EXPERIMENTAL STUDY OF THERMODYNAMIC ANALYSIS OF CLOSED SYSTEM NANOFLUID COOLED PV/T COLLECTORS

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Assist. Prof. Dr. Selcuk SELIMLI

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May 2022

I certify that in my opinion the thesis submitted by Othman Mohammed Jasim JASIM titled "EXPERIMENTAL STUDY OF THERMODYNAMIC ANALYSIS OF CLOSED SYSTEM NANOFLUID COOLED PV/T COLLECTORS" is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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

Othman Mohammed Jasim JASIM

ABSTRACT

M. Sc. Thesis

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Karabuk University
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The Department of Energy Systems Engineering

Thesis Advisor:
Assist. Prof. Dr. Selcuk SELIMLI
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The requirement for renewable energy and its application in electricity generation is increasing day by day. Solar energy has critical importance among the various types of renewable energy sources. In this thesis, the cooling of PV/T collectors was experimentally investigated with two flow patterned nanofluid circulation in an experimentation system. The experiments were done in the Karabuk city of Turkey in October 2021. A photovoltaic module, that is assigned as a reference, was used to evaluate the enhancement in electrical and thermal performance of two different flow patterned PV/T collectors. PVT collectors were obtained by placing the back side of PV modules and the PV/T collector (PV/T1) has the serpentine and the other (PV/T2) channelled module back side circulation. Solar panel systems are compared according to their first and second law efficiency. Resultantly, the temperature decline of PV/T1 and PV/T2 collectors was 29.49% and 50% compared to the PV module. Electrical power output of the PV/T1 and PV/T2 increased approximately

41% and 78.7% respect to PV module. The thermal power gain from the PV/T1 and PV/T2 collectors are 42.8 W, and 53.39 W. First and second law efficiency enhancement of PV/T1 and PV/T2 collectors are 39.23%, 50.97%, and 2.44%, 4.95% compared to PV module.

Key Words **:** Photovoltaic module, photovoltaic/thermal collector, solar energy, energy, and exergy efficiency, nanofluid.

Science Code **:** 91441

ÖZET

Yüksek Lisans Tezi

KAPALI SİSTEM NANOAKIŞKAN SOĞUTMALI PV/T KOLLEKTÖRLERİNİN TERMODİNAMİK ANALİZİNİN DENEYSEL ÇALIŞMASI

Othman Mohammed Jasim JASIM

Karabük Üniversitesi
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Yenilenebilir enerjiye duyulan ihtiyaç ve elektrik üretimindeki uygulaması her geçen gün artmaktadır. Güneş enerjisi, çeşitli yenilenebilir enerji kaynakları arasında kritik öneme sahiptir. Bu tezde, PV/T kollektörlerinin soğutulması, bir deney sisteminde iki akış desenli nanoakışkan sirkülasyonu ile deneysel olarak incelenmiştir. Deneyler, Ekim 2021'de Türkiye'nin Karabük ilinde yapılmıştır. Referans olarak atanan bir fotovoltaik modül kullanılmıştır. İki farklı akış desenli PV/T kollektörün elektriksel ve termal performansındaki artışı değerlendirmek. PV/T kollektörler, PV modüllerin arka tarafına yerleştirilerek elde edilmiş olup, PV/T kollektör (PV/T1) serpantin ve diğer (PV/T2) kanallı modül arka yüz sirkülasyonuna sahiptir. Güneş paneli sistemleri birinci ve ikinci yasa verimlerine göre karşılaştırılmıştır. Sonuç olarak, PV/T1 ve PV/T2 kollektörlerinin sıcaklık düşüşü PV modülüne göre %29,49 ve %50 olmuştur. PV/T1 ve PV/T2'nin elektrik güç çıkışı, PV modülüne göre yaklaşık %41 ve %78,7 arttı. PV/T1 ve PV/T2 kollektörlerinden elde edilen termal güç kazancı 42,8 W ve 53,39 W'dir. PV/T1 ve PV/T2 kollektörlerinin birinci ve ikinci kanun verimlilik artışı PV modülüne göre %39,23, %50,97 ve %2,44, %4,95'tir.

Anahtar Kelimeler : Fotovoltaik modül, fotovoltaik/termal kollektör, güneş enerjisi, enerji ve ekserji verimliliği, nanoakışkan.

Bilim Kodu : 91441

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My thanks and gratitude to brother Eng. Ahmed Al Hariri for his support.

I dedicate this thesis

To my beloved father and dear mother
To my dear brothers and sisters
To those who supported me, my beloved wife
To those in whom I see my success, my dear children
To all who love me in God.

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SYMBOLS

$A_{PV.area}$	: PV surface area
c_{fluid}	: Specific heat transfer coefficient
ΔE	: Energy difference
$\dot{E}_{electrical}$	: Electrical energy
$\dot{E}_{heat\ loss}$	: Lossed heat energy
E_{in}	: Inlet energy
E_{out}	: Outlet energy
$\eta_{electrical}$	: Electrical efficiency
η_{ex}	: Exergy efficiency
$\eta_{thermal}$	: Thermal efficiency
η_{o}	: The Overall efficiency
$\dot{E}_{solar}$	: Solar power
$\Delta \dot{E}x$	: Exergy difference
$\dot{E}x_{destroyed}$	: Exergy destruction
$\dot{E}x_{electrical}$	: Electrical exergy
$\dot{E}x_{fluid}$	: Fluid exergy
$\dot{E}x_{inlet}$	: Inlet exergy
$\dot{E}x_{outlet}$	: Outlet exergy
$\dot{E}x_{solar}$	: Solar exergy
$\dot{E}x_{thermal}$	: Thermal exergy
I	: Current
$\dot{m}_{fluid}$	: Fluid mass rate
$\Delta \dot{m}_{fluid,net}$	: Fluid mass rate difference
$\dot{Q}_{thermal}$	: Heat removal rate
S	: Solar irradiance

$T_{environment}$	: Ambient temperature
$T_{fluid\ ,inlet}$	: Inlet temperature of a fluid
$T_{fluid,outlet}$	: Outlet fluid temperature
T_{sun}	: Sun temperature
$T_{surface}$	: PV surface temperature
V	: Voltage
$\dot{W}_{heat\ ex.fan}$	: Supplied power to heat exchanger fan
$\dot{W}_{pump}$	: The power consumption of a pump

ABBREVIATIONS

PV	: Photovoltaic panel
PV/T	: Photovoltaic thermal collector
PV/T1	: A coil of copper pipe fixed on PV/T collector back
PV/T2	: A polyamide channel structure block attached PV/T collector

PART 1

INTRODUCTION

Throughout history, mankind has used a particular source of energy and with changing requirements and industrial requirements varying regarding efficiency and cost, then the search for a safer, more effective, and efficient alternative source begins. At the end of the eighteenth-century coal was discovered and became an alternative to firewood as a source of energy and heating. Then after the invention of the steam engine, coal became An important and indispensable source in the field of industry and heating at that time, Then after the industrial development, it takes place necessary to find a safer, less expensive, and more clean energy source, as oil and gas were discovered and became a primary source of energy for many years. Because of the efficiency of oil and gas and as a good source of energy and an important economic resource, coal has become one of the energy sources and not as it was before as the main one. The world has not stopped searching for a cheaper, safer, and more efficient energy source, in the last years, the concentration has been on sustainable energy, including solar, wind, tidal, geothermal, and nuclear energy, which are safe, environmentally friendly and cheap compared to conventional fuels. For all the energy sources in the electricity sector, the sustainable energy sources only increased use in 2020, despite the deterioration of the state of the global economy due to Covid-19. It recorded 505 TWh in Figure 1.1 [1], which is 20% higher than the average annual percentage growth since 2010. PV and wind power accounted for about a third of total renewable electricity generation growth for 2020, with hydropower accounting for another 25% and bioenergy remaining. The decline in demand for electricity when the financial crisis hit in 2008, along with record additions of photovoltaic and wind power in 2020, increased the proportion of renewable energy production in total electricity generation to a record increase of two percentage points. The production of renewable energies in the same year reached 28.6%, which is the highest level ever in the production of electricity from renewable energies. Power generation in 2020 was less than ambitious. And in the coming years, there will be an increase in the deployment of renewable technologies to quickly reach the level of zero emissions by 2050 [1].

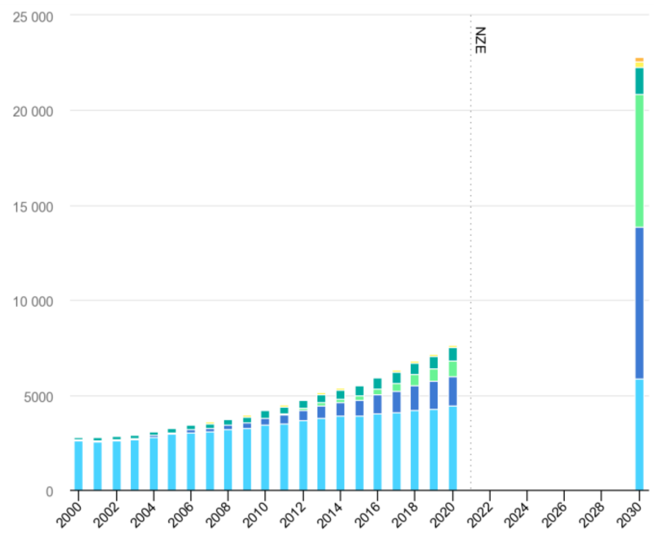


Figure 1.1. Renewable power generation (2000-2030) [1].

Because of the increase in global demand, energy types are fossil fuels, and coal, which are considered one most important sources of energy in the world today. They have a polluting effect on the environment due to the emissions they cause, and the high levels of carbon they produce compared to renewable energies, these sources are considered a cause of climate change, rising temperatures leading to rising sea levels, and worrying predictions about this as a result of continuous warming and acid rain from burning fossil fuels and coal are all due to emissions. Therefore, attention has shifted to renewable energies. Renewable energy has become a necessity for the entire world and the environment in particular because it is clean, environmentally friendly, harmless, and sustainable. Some of them can be exampled as tidal, solar, wind, geothermal, biomass, hydraulic, etc. The overall size of the global energy market and the share of renewable energy ones are geothermal, solar, wind and hydropower have been estimated at 28.6% of electricity production, and Figure 1.2 shows global electricity generation by sources.

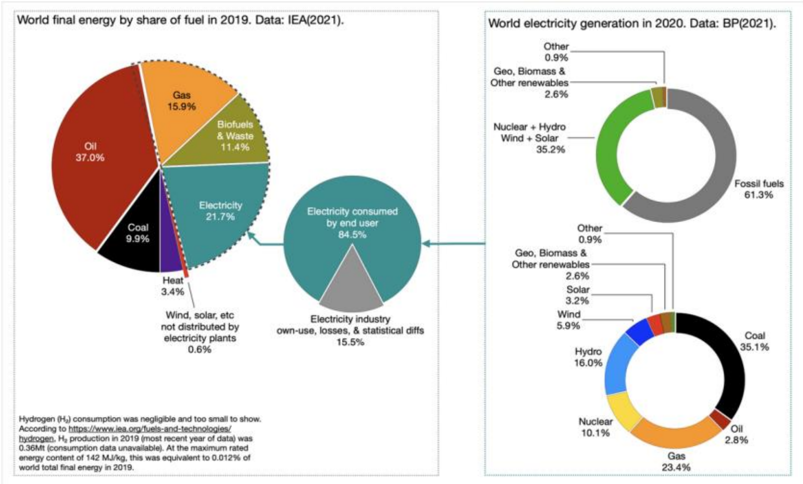


Figure 1.2. World annual energy share of fuels [2].

As for Turkey, solar and wind energy production rates have been moving at an accelerating pace, according to the report. Available documented data shows Turkey’s interest in renewable energy since 2014 and found that the rate of solar energy production for this year amounted to 17 GWh, and in 2017 it increased to 28,289 GWh. And in 2020, it reached 112.65 GWh [3]. All developed countries, including Turkey, are seeking to transition to 100% renewable energy sources in all fields of requirements. But the process of getting rid of the currently used fuel of all kinds in parts of industry, land, and air transport represents a great challenge. Despite this, there is an insistence to promote the principle of energy generation using renewable energy receiving the attention of the majority of policy makers, other than those related to the heating, cooling, and transportation sectors [4].

1.2. CATEGORIZATION OF ENERGY RESOURCES

Energy resources are divided into two parts:

- Non-renewable energy resources.
- Renewable energy resources.

