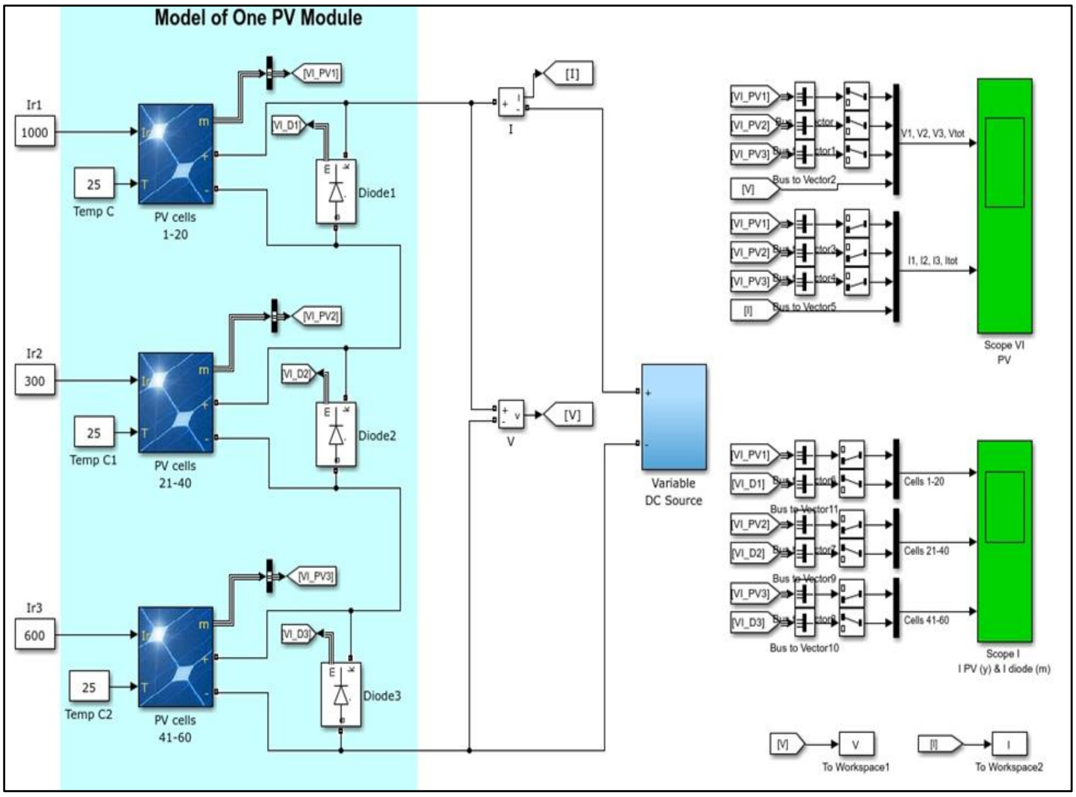


Figure A.1. partial shading of PV module

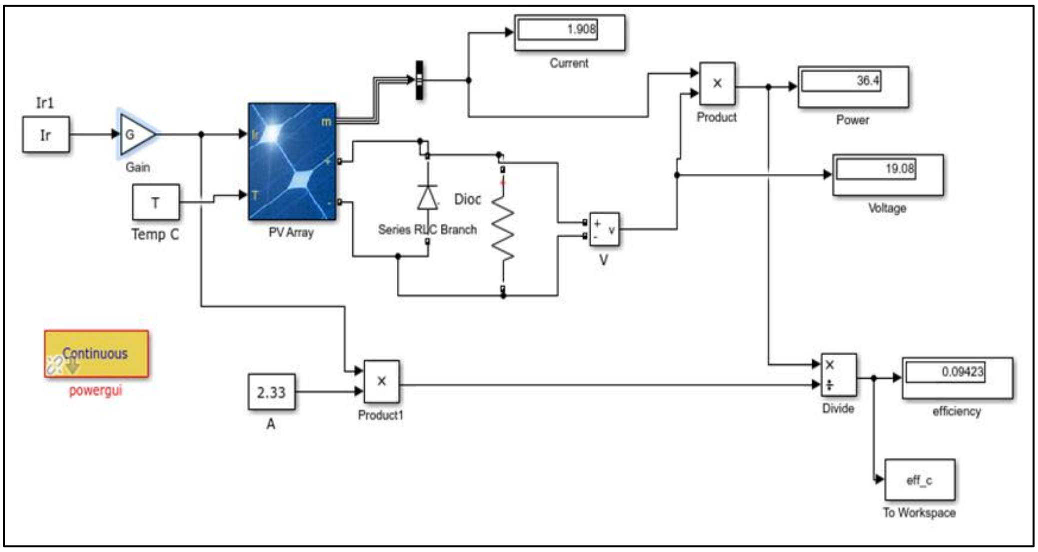


Figure A.2. PV Matlab system represented to get PV current considering the amount of dust.

The Matlab Simulink model was implemented to analyse different factors in the performance of solar cells. By inserting the irradiation and the temperature values into the model and taking into account the dust coefficient, the outputs of the panels (grid current, grid voltage, grid power) were obtained. These processes are repeating for the other factors.