1.2.1. Non-Renewable Resources of Energy

Non-renewable resources are anything that can be depleted with the progression of time or the increase in consumption, and there is no substitute for these materials after their use, and they are as follows:

- Coal.
- Petroleum.
- Natural gallons.
- Uranium[8].

1.2.2. Renewable Energy resources

One of the advantages of renewable energy sources is that they don't run out when used in power generation. Renewable energy resources can be represented in the following Figure 1.5 [8].

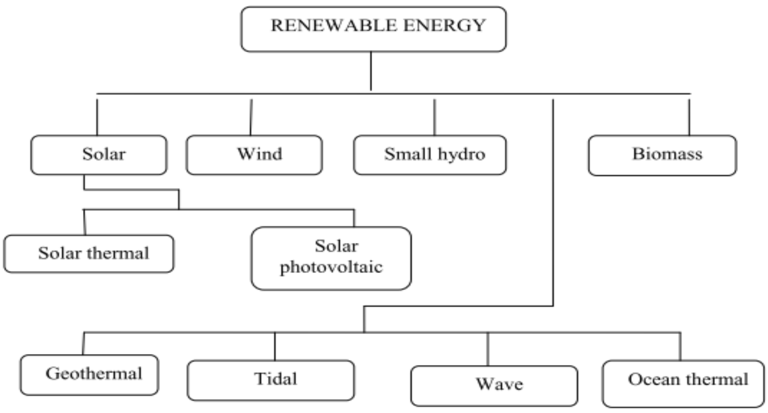


Figure 1.3. Renewable energy resources [8]

1.1. SOLAR ENERGY

The sun sends sufficient radiation around the world that exceeds the needs of all solar energy systems installed on the earth. The sunlight falling on the surface of the earth is sufficient to provide 7900 times sufficient energy to meet our energy consumption needs. Every spot on Earth is exposed to the sun’s rays and is enough to produce 1700 kWh of energy each year. The average radiation is about 1000 kWh per square meter and 1800 kWh per square meter in Europe and the Middle East, respectively [5]. Evaporation of water, movement of wind and rain, as well as waves and thermal energy of the oceans are caused by solar energy. Except for nuclear energy, the sun produces all forms of energy used. Solar energy is used to produce electricity by exploiting sunlight using an electronic device called a solar cell [6]. Solar energy offers a wide range of applications, besides being a good producer of electricity. It can also be used to heat homes and commercial centres, and benefit from it to raise the temperature of the water used in homes, as well as use in desalination. Solar energy can be considered a strong competitor to traditional fuel sources. Solar technology offers many benefits including:

- Reduce fuel consumption.
- Diversification of energy sources.
- Keep other natural energy resources from running out.
- Reducing harmful emissions, including carbon dioxide, at a low cost.
- Creating local job opportunities and revitalizing the local economy [7].

Global solar energy capacities and the addition each year were presented by comparing between 2007 to 2017 in Figure 1.3.

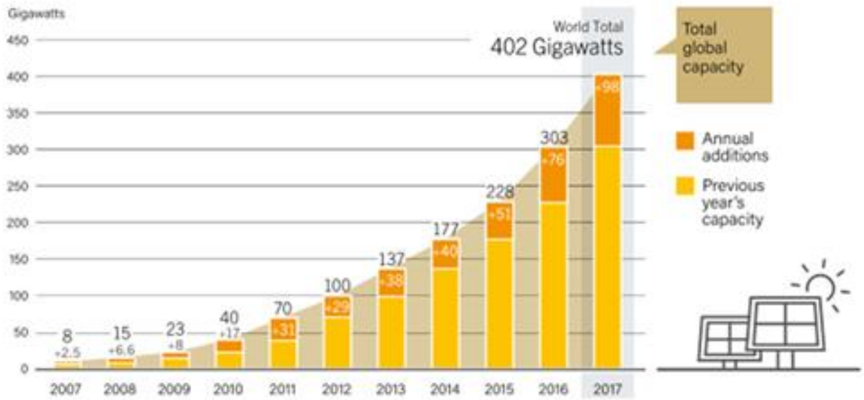


Figure 1.4. The number of units added from solar energy in the world, 2007-2017 [4].

Developing countries like United States, China, India, and Japan have paid great attention to increasing their production capacity from solar energy. Where the size of the installation of solar energy in the world approached 100 GW. Globally, the rate of installing panels every hour reached more than 39,900 photovoltaic panels, and developing countries and Turkey also had the largest share in adding solar energy, bringing together up to 84% of the recently added solar energy. That is, approximately 1 GW of solar energy has already been added to each continent separately. Developing countries and other countries added capacities are shown in Figure 1.4 [4].

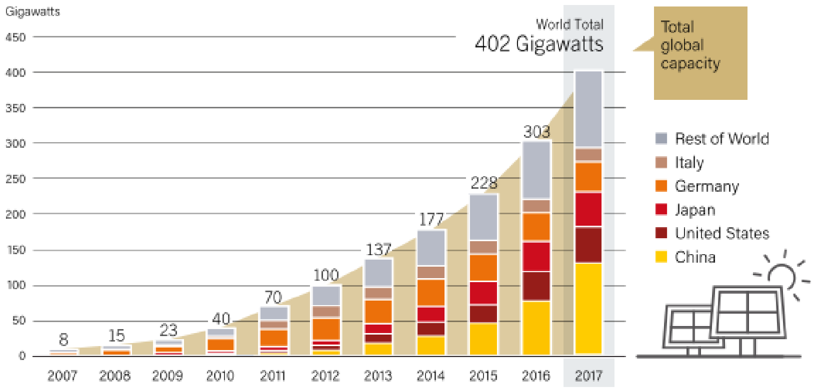


Figure 1.5. Solar Energy Added by Country, and Total Capacity Worldwide, 2007-2017 [4].

1.3. SOLAR ENERGY POTENTIAL OF TURKEY

Turkey is a net importer of energy. The potential in Turkey for renewable energy is very large. Energy sources in Turkey are many and varied, especially sustainable ones. The increase in demand for energy in Turkey encouraged the exploitation of this energy during the previous period. By 2020, the hydro, wind, and solar resources make up the vast majority of Turkey's renewable energy resources, with hydroelectricity accounting for 30.9 GW, wind energy accounting for 8.8 GW, and solar energy accounting for 6.7 GW of the total installed capacity [9]. As shown in Figure 1.5, it becomes clear to us that most of the eastern and southern regions of Turkey, and the coastal areas of the Mediterranean are more exposed to the sun, which means that the radiation rate is high, while the northern and north western regions of Turkey are less exposed to solar radiation.

Figure 1.6. Solar energy chance map of Turkey [10].

In 2017, Turkey set a record for solar power installation as it added 2.6 GW, double its total capacity to reach 3.4 GW at the end of the year, and was among the top ten countries in adding solar power [4] as shown in Figure 1.6.

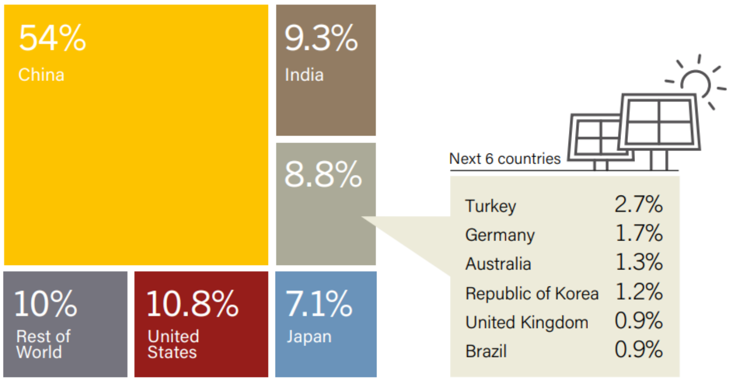


Figure 1.7. The ten largest countries and the rest of the world in adding solar energy, 2017 [4].

1.4. SOLAR CELL

At the beginning of the nineteenth century, when he began to generate electrical energy from light, this is the beginning of the development of solar energy [11]. These cells are the basic component of the system and are the smallest part of it. The cells respond to rays falling on them directly and indirectly and convert the radiation energy into electrical energy. Generally, solar panels make use of sunlight, which activates electrons inside the cell to produce current. The efficiency of the solar cell depends on two important things:

- Intracellular conversion efficiency.
- The ability of the solar cell to absorb photons.

Photovoltaic cells consist of silicon and germanium, which are considered semiconductors. The solar energy conversion process in a solar cell is illustrated in Fig. 1.7.

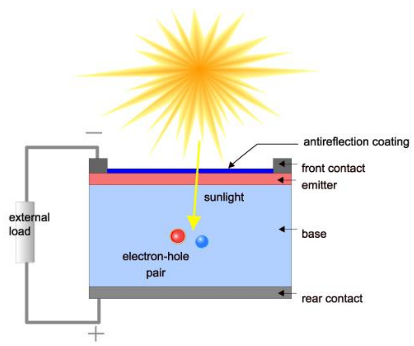


Figure 1.8. Sectional view of a solar cell [12].

The cell generates electricity after converting sunlight and its function is to capture as much sunlight as possible. It achieves this by eliciting a voltage at the terminals of the photocell whenever it is exposed to a sufficient amount of light. Cells are made of semiconducting materials that make up the cell and absorb sunlight falling on it. Meanwhile, photons of light stimulate the electrons to be directed from a low energy region to a higher one and so we get an electric current. This process is known as the photoelectric effect [13]. Most commercial cells are made of silicon: either a single crystal, polycrystalline or amorphous. Thin layers or slices of the material a few thousandths of a millimetre in thickness are processed, placed behind glass, sealed with a flexible polymer material, and assembled into frames to form solar panels. Two types of solar cells are introduced in the literature:

- Cells made of silicon made from silicon wafers or silicon ribbons. They are called Wafer-type cells.
- Cells that are deposited directly on the thin membranes are called Thin-film cells.

Flat panels can be connected in series to form a series of modules, and a certain number of panels can be delivered up to several meters. The flat panels are fixed at a specific angle, and they can be linked to a tracking device to increase the cells' access to the largest amount of solar rays, thus obtaining greater energy production. We can put the thin-film panels on the roof panels, roof tiles, or building facades. The photovoltaic cell consists of a very thin wafer of semiconducting material, such as silicon, that has been distorted with other elements, such as phosphorous or boron, on either surface. These doping elements from impurities within the chemical structure of silicon, in essence, provide two thin layers of dissimilar semiconducting materials consisting of:

- n-type semiconductors with phosphorous atoms give an excess of free electrons with negative electric charges.
- P-type semiconductors with the presence of boron atoms cause a shortage of electrons because the lack of electrons will cause the presence of a positively charged layer.

This absence of negatively charged electrons is equivalent to having a positively charged layer. Because the carriers are created close to a p-n junction, they are separated and swept away to opposite ends of the wafer and appear on its surface. There they can be collected at the external terminals of the cell [14]. Efficient conversion of sunlight into electricity is the standard by which the efficiency of the photovoltaic cell is determined. It is expressed as the maximum energy of 30% is the efficiency of cells under ideal conditions. A lot of sunlight falls on cells, part of the rays are converted to heat, part is reflected, and part is absorbed by the material the cell is made of, so the efficiency of standard cells is 15%. The conversion efficiency of commercial single crystal cells can reach 18%, but crystal cells are about 14%. They have an efficiency of less than 1%. The photoelectric conversion process depends on several parameters. First, the intensity of illumination affects the number of electrons that can be excited, that is, the intensity of the current. The photoelectric effect cannot occur below the threshold voltage. Whatever the intensity of the radiation, it is a function of frequency ν. As in the case of voltage, represents the boundary value corresponding to the radiation frequency. The cell performance gradually decreases with the increase in cell temperature, in Figure 1.8 [14].

In brief, When the module works under criterion conditions of irradiance (0.8 kW/m2), the spectral allocation of AM 1.5, the Location temperature of 20°C, and wind speed (>1 m/s), The normal operating temperature of the cell is the working temperature of the cell. when the cell temperature raising above 25°C, the power produced decreases.

$$T_c = T_a + \left[\frac{NOCT-20}{0.8} \times S\right] \tag{1.1}$$

where T_c and T_a are the cell temperature and ambient temperature respectively in °C and S is the solar irradiance in kW/m^2.[11]

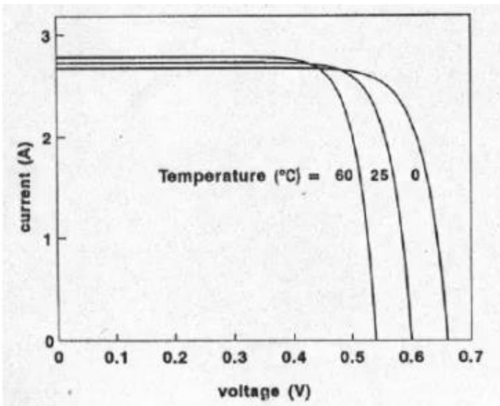


Figure 1.9. The effect of temperature increase on photovoltaic cells [14].

The solar radiation reaching the earth fills the global need for the operation of solar energy systems.

0.5 - 0.6 volts is the output of a single solar cell, and with this small effort, a modest number of electrical devices will work for this voltage, for this reason, several solar cells are connected to increase the voltage output of the unit. The photovoltaic modules are connected to 12 V batteries to enable some modules to operate. Where the batteries work to compensate for the shortfall that occurs during the night or in non-standard conditions, or they are charged while the cells reach the stage of overvoltage. To make the operation more reliable and optimal, about 33-36 series of solar cells are linked in parallel. The solar cells are linked in parallel and series to obtain a high voltage. To obtain the required current and photovoltaic voltage, the units are linked alternately in series and parallel as well. These sets of modules are referred to as arrays [11], as shown in Figure 1.16.

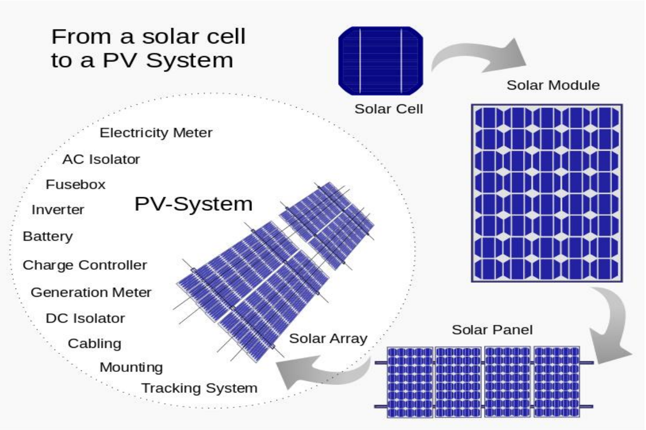


Figure 1.10. From a solar cell to a PV system [15].

1.5. SOLAR PHOTOVOLTAIC TECHNOLOGY

Photovoltaic cells have the action of converting solar energy into electrical energy by using semiconductors which occurred with the photovoltaic effect. Photovoltaic cells are used in solar modules, which are composed of several solar cells, which contain photovoltaic elements. One of its advantages is that it generates electricity quietly, cleanly, and reliably. The photovoltaic system contains solar or photovoltaic panels, and these cells are responsible for converting the solar energy represented by light and converting it into electricity. The reason they are called solar cells is that the light source is mostly the sun. Photovoltaic energy is the sum of two words whose first source is Greece, which is (photo) and (volt). A photovoltaic cell consists of one or two layers of semiconducting materials. When light touches the surface of the cell, the process of creating an electric field occurs through the layers of the cell, causing the flow of electricity. The intensity of the electricity conversion is related to the intensity of the irradiation that falls on the solar cell. Since silicon is a semiconducting material, it is an essential material in the manufacture of solar cells. It is found in abundance in the sand and is a material abundantly available in the mass of the earth. The good thing about silicon is that it can generate electricity even on a cloudy day, even if the generation is in smaller quantities than it would on a sunny day [7].

1.6. BRIEF HISTORY

The phenomenon of electricity generation from light was discovered in the early nineteenth century, but it was not applied until the mid of 20th century. In 1839, the physicist Edmund Becquerel accidentally recorded the photoelectric effect. Then the possibility of selenium as a photoconductor was work discovered by Willoughby Smith. After that, research and discoveries continued in this field, until Bell Chopin laboratories manufactured photovoltaic cells with an efficiency of 6%. Specifically, in 1958, the first photovoltaic cell was developed for space programs in the United States, where the cells were few in number and expensive. And he began to develop photovoltaic cells as a source of energy in laboratories in America in the early seventies of the twentieth century [16].

1.7. SUNLİGHT AND CONVERTİNG İT TO ENERGY

Solar energy is converted into electrical energy through solar cells. Sun's surface temperature is estimated to be 6000°C. Due to combustion and high temperatures, gases are formed, and these gases are the reason for sending different spectra of light starting from ultraviolet to infrared, through the visible, to infrared. Light comes as waves or as particles as it is known in quantum theory, Depending on the certain fundamental interaction of light with the substance; This phenomenon is called wave-particle duality. Light contains energy, which is primarily made up of groups of photons. Photons contain energy that reflects the temperature of the sun Photon energy values (hv) range from 3.5 eV (ultraviolet region) to 0.5 eV (infrared region). The visual area is ordered from 3.0 V (purple) to 1.8 V (red). The Sun's peak values are in the yellow region of the visual region at about 2.5 V. The peak of the Sun's power happens in the yellow region of the visible region, at about 2.5 eV. At noon and on a clear day, the Earth receives 1,000 watts of solar energy per square meter (1 kW/m^2). Photovoltaic cells contain a light-absorbing portion that absorbs only solar

photons at a certain limit of photon energy. The lower bound is called the energy and is specifically called the "energy gap" or "band gap". Photons with energies below the band gap pass through the absorber, while photons with energies above the band gap are absorbed. Light absorption in PV cells can occur in inorganic semiconductors, organic molecular structures, or a combination of both. Electrons (e^-) in inorganic semiconductor materials such as Si have energy that falls within specific energy bands called bands. The energy bands or bands contain energy gaps between them. The "valence band" is the band on which electrons have the highest energy. The "conduction band" is called the next range of electron potential energies, in the valence band the lowest energy separates an electron in the conduction band from the highest energy of the band gap. When all the electrons in the absorber are at their lowest levels. The energy state, the valence band, and the conduction band are empty of electrons. This is the usual situation in the dark. There is no energy between the valence and conduction bands. Negative charges are generated when photons transfer electrons through a band gap, so negative charges are in the conduction band to generate a positive charge. The energy state of the electrons increases from the valence band to the conduction band due to the absorption of photons. Since there are no energy states between the valence and conduction bands, after the electrons move through the band gap, negative charges form in the conduction band and leave behind a positive charge called (H^+) holes in the valence band. Pairs of negative electrons and positive holes are formed, due to the absorption of photons in a semiconductor. In a photovoltaic cell, when light is absorbed, it causes electrons and holes to form on opposite sides of the cell's structure, where charges are collected and passed through wires connected to the cell to produce current and voltage.
hence the generation of electric power [17].

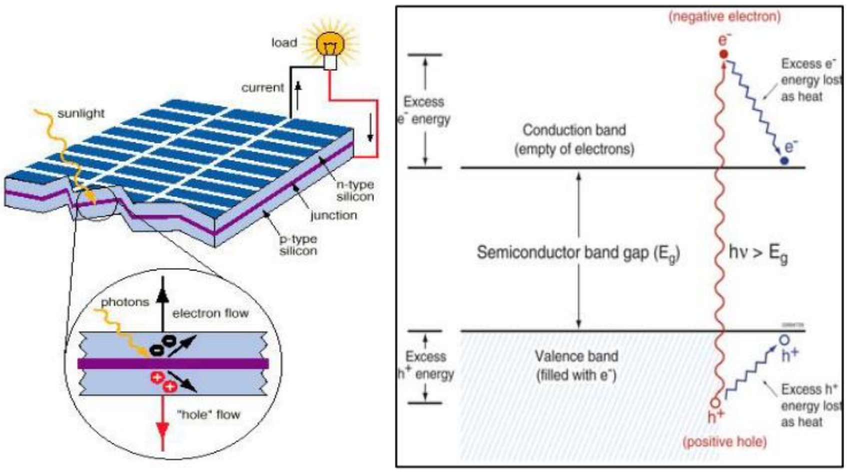


Figure 1.11. Photovoltaic energy conversions [8,17].

1.8. TYPES OF PHOTOVOLTAIC CELLS

Photovoltaic cells rely mainly on incident light, which helps the movement of electrons and holes and how to form them, which generates (electrical voltage). The efficiency of electron formation, holes, separation, and assembly is sufficient to determine the photoelectric current. Also, the difference between the energy of electrons and holes is known before leaving the cell. The electrical energy generated is the result of photovoltaic and photovoltaic cells, In partition with incident solar radiant energy, Thus the conversion efficiency of solar energy into electrical energy is determined by Peak power (W_p), which expresses the power of the solar cell generated at peak hour on a clear day. Photovoltaic cells are divided into three types:

- Cells based on solid inorganic semiconductors, called inorganic cells.
- Cells that rely primarily on organic semiconductors, and are called organic cells.
- Cells composed of a mixture of semiconductors and molecules, called photo electrochemical cells.

An inorganic solar cell contains freely moving negative electrons (called an n-type semiconductor), as well as containing holes and is freely moving positively (called a-type semiconductor). As shown in the figure below. Due to the permittivity of the p-n junction, the photogenerated electrons and holes separate and transfer to external wires to produce electrical energy. The best thing about photovoltaic cells is that they do not emit sound and do not contain moving parts [17].

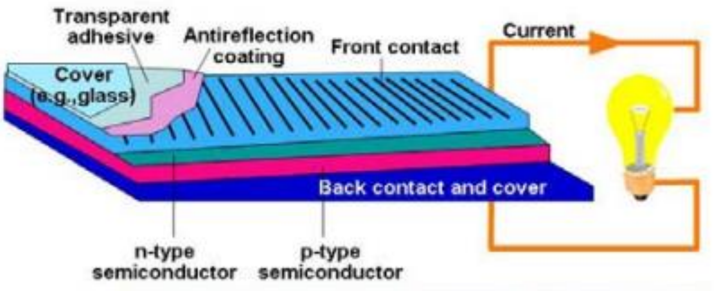


Figure 1.12.The structure of an inorganic solar cell [17].

1.9. PHOTOVOLTAİCS (PV)

It is one of the electrical power generation systems and is considered one of the best and most efficient power supply systems. It is also harmless to the environment. To increase its production and reduce its costs, companies are working hard and researching to develop cell structures. In many countries, the cost of installing panels, producing energy, and providing them to the consumer at a price close to the price of conventional electricity, makes the consumer inclined to the process of so-called self-supply of electricity. Among the advantages of photovoltaic electricity generation are:

- Reliably generating power at a low cost and with the ability to be independent of the grid.
- It is easy to install and weather resistant.
- Many small systems have started to use solar energy as a source for operating them, such as solar-powered pocket calculators, as well. For home use and large-scale installations.
- What distinguishes the photovoltaic system also is that it does not contain moving parts or is susceptible to damage by vibrations.
- Quiet and emission-free electricity generation.
- Very environmentally friendly, silicone is the primary material used in the manufacture of cells.[18].

1.10. TYPES OF PV SYSTEMS

Photovoltaic systems fall into two categories:

- Photovoltaic systems are connected to the grid.
- Independent PV systems.

Grid-connected photovoltaic systems fall into two categories:

Systems without a storage system and systems classified as Bimodal PV Sytems have storage systems. Grid-connected PV systems can also be separated into two categories: those that are directly connected to the facility and those that are categorized as two-mode PV systems. Autonomous PV systems can be divided into three categories: Battery-free, battery, and hybrid systems. Without battery systems, they are direct-coupled systems, and battery systems may include self-regulating DC systems or AC systems with a battery and load charge controller. Hybrid PV systems may include systems with wind turbines, water turbines, diesel generators, fuel cells, or other sources [19].

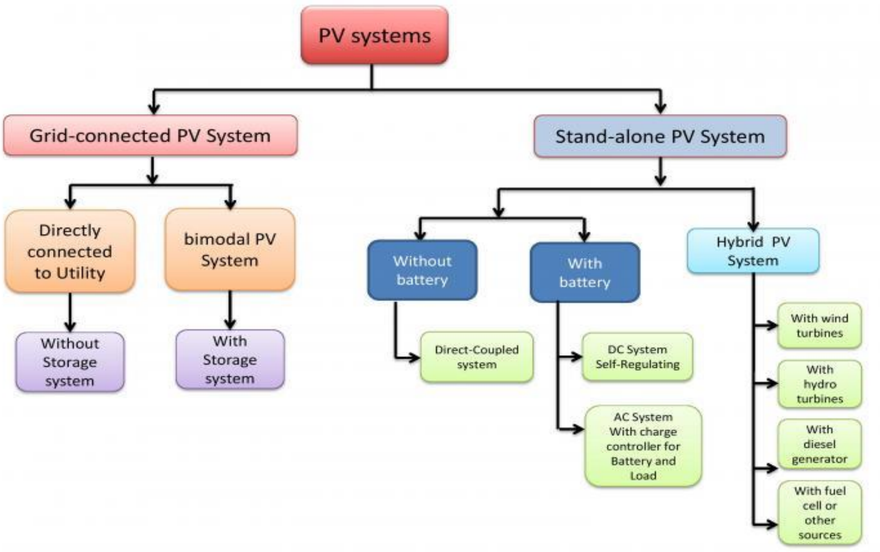


Figure 1.13. PV systems types [19].