Matlab Code 1

```
clear all
ModelName = get_param(gcb,'Parent');

GG=400:200:1200;
T=15.15:10:55.15;
Tcell=T(2);
h1=subplot(221);
hold on
 h2=subplot(222);
 hold on
  h3=subplot(223);
 hold on
   h4=subplot(224);
 hold on
 xlabel(h1,'Voltage (V)')
ylabel(h1,'Current (A)')
 xlabel(h3,'Voltage (V)')
ylabel(h3,'Current (A)')
 xlabel(h2,'Voltage (V)')
```

```
ylabel(h2,'Power (W)')
xlabel(h4,'Voltage (V)')
ylabel(h4,'Power (W)')
title(h1,['Irradiance effect on PV Array Performance,
T=',num2str(T(2)),char(176),'C']);
title(h2,['Irradiance effect on PV Array Performance,
T=',num2str(T(2)),char(176),'C']);
title(h3,['Temperature effect on PV Array Performance,
G=',num2str(1000),'W/m^2']);
title(h4,['Temperature effect on PV Array Performance,
G=',num2str(1000),'W/m^2']);
for i=1:length(GG)
    G=GG(i);


    sim(ModelName,10)
   I_mat{:,i} = VI(:,2)';
   V_mat{:,i}=VI(:,1)';
   plot(h1,VI(:,1),VI(:,2));
   P=VI(:,1).*VI(:,2);
   plot(h2,VI(:,1),P);
   [M,I]=max(P);
    legend_info{i} = ['G =
',num2str(G),'W/cm^2','Vmpo=',num2str(VI(I,1)),'V'];
     legend_info1{i} = ['G =
',num2str(G),'W/cm^2','Pmpp=',num2str(M),'Watt'];
end
legend(h1,legend_info);
legend(h2,legend_info1);
G=1000;
for i=1:length(T)
   Tcell=T(i);


    sim(ModelName,10)
   I_mat{:,i} = VI(:,2)';
   V_mat{:,i}=VI(:,1)';
   plot(h3,VI(:,1),VI(:,2));
   P=VI(:,1).*VI(:,2);
   plot(h4,VI(:,1),P);
   [M,I]=max(P);
    legend_info2{i} = ['T =
',num2str(Tcell),'C',char(176),'Vmpo=',num2str(VI(I,1)),'
V'];
     legend_info3{i} = ['T =
',num2str(Tcell),'C',char(176),'Pmpp=',num2str(M),'Watt']
;
end
legend(h3,legend_info2);
legend(h4,legend_info3);
```

Matlab Code2

```
%% Import the data
[~, ~, raw] = xlsread('data1.xlsx','Sheet1','A2:I11');

%% Create output variable
data1 = reshape([raw{:}],size(raw));

XDates = [datetime(2022,3,15:5:30)
datetime(2022,4,5:5:10) datetime(2022,4,20:5:25)];
dd=datenum(XDates);
%dt2 = datetime(dd, 'ConvertFrom', 'datenum')
% datenum(num2str(dd, '%d'), 'mmdd')
[d,t] = meshgrid(dd,8:1:17);
figure
z=data1(:,2:9);
ribbon(t,z)
xlabel('Day')
XDates.Format='dd-MMM';
xx=datestr(XDates,'mmmm/dd');
%xx={XDates}
xticklabels(xx)
ylabel('Time (hours)')
zlabel('solar irradiance (W/m^2)')
grid on
%ytickformat('MM-dd')
%datetick('y','mmmdd','keepticks','keeplimits')
%datetick('x','mmmm-dd').
```

APPENDIX B

Ref.	year	Methodology	Findings
Olawale S. I et al.[67]	2012	Experimental numerical.	Breakdowns or declining performance were caused by inadequate maintenance, a lack of technical expertise, insufficient training, and inexperienced project management.
A. Jawed [68]	2014	Experimental numerical.	As the temperature rises, the ultimate efficiency vanishes and the maximum. The efficiency is 18.34% at 20 °C, but it is just 13.71% at 80 °C.
Suleiman et al. [69]	2014	Experimental numerical.	The amount of energy produced by solar panels was between 9% and 31% lower because of talc powder traces, between 60% and 70% lower because of dust, between 70% and 80% lower because of sand, and between 77% and 83% lower because of algae.
Bakade et al. [70]	2014	Numerical.	One of the primary things that disturbs solar panels is the shadows cast on their tops. According to software analysis, clouds are to blame for this shading. This might contribute to improving the solar panels' efficiency.
B.V. Chikate et al. [71]	2015	Experimental. numerical	Performed research on a variety of environmental factors, including sunlight exposure, high temperatures, dust, and filth, that have an impact on the effectiveness of a solar system.
L. Boyle et al. [72]	2015	Experimental. numerical	It was discovered that the pace of mass collecting on the solar panel varied seasonally, regionally, and after 1e5 week arrangements, absolute mass groups up to 2 g/m2 were seen at the point of order. This rate was predicted to be between 1 and 5 mg/m2/day. It was discovered that the transmission dropped by 11%.
Abd-Elhady et al. [73]	2016	Experimental. numerical	Proposed a different strategy to boost solar panels' effectiveness. The method is carried out by applying a little layer of oil to the front of the solar panel in order to gauge how much light is passed to it and, therefore, how effective it is.