1.10.1. Grid-Connected System Or Utility Interface (UI)

This system is used in areas where there are frequent power cuts, as the network here serves as a backup support factor, and there is certainly no need to store energy in batteries unless there is a continuous power outage from the network. This makes grid-connected photovoltaic systems relatively simple. Without the support of such a system, it is difficult to compete with the energy obtained from the grid, which is considered cheap compared to the photovoltaic systems connected to the grid. In this system, we can install PV arrays on poles as well as place them on the roof. Batteries are sometimes added as a spare if the utility network has a problem. One of the most important units in this system is the power conditioning unit, which changes the direct current into alternating current, as the energy received from the PV and before it is distributed to the loads and the utility network passes through this important unit, which maintains the quality of supply and helps to operate the photovoltaic system more efficiently Figure 1.14. At midday, and with the high cost of electricity at this time, photovoltaic systems work to save energy in the places where they are installed, and this is achieved when the cost of electrical energy is high, and photovoltaic systems installed in homes or companies are an integral part of it. Building-mounted photovoltaic panels are becoming popular as the prices of photovoltaic systems are declining and the technology is getting more mature [11].

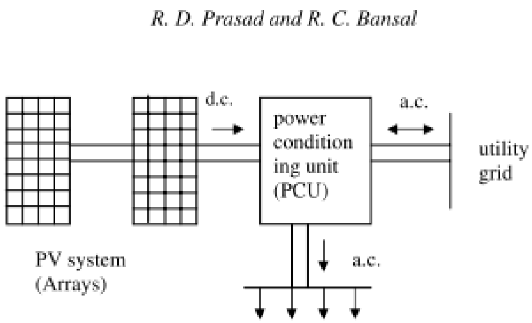


Figure 1.14. Grid connected PV system [11].

1.10.2. Stand-Alone System Or Off Grid System

In this system, the cost must be taken into consideration and compared with the cost of connecting to the site with a network or a diesel generator. To ensure the quality of the system, great care must be taken during the design of standalone systems. It is the responsibility of those using this type of connection to constantly check and maintain the battery unit. They must be prepared to adjust their power requirements and must take responsibility for the safe operation of the system in exchange for the electricity that is truly valued. For stand alone solar systems with battery storage charge controllers, inverters are important components apart from the solar panel and battery [11], as shown in figure 1.15.

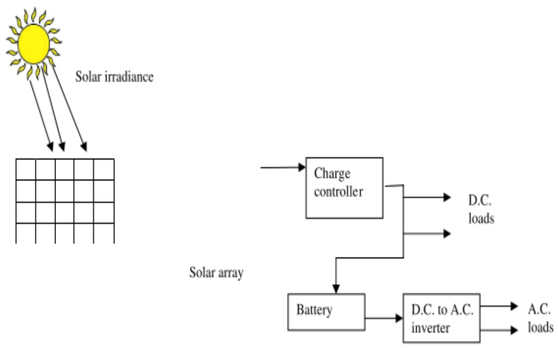


Figure 1.15 Simple schematic of stand-alone solar with battery storage [11].

1.11. THE MAIN ELEMENT OF A SOLAR POWER

The solar cell can provide a limited amount of power under constant current voltage which is not practical for most applications. Because of the limited size of the solar cell, it gives a certain amount of power which is not enough for some electrical devices. To take advantage of the electricity produced from solar cells and use it in devices that require a specific voltage or current to operate. Many solar cells are connected to form a solar cell. It is also called a photovoltaic unit. To increase production, many panels are linked together in a solar array. Solar panels are the main part of the system, but there are many other components required for the working system. It depends on whether the system is connected to a network or the system is independent. The most important components of the system are:

A structure dedicated to installing panels and directing them towards the sun. Energy storage is one of the most important parts, especially in non-grid systems, because the system can work at night or when the weather is bad. Batteries are used as energy storage units.

- DC-DC converters are used to convert the unit's variable output due to weather or other influences, to a similar constant voltage output. They can be used to charge the battery or used as an input for an inverter in a grid-connected system.
- Inverters or AC transformers are used in grid connected systems to convert DC electricity from PV modules into AC electricity that can be fed into the power grid.
- Cables are used to connect the various components of the photovoltaic system and the electrical load. It is important to choose cables of sufficient thickness to reduce resistance losses.

The electrical devices connected to the system must be taken into account during planning, as well as whether the loads are AC or DC [13].

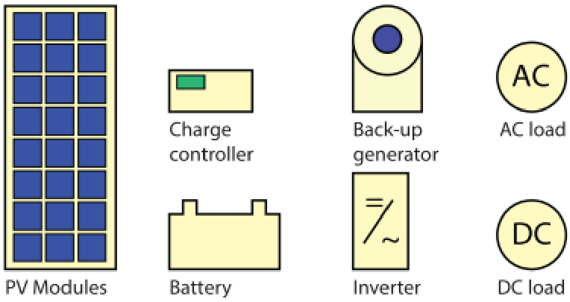


Figure 1.16. The different components of a PV system [13].

1.12. MAJOR TYPES OF PHOTOVOLTAIC PANELS

Types of PV modules can be available in two different types crystalline technology, thin film technology, and their subcategories, as shown in Figure 1.17.

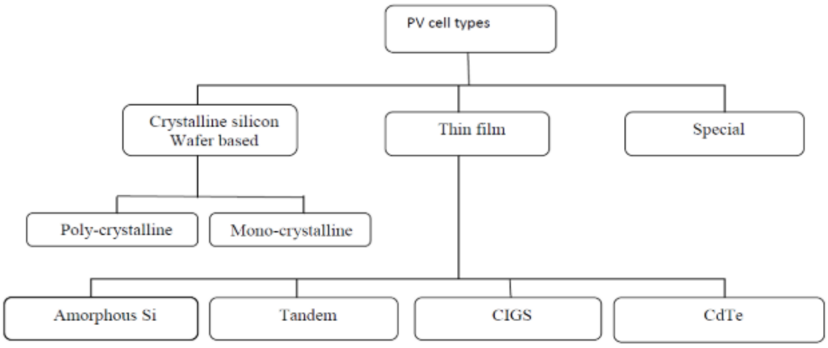


Figure 1.17. The technology is used for PV cells [8].

Table 1.1. Conversion efficiency of cell [8].

PV cell technology	Module efficiency
Mono-crystalline	20-27%
Poly-crystalline	14-18%
Copper indium gallium selenide	10-13%
Amorphous silicon	5-7%

1.12.1. Crystalline Technology

Silicon is hardly an available element globally after oxygen. It is considered one of the most important elements in making solar cells with crystalline silicon technology and a reason to rise the efficiency of the cell, as the efficiency of solar cells reaches 20% [20].

1.12.2. Mono-Crystalline Silicon

It is considered one of the ancient photovoltaic technologies. The efficiency value changes depending on the manufacturing method. High purity single-crystal silicon cells are manufactured by cutting the manufactured rods into wafers. The efficiency of a cell made of pure monocrystalline silicon reaches 17-18%. The Czochralski method was invented by chemist Jan Czochralski in 1916 and is applied to obtain monocrystalline silicon cells. Silicon is n-type or p-type depending on the type of impurity added to the cell, such as boron or phosphorous, which contributes to changing the electrical properties of the cell. Although the efficiency value varies depending on the manufacturing methodology. This additive is useful for increasing electrical conductivity. The appearance of the monocrystalline cell is blue, black, or dark [20] as seen in Figure 1.9.

Figure 1.18. Monocrystalline silicon cell [20].

1.12.3. Multi-Crystalline Silicon

These cells are formed by melting silicon and pouring it into a rectangular covered with a graphite crucible, then cut into rods and then flakes. This technology is one of those technologies taken from crystalline silicon technology, but it is less efficient than monocrystalline cells and also less expensive. The efficiency of crystalline silicon cells ranges from 13 to 14%. Currently, cells can be produced with an efficiency of up to 22.3% in a laboratory environment, and production efficiency is widely ranged between 14-20% [20].

1.12.4. Thin Fim Technology

Thin-film PV modules do not cost much material such as crystalline silicon as exampled in Figure 1.10. About 35 to 260 nm is the thickness of the cell. Thin-film PV modules use less materials and are more efficient manufacturing processes compared to crystalline silicon. The semiconductors are deposited on a coated glass, stainless steel, or polymer substrate. The average conversion efficiency of the cell is 7-10%. Because of its inefficiency, this type of cell needs large areas to compensate, so land unsuitable for cultivation is considered a suitable place for this technology.

The three main technologies for thin-film photovoltaic cells in the sector are copper, indium, gallium, selenide, amorphous, silicon, and cadmium telluride [20].

Figure 1.19. Thin film solar cell [21].

1.12.4.1. Amorphous silicon thin film technology

As this type of technology is a reliable source of energy, it is widely used in delicate objects such as watches, calculators, and electronic equipment. This technique, which is considered one of the old techniques, is made from the deposition of silicon thin film cells by a chemical vapor deposition method, from silage gas and hydrogen gas. This deposition leads to (amorphous silicon, crystal silicon, and nanocrystalline silicon). Although the production cost is low, the energy conversion effectiveness of this type is lower than that of cells made of silicon. Because of the small number of charge carriers collected for photons, the thin-film solar cells' quantum efficiency is lower. The efficiency is up to 14%. Primary silicon is considered optimal for high voltage open circuits because it contains a small portion of nanoscale silicon [20].

1.12.4.2. Cadmium telluride thin film technology

Because cadmium telluride (CdTe) is a crystalline compound, it is one of the semiconductors, so it is effective for absorbing light. In vitro, the efficiency of cadmium reaches 16%. Compared with other thin films, CdTe is easier to deposit and lower cost. Where many units can be produced. Because cadmium contains good physical properties, it can work at the lowest level of light and convert it into electricity more efficiently than conventional cells. The problem of cadmium pollution and its limited availability are among the main concerns of this technology [20].

The Figure below shows models of solar modules based on the type of silicon cells, whereas we have previously shown that the majority of solar cells are made of silicon [22].

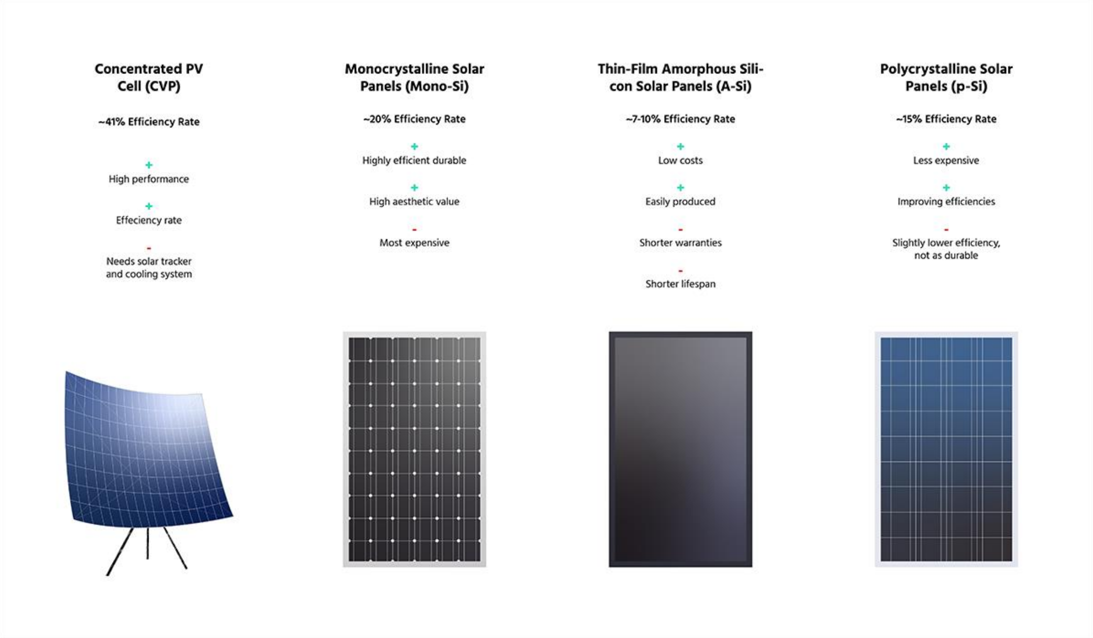


Figure 1.20. Models of solar modules [22].

1.13. SOLAR PANEL COOLING TECHNOLOGIES

Solar energy harvesting facilities must be improved to improve the economic return. The main objective of developing solar power systems is to maximize the energy conversion efficiency from solar power to electrical energy and improve its production. The total solar energy falling on the panels is a function of several variables, day, time, latitude, longitude, the orientation of the panels, and ambient weather conditions [11]. The efficiency of the panels is decreased by the increase in temperatures due to the transformation of 50% or more of the solar radiation into harmful heat for the panels. Solar panels vary in efficiency according to the material the panels are made of. Several studies have been conducted to eliminate the overheating of the panels to increase their efficiency. There are many ways to cool panels, including:

- Jet crash.
- Air-flow Cooling.
- Cooling by immersion in liquids.
- Electrothermal cooling.
- Small duct cooling.
- Phase change cooling (PCM).
- Liquid direct applied cooling and liquid circulated heat pipe cooling.

As shown in Figure 1.11 [23].

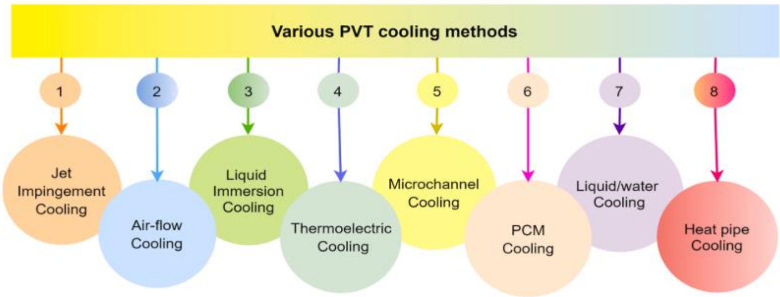


Figure 1.21. Schematic diagram of uniform cooling methods [23].

1.13.1. Nanofluids

Scientists and researchers define nanofluids as a mixture of small nanoparticles ranging in diameter from 1 nanometer to 100 nanometers, well mixed with a liquid considered basic such as ethylene, water, glycol, and thermal oil. The improvement of system performance mainly depends on the properties of the nanofluid in terms of thermal conductivity, viscosity, specific heat, heat capacity, and heat transfer coefficient. The higher the thermal conductivity of the nanofluid, the higher the heat transfer rate, and this leads to an increase in the overall efficiency of the system.

Nanoparticles are classified into three types

- Carbonate particles.
- Particles of basic minerals.

- Nano compounds.

The Figure 1.22 shows in detail the classification of nanoparticles.

The physical properties of the liquid mixed with the nanocomposites are improved because the nanocomposites have high thermal conductivity and can withstand heat. This is one of the reasons for the improvement of the system and the lower cost of its operation. As the nanocomposites increase the chance of nanofluids absorbing solar radiation and as a result, the temperature of the cells decreases, and the nanofluids can be considered as an optical filter. Several advantages and challenges are associated with the use of nanofluids in a solar thermal photovoltaic (PV/T) system [24].

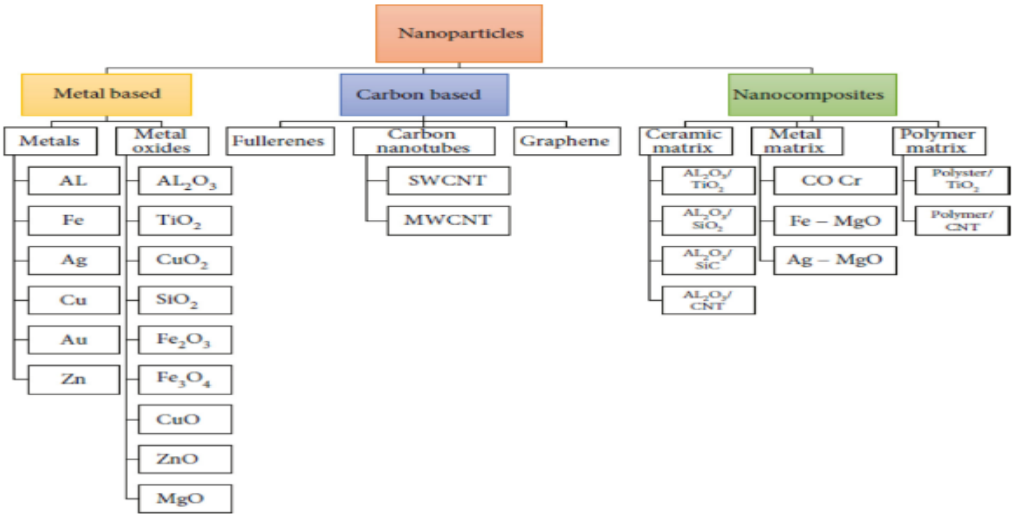


Figure 1.22. Nanoparticles [24].

1.13.2. Features of Nanofluids

- Nanofluids have a high rate of heat transfer, much better than water or oil.
- Nano liquid has better optical properties than water and oil.
- Because of the small size of the nanoparticles and their large surface area, the heat capacity and absorption are very high when compared to the traditional liquid.

- Because of the smallness of the nanofluids, they are free from the problems of sedimentation, fouling, and clogging.
- Nanofluids are thermally stable over a wide range of temperatures.
- When heat is absorbed and reduced, nanofluids are a source of protection for the material.
- The possibility of heat transfer with a high density of convection causes an increase in the efficiency of the system.
- The cost of the solar system is reduced due to the use of nanofluids due to the decrease in the heat transfer area of the solar system [24].

In this thesis, three 20 W photovoltaic panels are designed. One of the boards used a coil of copper tubing tied to its back and the second back of the plate is connected to a polyamide structural channeled block to circulate cooling nanofluid that is Al_2O_3. The thermal and electrical gains are temperature, voltages, amperages, power, electrical, thermal efficiency, and the total efficiency which is gotten from the three systems were compared. Literature related to the subject of this study is presented in Part 2. Theoretical base relations of the applied cooling theory are presented in Part 3. The experiment and its methods are explained in Part 4. The findings and suggestions are presented in Part 5. Concluded results are given in Part 6. Finally, the summary of the study is seen in Part 7.

PART 2

LITERATURE REVIEW

After renewable energy systems became a reality and the demand for them increased, efforts of researchers continued to improve their efficiencies, including increasing the gain of the solar panels. In the literature, we explain some research on the cooling of photovoltaic energy to increase its efficiency.

Gupta et al. studied a nanoscale solar collector (PV/T) system. Specific ratios of nanofluids were selected and the overall solar power system efficiency, thermal efficiency, and electrical efficiency were improved, found that the behavior of the solar power system was enhanced by the exploitation of high thermal conductivity nanofluids [24].

Abdo and Saidani studied cooling solar panels experimentally by using hydrogel spheres impregnated with Al_2O_3 aqueous nanoparticles at different concentrations. This was compared with panels cooled using only water. The panel temperature decreased by about 17.9°C, compared with reference panel [25].

Al-Zaabi et al. searched the action of low temperature on solar panels' electrical power production capability by using cooling water. They compared the system with and without cooling to see the improvement in efficiency. They gain an enhancement in electrical efficiency of approximately 15-20% [26].

Cui and Zhu obtained a higher efficiency of the system after studying pouring nanofluids on the front of the panels to get greater cooling. Experiment with different nanoscale measurements [27].

Schiro et al. Theoretical and experimental analyses were performed using water to cold a front face of a solar panel without changing the panel structure or composition. Overall energy gain was calculated [28].

Elminshawy et al. worked on decreasing the temperature of photovoltaic panels with a buried heat exchanger with atmospheric air being pushed at different temperatures and flow rates as well. The airflow is concentrated at the back surface of the photovoltaic module. The study sought to increase efficiency [29].

Al-Waeli et al. studied an experimental and theoretical investigations for a proposed study of three different types of cooling for solar panels. Where they used the method of cooling with water and a reservoir filled with PCM and PCM/nano-SiC. The nanofluid was passed into the cooling tubes, and it was found from the results that nano-PCM and nanofluid improve the electrical efficiency in good proportions, compared to photovoltaic cells without cooling [30].

Kabeel and Abdelgaied worked to solve the problems of freshwater production in rural areas. The study relied on the cooling of solar panels, reflectors were used to increase the concentration of radiation, with air being pumped to cool the panels. An increase in electricity production and the overall efficiency of the system were recorded [31].

Elminshawy et al. worked on the improvement production of a V-trough PVwith a connection to a cooling system using water and a heat exchanger. The new system was able to cool the panels by a difference of 32.2°C at most, and a remarkable increase in the production of electrical energy was generated, and electrical energy increased by 28% [32].

Bahaidarah et al. studied the performance of the PV module, after the attachment of the heat exchanger on the backside of the photovoltaic panel, the heat of the board was reduced to about 20%, which increased the efficiency to 9% [33].

Ali et al. researched to study the improvement of plate cooling efficiency using nanofluids. The panels have been cooled and the efficiency increased. They found that by increasing the concentration of nanomaterials in specific quantities, and by increasing the flow, the efficiency increases [34].

Rajasekar et al. work on a study whose purpose is to low cooling the solar panels by spraying water as a thin layer on it and the back surface is filled with coconut pulp. It was found from experience that the overall efficiency of a photovoltaic panel cooled by coconut pulp and using a clay pot increased by 64%, outperforming the rest of the panels [35].

Dorobantu and Popescu studied using water to cool the solar panels. They get a 9.5% increase in electrical yield by lowering the plate temperature [36].

Joy and Zachariah studied plate cooling by circulating a mixture of ethylene glycol and water on the back-side of the panels. The average electrical efficiency without cooling was 9.56% and with cooling with water and ethylene glycol was 10.69% and 11.23%, separately. The mean thermal efficiency of the panels was 46.18%, and 17.94% using water and ethylene glycol separately [37].

Fudholi et al. calculated the behavior analysis of PVT water collectors, by using a liquid as water as a coolant, it was found through studies that both energy efficiency and thermal efficiency increase [38].

Rukman et al. designed a cooling system mostly focused on water and air-based PV/T systems. The design goal is to expel heat in the solar panels and reuse the hot air and water appropriately. An increase in photovoltaic and thermal efficiency was recorded [39].

Sanchez et al. researched the optimal operation of the solar power plant. Deal with the change in temperature and radiation throughout the year. The results were obtained theoretically by simulation, to improve the temperature in the station [40].

Rajvikram and Sivasankar studied cooling the panels, using PCM by adding finned to get better the thermal conductivity of PCM. It has been shown that PCM supported by a heatsink is an effective method to lower the heat of the PV panels and increase the efficiency of the photovoltaic panel [41].

Abdo et al. studied the use of seawater to cool photovoltaic panels using brine impregnated activated alumina. Different proportions of saline solution were used with different radiation intensities [42].

Ghadikolaei worked by cooling the solar panels with water pressure technology, the cooling had a positive on the panels and shows the gain of the PV was rising [43].

Karaaslan and Menlik studied experimentally develop the behavior of solar cells by lowering their temperature. Hybrid water nanofluids and ethylene glycol were used. An increase in system efficiency has been reported [44].

Nizetic et al. studied Air cooling was carried out with fins installed on the back surface of the solar panel. A system showed an increase in efficiency [45].

Lari and Sahin studied the demand for hot water in any building. The nano-liquid cooled photovoltaic/thermal system was designed. the electrical becomes greater an 11.7% in solar panel systems [46].

Peng et al. calculated the effectiveness of heat on the gain of PV panels. An ice contact cooling test was carried out on the back surface to show improvement in efficiency after ice-cooling. The increase was 47% in terms of efficiency [47].

Castanheira et al. worked on a project to cool off a 20 kW solar power plant. The cooling assembly is designed to reduce its cost as well as to reduce the amount of water used. Experimental test results showed the possibility of raising gain yearly by 12%, up to 17%, and decreasing the temperature to more than 30°C [48].