Y. Al-Dour et al. [74]	2016	Numerical	Did research in Baghdad, Iraq, which has a yearly sun radiation exposure of more than 3000 h. From 4836MJ/m2 in January to 9686MJ/m2 in June, the sun intensity fluctuates hourly. Iraq has a wide distribution of radiation powered by solar energy, making the photoelectric finding the most suited in every way.
Zaihidee et al. [75]	2016	Experimental	The solar panel's 20 g/m2 collection of dust reduces the circuit's current. Efficiency in the open circuit is reduced by up to (15-21%, 2-6%, and 15-35%) in the short circuit and voltage, respectively.
Taziwa et al. [76]	2017	Experimental	In spite of more summer sunshine, research on 3.8kWp frame-connected PV frames in South Africa over the long term (February to August) reveals that the frames perform better in cooler months than in summer.
Srivastava et al. [77]	2017	Experimental. numerical	They used the MATLAB program to predict and assess the impact of dust particles and shadowing on solar panel efficiency. The results were then compared to experimental data. where black-lined pictures were utilized in the modeling to obscure light
Zele Zhang. [78]	2018	Numerical	Through the use of the MATLAB program, the impact of various environmental circumstances was investigated. It was considered how heat, humidity, and radiation intensity affected the effectiveness of solar panels.
Rashel [79]	2018	Numerical	MATLAB software was used to simulate solar cells while taking into consideration actual weather conditions. The performance of the solar cell was modeled in relation to several parameters. The software has been given information on the temperature, wind speed, and sun radiation intensity.

Rahmatmand et al. [80]	2018	Experimental	This study removed snow from photovoltaic solar-powered chargers using a heated approach. Three boards at each corner and nine sun-powered chargers installed independently on the Bended points of (30°, 45°, and 55°)
Hussein A et al. [81]	2020	Experimental	The GCPV execution rate was 64.92%, according to the data, and the highest PV and inverter efficiencies were 10.80% and 94.00%, respectively. The curtailment ratio was 19.64%, and the normal output was 141.39 kWh/kWp. The GCPV framework's performance is cost-effective and within the predicted timeframe.
S. Yu et al. [82]	2021	Experimental. numerical	Their work involves developing a MATLAB software to enhance solar cell performance by estimating the amount of dust accumulated on their surface and the solar cell's efficiency. Where in the mathematical model statistical approaches were applied. When compared to the experimental findings, the model utilized produced satisfactory results.

APPENDIX C

Uncertainty analysis:

The dominion of projected quantity is known as "Uncertainty". The errors in parameters are categorized into two kinds: systematic error and random error. The random errors can be eliminated by employing the intact experimental procedure and the operating conditions; however, systematic errors are inevitable and cannot be eliminated. Corresponding to the type of errors, the major categories of uncertainty are internal uncertainty (Type A) and external uncertainty (Type B). Type B uncertainty is related to systematic errors and computed from the data available in calibration test reports or manuals of the instruments; whereas type A uncertainty is linked with random errors and can be assessed using statistical analysis.

The experimental uncertainty (Type A) can be derived using the standard deviation (Eq. (C1), and calculated using Eq. (C2). The standard uncertainty (u) (Type B) of instruments can be calculated using Eq. (C3) (Lira, 2002) [93].

Standard Deviation,

$$\sigma = \sqrt{\frac{\Sigma(\mathrm{X}-\bar{\mathrm{X}})^2}{n^2}} \quad \text{(C1)}$$

$$\%\, Uncertainty = \frac{\sqrt{\frac{\Sigma(\sigma)^2}{n^2}}}{\Sigma\bar{\mathrm{X}}} \quad \text{(C2)}$$

$$u = \frac{a}{\sqrt{3}} \quad \text{(C3)}$$

An uncertainty in the output parameter can be estimated using the uncertainty in instruments utilized to measure the input parameter using Eq. (C4) [94].

$$w(R) = \left[\left(\frac{\partial R}{\partial z_1} w(z_1)\right)^2 + \left(\frac{\partial R}{\partial z_2} w(z_2)\right)^2 + \cdots \left(\frac{\partial R}{\partial z_n} w(z_n)\right)^2\right]^{\frac{1}{2}}$$

Nomenclature	
n	accuracy of instrument
R	resultant parameter
w	uncertainty
X	observation value
$\bar{\mathbf{X}}$	the average value of observation
Z	input measuring parameter

RESUME

His name is Tareq Aziz Dawood ALMAZROAY. His primary and elementary education in Iraq. He completed his undergraduate studies at the University of Technology in 2011 in Iraq. Then he started his Master’s degree in Department of Mechanical Engineering at Karabuk University in 2020.