Siakamar et al. used an innovative phase change material (PCM) to cool solar panels. They used sheep fat to increase the efficiency of panels and added copper nanoparticles, and then compared with cooling by using paraffin wax. The sheep fat and paraffin wax presented a good result, but sheep fat is best than paraffin wax. When adding copper nanoparticles to sheep fat they noted a decreased temperature of the PV panel higher than the rest of addition the materials [49].

Rajput and Yang studied using cylindrical finned heat sinks to cool plates. Using a pin fin heat sink. The results achieved a temperature drop of 58.4°C with the heat sink [50].

Abdo et al. worked on a new experimental study using hydrogel pellets to cool solar panels. It was compared to the uncooled system. The best values were obtained by using 3 lines of fin hydrogel granules. The chipboard heat decreased by 14% of the value of the uncooled chipboard, and the generation efficiency of the plate was raised to 7.2% compared to the uncooled plate [51].

Sarafraz et al. attempted to decrease the heat of the PV panels and improve the production of both electrical and thermal energy for the PV/T collector system and it was covered by a cooling cover filled with PCM paraffin. He used a PCM with a carbon nanotube. The experiment showed when using this cooling system a rise in electricity output and thermal production by 20% and 130% separately. [52].

Al-Khanjari et al. theoretically worked out using the nanofluids to get better the output of the PV/T collector, and used computational fluid simulations using pure water and nanofluid of Ag and alumina. The results that nano of Ag has the best [53].

Jamil et al. experimented with three different PCM devices based on nanoparticles to lower the heat of the solar panels and rise the electrical efficiency. Use of graphene nanomaterials and magnesium oxide nanoparticles. The highest performance of the photovoltaic panel was obtained when using graphene nanomaterials. The percentage of increase in electrical energy was 33.07% [54].

Irwan et al. presented an experiment that sprayed water on the front of the surface of a PV panel. The experiment showed a rise in electrical efficiency [55].

Bahaidarah et al. they used a water-cooled crossbred system. They reduced the heat of the solar panel to about 20% and increased the efficiency by about 9% [56].

Badgujar and Sarda presented the design for cooling PV panels containing simple cooling channels using a polycrystalline PV panel. The results were a lower plate temperature of 27.5°C, upon irradiation of 895 W/m², and a 1.61% increase in overall efficiency [57].

Bijjargi et al. calculated the raised temperatures on the performance of PV solar, they connected a screw tube and considered it as a heat exchanger at the same time and added a fan to the backside of the panel. The heat was reduced, which increased the gain of a system by a value of 12-14% [58].

Yasodai et al. experimentally worked to cool photovoltaic panels using an automation system for solar panel cooling when using a commercial sensor equipped with a RISC-based microcontroller. It considers an effective style to decrease the temperature of PV panels with less cost. The efficiency of the solar panel is improved from 3% to 5% [59].

Rasham et al. did a study on interrupted and continuous water cooling to goodness the thermal performance of PV modules. They achieved a betterment in electrical efficiency and output power [60].

Bashir et al. analyzed a water cooling system to absorb heat from photovoltaic cells by labor on the backside of a surface by entering the flow of water across hols. The temperatures were taken at the different points on the backside of the panels and the inlets and outlets of water. Temperatures of panels are decreased, efficiency was raised, and noted that the total power output of the system has gone up [61].

Abdulmunem our types of filters (red, yellow, blue, and green) are installed. The effect of filter colors on solar panels on temperature rise and electrical performance has been studied. The results came out with the photovoltaic technology that was affected by color filters. The violet filter gave the light that contains the most photons energy, that is, it gives the lowest temperature, and gives the best electrical performance. The results also showed that there are two factors influenced by the behavior of PV panels, namely, the wavelength of solar light and the temperature of the photovoltaic panels [62].

Gotmare and Prayagi presented a practical experiment on Optimizing the behavior of the solar panels by jointing a cooling device to the backside of the PV panels. Note increasing with the value of the current after cooling, as well as higher energy and electricity efficiency [63].

Elnozahly et al. experimentally examined the performance by automatic cooling and cleaning the front of the PV panels. Results arrive at about 45.5% and 39% in the unit temperature on the front and back sides, respectively. As a result, the efficiency of the cryogenic unit and surface cleaning is 11.7% compared to 9% for the unit [64].

Ali et al. studied theoretically and experimentally the cooling of PV panels and performed CFD calculations of a solar panel using micro-channel cooling. They used a monocrystalline cell where two 35 W plates were made for the experiments; The results came out that the panel temperature decreased by 15°C, and caused an increase in power by about 14%, with a flow rate of 3 L/min [65].

Masalha et al. tried to decrease the heat of the solar panels by using a 10 mm spherical porous glass media-packed cooling tube on the back surface. They used three different cooling ducts thickness. Using water quenching with porous glass media, the temperature drop using water reached 20.5%, while quenching using porous glass media reached 42.17%. The cooling channel has a thickness of 5 cm and a low volume ratio of 2 L/min, which is an ideal condition for refrigeration. The power after pore cooling increased to 12.07 W [66].

Salih et al. suggested investigation and improvement of photovoltaic array efficiency and energy saving. They used spraying and forced water cooling and implemented them at a fixed flow rate on the front surface of the PV panels. Where the rate of water spraying during the work plate is every five minutes. The electrical performance of the panels is improved. It achieves economical results due to an increased energy savings of 7 W in the middle of the day [67].

Salameh et al. studied on cooling solar panels and improving their efficiency, numerical simulations were carried out on PV / T systems. By connecting an eleven-channel cooling system arranged symmetrically to each other on the rear side of the PV. The highest thermal efficiency was 68% at the flow of 5.4 L/min [68].

Wu et al. air cooled PV/T systems performance check. Cooling channels were connected above and below the solar panels. The efficiency value changes when the air inlet temperature is different [69].

Vittorini and Cipollone presented the modeling of a finned cryogenic PV module in an external case. Fin capabilities have been developed to control unit temperature and improve electrical efficiency [70].

Chandrasekar et al. implementation of a new method for cooling the PV module at work. They used cotton priming for PV modules to cool them, and added Al_2O_3/ nanofluid and CuO/aqueous nanofluid. The maximum output power is found with a maximum unit efficiency of 10.4% [71].

Baloch et al. conduct an experimental implementation of a cooling technology called a convergent channel. The temperature has been drastically decreased to 45.1°C and they got 35.5% of the energy output [72].

Karami and Rahimi created cooling channels with water and nanofluids containing Boehmite. Water performed less than nanofluid. and using the nanofluid led to a higher lowering in the average temperature of the solar cells. and obtain higher electrical efficiency [73].

Jing et al. prepared highly dispersed aqueous/silica nanofluids with different molecular sizes. The use of nanofluidic increased efficiency by 7% [74].

Zhang et al. discussed the installation of applied on PV panels systems with a porous cooling channel. After several numerical calculations, increased the heat transfer in the channel, overall efficiency was boosted by 18.04% with increased flow [75].

Rahim et al. designed a conical wind tunnel cooling device to use the wind to decrease the heat in a PV cell. Results showed the total energy output was increased by 36% [76].

Valeh et al. provided experimental data After installing a double flow of water and air in a solar cell. The presented system can increase the efficiency of the panels [77].

Yang and Zuo installed a cooling system with a multi-layer to cold the front surface temperature of the solar cell and standardize the surface temperature distribution. They got a higher efficiency [78].

Younas et al. they experimentally applied simple cooling channels using a polycrystalline PV panel. They observed a temperature decrease of 27.5°C compared to a reference PV panel. This also resulted in an estimated 1.61% efficiency increase and a 12.85% performance increase for the photovoltaic cell [79].

Duan worked on a PCM composite with metallic foam as a heat sink to cool photovoltaic (PV) panels. He experimented with several different tilt angles (φ = 0°, 30°, 60°, 90°). Changing angles had no apparent effect on PV cooling [80].

Arshad et al. used mirrors to increase the concentration of solar radiation while connecting a cooling system to the panels The cooler the solar cells, the more efficiently the system works in focused light. The total output of solar panels is up to 52% [81].

Hossain et al. presented an experimental to development of PV/T-based serpentine tubes for flow. The maximum efficiency of PV was found to be 7.16% and the efficiency of PV was 9.89%. Rely on different flow levels [82].

Zanlorenzi et al. investigated the ability to reduce the temperature of photovoltaic panels using water automatically. After the experiment, the operating temperature declined and the gain of the photovoltaic panel increased by 33.28% [83].

Khanna et al. used a PCM to lower the heat of solar panels. They were able to increase the power and enhance the electrical effectiveness provided by using PCM in different working conditions [84].

Emam et al. improved the performance of the inclined concentrated phase variable material system by changing the tilt angles. Achieved 45° Better electrical efficiency of cells, and help prevent solar cell hotspots [85].

Haidar et al. studied theoretically and experimentally the cooling of photovoltaic panels by evaporation. They obtained a 14% increase in solar panel efficiency after lowering the panel temperature by more than 20°C [86].

Ebaid et al. experimentally studied the cooling of photovoltaic panels using Al_2O_3 nanofluid, polyethylene glycol, and water as cooling mediums under different irradiation intensities. However, the Al_2O_3 nanofluid showed better performance. Higher efficiency is obtained for cooled plates compared to uncooled plates [87].

Fakouriyan et al. studied the reduction of solar cell temperature in a simplified manner and without high costs. Where they added a water cooling system that makes the panel temperature completely equal. The came out that the overall energy efficiency rise to 61.7% [88].

Bhattacharjee et al. for a plate-lowering study introduced three new absorbent designs, semi-elliptic, helical, and semi-circular serpentine, and placed them on the back surface for cooling purposes. The semi-flat helical design was the most efficient. Efficiency increase reached 4.32% [89].

Nizetic et al. worked on PV panel cooling, with water spraying on panel surfaces. The heat of the panels was minimized from 54°C to 24°C. 16.3% rise in electrical energy production and 5.9% rise in electrical efficiency of the photovoltaic panel using cooling technology [90].

Alami presented a study on reducing the heat of a PV panel with evaporative technology, with an integrated layer of clay at the back of the unit, and this layer of clay let the water evaporate. It is well known that clay is inexpensive and effective, and environmentally friendly. The results were a 19.4% enhancement in the outcome of voltage and a 19.1% increase in outcome power [91].

Odeh and Behnia suggested a cooling system for solar panels, where the photovoltaic panel is cooled by introducing the formation of water droplets on the front surface of the panel. The outcome shows a rise of about 15% in system output [92].

Wongwuttanasatian et al. used palm wax as a phase changer. Design three different enclosures for PCM, such as fluted, tubular, and fin enclosures. The cooling with finned showed was the best. They discovered that palm wax can using it with cooling. The plate temperature decreased by 6.1°C. Module efficiency is improved by 5.3% [93].

Jasim et al. experimentally studied the cooling of PV/T collectors considering two different flow arranged liquid flow circulated loop to enhance electrical gain relative to PV module. They get enhancement in electrical performance with different rates in two different flow arrangements [94].

Nizetic et al. discuss theoretically the effect of the back surface of a photovoltaic panel its effect on temperature distribution, and its effect on efficiency. According to the results, a proposal was made to redesign the backside of conventional solar panels to increase their efficiency. The lower the temperature of the panels, the higher their efficiency [95].

Bahaidarah studied experimentally and theoretically the feasibility of jet impact cooling of photovoltaic panels and the impact of cooling on panels. The temperature of the photovoltaic panels has been reduced for several months. Energy production and conversion efficiency have also been increased through the use of jet cooling [96].

PART 3

THEORETICAL BASE OF STUDY

Energy relations:

The energy balance equation can be shown in Eq. (3.1) and specified for the PV module and PV/T collector as in Eq. (3.2) and Eq. (3.3):

$$\Delta E = \sum E_{in} - \sum E_{out} \tag{3.1}$$

Eq. (3.1) gives us a description of the system energies for both the input and the output. If the system is stable, the resultant change in energy will be zero.

$$\dot{E}_{solar} = \dot{E}_{electrical} + \dot{E}_{heat\ loss} \tag{3.2}$$

$$\dot{E}_{solar} = \dot{Q}_{thermal} + \dot{E}_{electrical} + \dot{E}_{heat\ loss} \tag{3.3}$$

The equation is applied to the PV module and it is also applied to the PV/T collector as in Eq. (3.4):

$$\dot{E}_{solar} = SA_{PV.area} \tag{3.4}$$

In Eq. (3.4), S presents solar irradiation. The electrical power gained from the module and PV collector can be determined with Eq. (3.5):

$$\dot{E}_{electrical} = VI - \dot{W}_{pump} + \dot{W}_{heat\ ex.fan} \tag{3.5}$$

In Eq. (3.6), the heat loss was calculated from the PV/T collectors and the PV module [97]:

$$\dot{E}_{heat\ loss} = hA(T_{surface} - T_{environment}) \tag{3.6}$$

The mass balance for the circulated cooling fluid can be written for the PV/T collector as in Eq. (3.7):

$$\Delta\dot{m}_{fluid,net} = \sum \dot{m}_{fluid,inlet} - \sum \dot{m}_{fluid,outlet} \tag{3.7}$$

In case of steady fluid circulation $\Delta\dot{m}_{fluid,net} = 0$, the net change of mass is zero. Calculate the heat removed from the PV/T collector with a circulating fluid in Eq. (3.8):

$$\dot{Q}_{thermal} = \dot{m}_{fluid} c_{fluid} (T_{fluid,outlet} - T_{fluid\ ,inlet}) \tag{3.8}$$

Thermal efficiency and Electrical for PV module and PV/T collector can be defined in Eq. (3.9) and Eq. (3.10) [98]:

$$\eta_{electrical} = \frac{\dot{E}_{electrical}}{\dot{E}_{solar}} \tag{3.9}$$

$$\eta_{thermal} = \frac{\dot{Q}_{thermal}}{\dot{E}_{solar}} \tag{3.10}$$

The first law efficiency of the systems can be equated as in Eq. (3.11):

$$\eta_o = \eta_{electrical} + \eta_{thermal} \tag{3.11}$$

Exergy relations:

General exergy balance is written as in Eq. (3.12):

$$\Delta\dot{E}x = \dot{E}x_{inlet} - \dot{E}x_{outlet} - \dot{E}x_{destroyed} \tag{3.12}$$

The exergy change of the system is equal to zero for the steady-state process. The exergy balance for the PV and PV/T collector can be specified as in Eq. (3.13) and Eq. (3.14).

$$\dot{E}x_{solar} = \dot{E}x_{electrical} + \dot{E}x_{thermal} + \dot{E}x_{destroyed} \quad (3.13)$$

$$\dot{E}x_{solar} + \dot{E}x_{fluid,inlet} = \dot{E}x_{electrical} + \dot{E}x_{fluid,outlet} + \dot{E}x_{destroyed} \quad (3.14)$$

Exergy solar can be written as in Eq. (3.15) [99].

$$\dot{E}x_{solar} = \dot{E}_{solar}(1 - \frac{4T_{environment}}{3T_{sun}} + \frac{1}{3}(\frac{T_{environment}}{T_{sun}})^4) \quad (3.15)$$

Thermal exergy of the PV module and PV/T collector be written as in Eq. (3.16) and Eq. (3.17) [100].

$$\dot{E}x_{thermal,PV} = \dot{E}_{heat\ loss}(1 - \frac{T_{environment}}{T_{sun}}) \quad (3.16)$$

$$\dot{E}x_{thermal,PV/T} = \dot{E}x_{fluid} \quad (3.17)$$

Mass flow exergy for the PV/T collector can be presented as in Eq. (3.18) [101].

$$\dot{E}x_{fluid} = \dot{m}_{fluid}\,(ex_{fluid,outlet} - ex_{fluid,inlet}) \quad (3.18)$$

Electrical exergy can be described as in Eq. (3.19) [102]:

$$\dot{E}x_{electrical} = \dot{E}_{electrical} \quad (3.19)$$

Destroyed exergy can be written as in Eq. (3.20):

$$\dot{E}x_{destroyed} = \dot{E}x_{inlet} - \dot{E}x_{outlet} \quad (3.20)$$

The second law of efficiency for PV and PV/T collectors can be written as in Eq. (3.21) and Eq. (3.22) [103]:

$$\eta_{ex} = \frac{\dot{Ex}_{electrical} - \dot{Ex}_{thermal,PV}}{\dot{Ex}_{solar}} \tag{3.21}$$

$$\eta_{ex} = \frac{\dot{Ex}_{electrical} - \dot{Ex}_{thermal,PV/T}}{\dot{Ex}_{solar}} \tag{3.22}$$

PART 4

METHODOLOGY

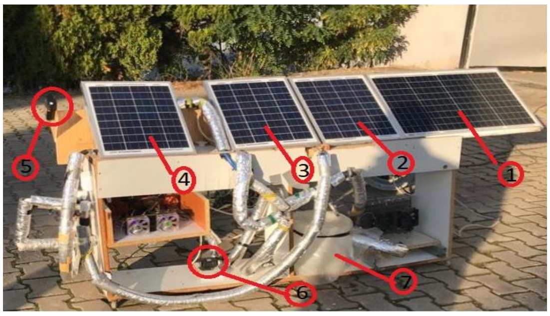
4.1. EXPERIMENTAL SETUP AND MEASUREMENT PROCEDURE

In October month of 2021, practical experiments were conducted. For seven hours between 10:30 to 17:00 on sunny days. When we experimented, the atmosphere temperature, the PV panel back surface temperature and PVT's collectors, solar radiation, voltage, and current of the panels produced were measured. The experiment used three 20 W polycrystalline solar panels; its properties are shown in Table (4.1). The first panel was a reference panel, the second one (PV/T1) has a coil of copper pipe fixed on its back. The third one (PV/T2) The back surface is glued with a polyamide channel structure block (30×30) cm in size and 18 mm in thickness for cooling. PV/T collector back sides and piping are isolated with aluminium tinfoil isolation material. Properties of solar panels are given in Table 4.1.

Table 4.1. Characteristics of the solar panels used.

Peak power (P_{max})	20 W
Voltage for the open circuit condition (V_{oc})	22.10 V
Voltage value for peak power (V_{mp})	18.00 V
Current value for peak power (I_{mp})	1.11 A
Module class	Class A
Current for short circuit case (I_{SC})	1.35 A
Size (mm)	360x43,5x17

The fluid used as a coolant in the experiment was water compared with nanofluid Al_2O_3 in closed-type circulation. For temperature measurement, ten thermocouples were used. were positioned on the back surface in the middle point of the panel, which is used in three panels, and four of them were used to measure coolant flow temperature by placing them on the heat exchanger and in the inlet and outlet of the panel flow line. These thermocouples are connected to a datalogger. The coolant is circulated by a 19 W DC pump, which is supplied with power from an additional solar panel. The liquid starts from the pump to the inlets PV/T1 and PV/T1, and then to the heat exchanger before returning to the liquid tank. The flow was measured by a digital flow meter, with a volume of 0.4 litres per minute. The temperature entering and exiting the heat exchanger was measured by a pair of thermocouples. The voltage and current of each module were also recorded every five minutes using the voltage and current measurement circuit shown in Figure 4.1.



1- Power supply panel.
2- Reference panel.
3- PV/T1.
4- PV/T2.
5- Solar meter.
6- circulation pump.
7- Coolant tank.

8-Flow meters.
9- DC volt-Amp meters.
10- Datalogger.
11- Heat exchanger.

Figure 4.1. Experimental setup visualization.

The equipment of the experiment setup and the measurement instruments are seen in Table 4.2.

Table 4.2. Technical specifications of setup equipment and measurement instruments.

Measurement value	Device	Properties	Parts and details	
Solar radiation	TES 1333R solar power meter	Irradiance range: 0-2000 W/m^2 , accuracy: ± 10 W/m^2 or ±5	Fan	12V, 0.15A
Data collection	Elimko E680 datalogger	Working ranges −5 to 55°C - 85–265 V AC, Standard working limits −200 + 1300°C	Heat exchanger	Aluminium finned copper tube heat exchanger
Temperature	Type K thermocouple,	-75°C _ +260°C Length 2m	Pump	12V DC, 19W
Modules power	14.7 ohm load,	20W aluminium resistance	Power supply panel	50W monocrystal, 424 mm x 674 mm x 25 mm
	Dijital DC volt amper meter	Operating voltage: DC 4.5~30V Voltage measurement: DC 0 ~ 100V Current measurement: 1A ~ 10A		

PART 5

RESULTS AND DISCUSSION

PV module and PV/T collectors were tested experimentally on a clear day in October. These parameters are ambient temperature, solar radiation, PV panel's backside temperatures, and produce the current and voltage were measured, where the rate flow of the coolant fluid was constant. The solar radiation and Ambient temperature are presented in Fig. 5.1.

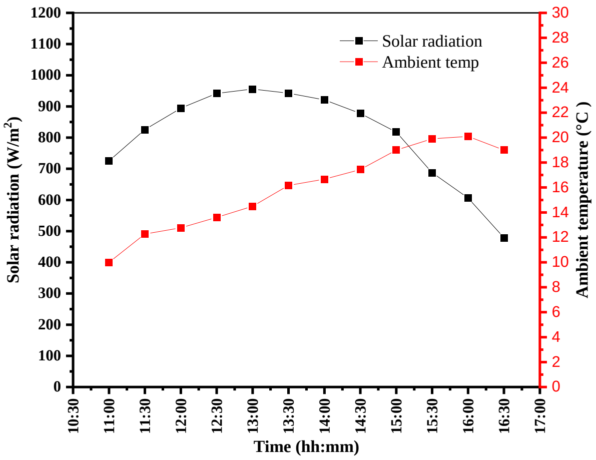


Figure 5.1. Solar radiation and ambient temperature.

While the ambient temperature in the first half-hour was 10°C and reached 14.5°C at 13:00 The radiation has arrived at its highest level. It variated in the range of 19°C and 20°C till the end of the experiments. At the start, the solar radiation was 725.5 W/m^2, and the maximum value during the experiment was 955.5 W/m^2, and the afternoon started decreasing until 479 W/m^2 at 16:30. PV panels' backside temperatures are visualized in Figure 5.2.

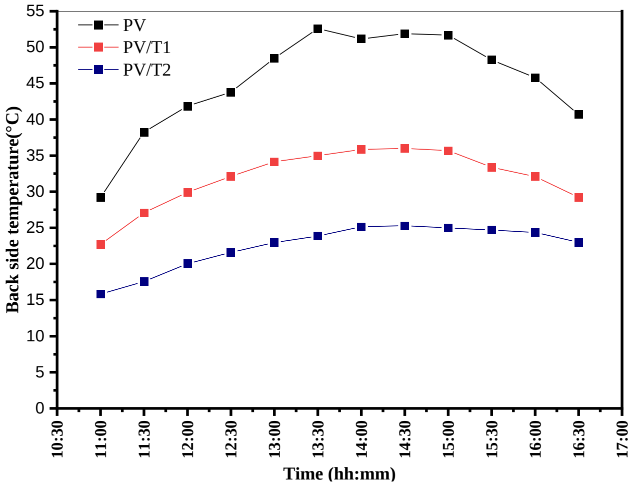


Figure 5.2. Backside temperature of panels.

As seen in Figure 5.2, the reference panel's temperature was 29.2 ºC in the morning and the max backside temperature value was 52.6°C at 13:30, and 40.7°C at 16:30. The mean temperature for the PV module in the experiment was 45.3°C. PV/T 1 collector which was cooled with copper pipe installation, the average temperature through the experiment time was 31.94°C. When the temperature, in the beginning, was 22.7°C, and at 13:30 it was 36°C and 29.23°C at 16:30. For PV/T2 collector with channelled flow installation, the average backside temperature was 22.45°C, where it was at 11:00 15.83°C, and at the end of the experiment, the temperature was 23°C at 16:30. Compared to the reference panel PV/T1 was cooler by 29.49%, and PV/T2 was 50% cooler than PV. Because of the temperature differences between the panels, the values of currents and voltages resulting from the panels differed, current and voltage curves are shown in Figure 5.3.

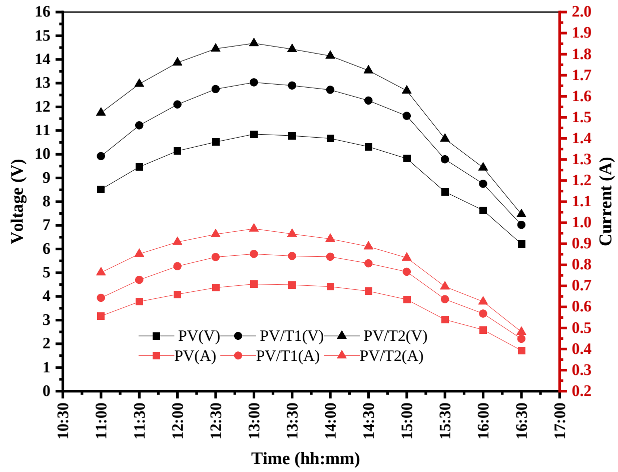


Figure 5.3. Voltage and current curves.

As the current and voltage values were recorded when we started at 11:00 for the reference panel, 0.56 A and 8.52 V. While these values reached 0.71 A and 10.85 volts at 13:30. The time average for current and voltage was 0.61 A, and 9.45 volt respectively. The current and voltage gained from the PV/T1 collector were 0.64 amp, and 9.92 volts in the beginning. In peak time they reached 0.85 amp, 13.03 V. The average for these values along the experiment time was 0.73 A, and 11.17 V respectively. For PV/T2 collector with channelled flow installation, the average values of current and voltages are 0.82 A, 12.51 V. Thermal power and Electrical for PV modules and PV/T collectors can be seen in Figure 5.4.

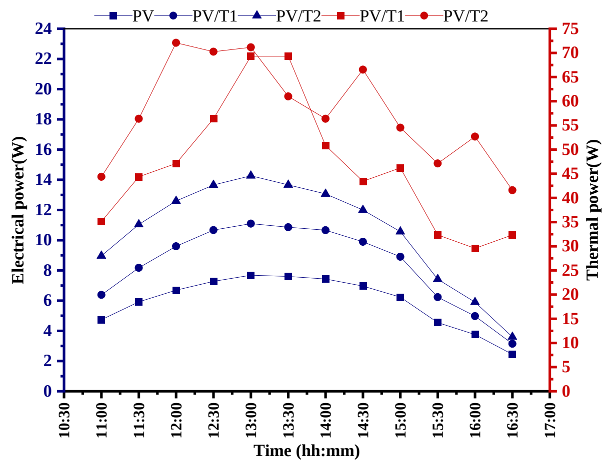


Figure 5.4. Electrical and thermal power.

The calculation of electrical power for PV module and PV/T collectors depend on the values of current and voltage where 5.94 W for PV module, 8.38 W, and 10.56 W for PV/T1 and PV/T2 respectively as seen in Figure 5.4. After the use of the applied cooling system, we obtained a 41% increase in the electrical energy resulting for PV/T1 and 78.7% for PV/T2, compared with the electrical energy produced by the reference panel. As it is known, part of the energy delivered to the panel is transformed into electrical energy, and the other part is transformed into heat convection, which causes a decrease in the efficiency of the panels. Where the average heat energy gained was calculated as 42.8 W, and 53.39 W for each PV/T1 and PV/T2 collector respectively. The energy conversion efficiency of the module and collectors are visualized in Figure 5.5.

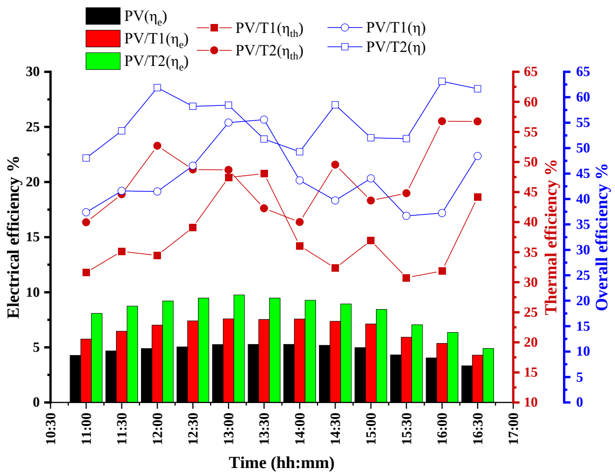


Figure 5.5. Electrical, thermal, and overall efficiencies.

The electrical efficiency for PV modules and PV/T collectors is calculated by the first law of thermodynamics. The temperature difference is clear in the electrical efficiencies values for PV modules and PV collectors as given in Figure 5.5. The electrical efficiency for the PV module was evaluated as 4.71%, 6.61% for PV/T1, and 8.31% for PV/T2 with the lower temperature. Compering modules and collectors to each other PV/T2 collector has the highest electrical efficiency value. the electrical efficiency of the PV/T1 collector was determined 1.9% upper than the PV module. PV/T2 collector electrical efficiency was 3.6% upper than PV module efficiency. The thermal efficiencies for PV/T collectors are presented in Figure 5.5. PV/T2 collector has thermal efficiency higher than PV/T1 collector, on the other hand, has higher thermal gain. The thermal efficiencies were 37.33% for PV/T1, and 47.37% for PV/T2 collectors which is 10.04% higher. The overall efficiency equals both thermal and electrical efficiencies. The overall efficiency for collectors is visualized in Figure 5.5. 43.94% and 55.68% are calculated for PV/T1 and PV/T2 collectors. Since the PV module doesn't have thermal gain, the overall efficiency for it equals electrical efficiency which is 4.71%. The overall efficiency of the PV/T1 collector is 11.71% upper than the PV/T1 collector. PV modules and PV/T collectors are also analysed consistent with the second law of thermodynamics. The solar exergy during the experiment was 115.13 W, and the electrical exergy values are as seen in Figure 5.6.

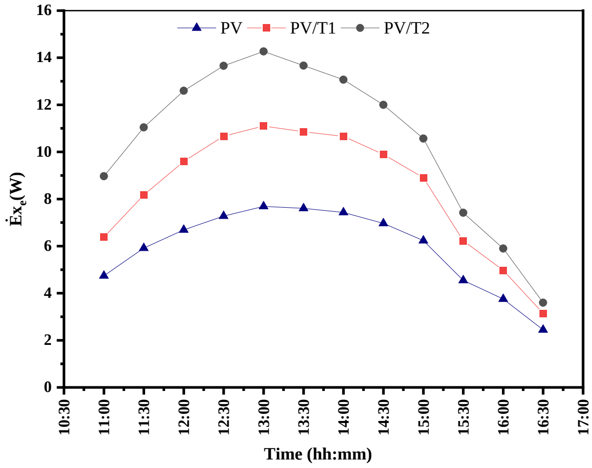


Figure 5.6. Electrical exergy for PV module and PV/T collectors.

About 5.94 W is converted to electrical exergy by PV module and 109.19 W as destroyed exergy. And the PV/T1 collector electrical exergy were 8.38 W and the destroyed exergy was 106.25 W. The electric exergy value of PV/T2 collector was 10.56 W and the destroy exergy was 103.85 W. Where the PV/T2 exergy destroy less than PV module by 5.34 W and 2.4 W less than from PV/T1. The electric exergy value of PV/T2 is higher than PV module and PV/T1 by 4.62 W and 2.18 W respectively. Thermal exergy can be seen in Figure 5.7.

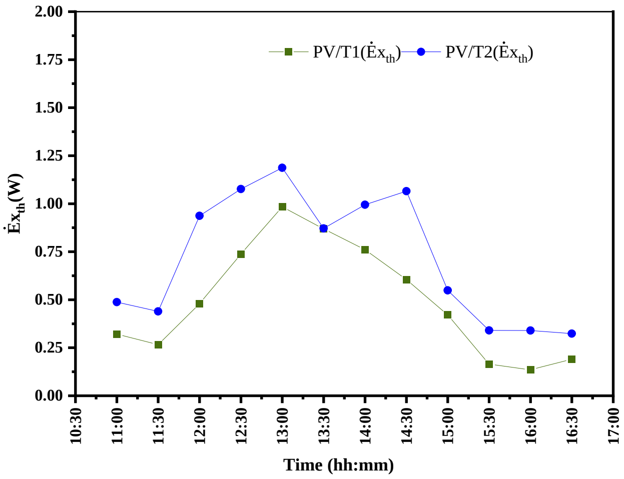


Figure 5.7. Thermal exergy for PV/T collectors.

For the PV/T1 collector, 8.13 W electrical exergy and 0.46 W thermal exergy are gained, and 104.64 W is destroyed. In the PV/T2 collector 10.56 W, and 0.72 W are converted to electrical and thermal exergy respectively. And the destroyed exergy is 103.85 W which is lower than PV/T1. Destroyed exergy and solar exergy are shown in Figure 5.8.

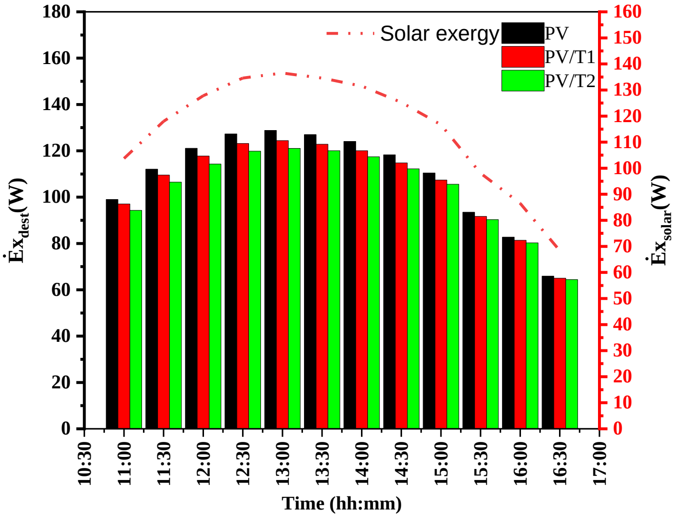


Figure 5.8. Destroyed exergy and solar exergy.

The exergy efficiency for PV modules and PV/T collectors is shown in Figure 5.9.

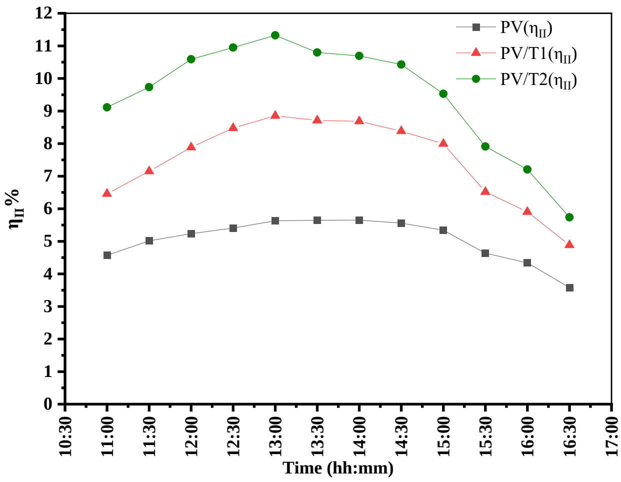


Figure 5.9. The second law efficiency for PV modules and PV/T collectors.

The second law efficiency for the PV module changed between 4.57% and 3.58% from 11:00 to 16:30 in Figure 5.9. The average along the experiment time is 5.05%. The exergy efficiency for the PV/T1 collector ranged amidst 6.46% and 4.88%. The average value during the day was 7.49%. The exergy efficiency for the PV/T2 collector during the experiment time is 10%. By comparing the PV module and PV/T1 collector, PV/T2 exergy efficiency is 4.95% upper than the PV module and 2.51% higher than PV/T1 collector.

PART 6

CONCLUSION

A little part of the solar radiation reached by the solar PV panels is converted into electrical energy, and a big share of solar energy turns into heat lost to environment. Increase in photovoltaic cell, which is energy conversion takes place, temperature creates a negative effect and manipulates the conversion process more. This means higher cell temperature lower electrical yield. Many studies and experiments aimed to lower the temperature of the PV panels or get remove the heat energy stored in the panels and convert it into controllable form to use in different systems. In this experimental study, the cooling system that we mentioned in the context of the description was applied to PV/T collectors by using Al_2O_3 nanofluid as a cooling element. The thermal and electrical profitability of the system is evaluated with the energy base assessment. It is determined that the temperature reductions were 29.49% and 50% for PV/T1 and PV/T2 collectors compared to PV modules. PV/T1 and PV/T2 electrical yield enhancement is nearly 41% and 78.7% respect to PV module. The thermal useable power utilization from the PV/T1 and PV/T2 collectors are 42.8 W, and 53.39W. The increase in the first and second law efficiency of PV/T1 and PV/T2 collectors is 39.23%, 50.97%, and 2.44%, 4.95% relative to the PV module.

PART 7

SUMMARY

In this experimental study, the efficiency of solar profitability was raised as much as possible by cooling with a nanofluid Al_2O_3 in closed-type circulation. Where we used a coil of copper tubing fixed to one of the backplates, and on another plate, the cooler was attached to a polyamide duct structure, and a reference plate for comparison. The efficiency difference was calculated in each case and electric and total energy. The thermal and electrical gain rise was observed with first and second law analyses compared to the PV module. We assessed that increase in the production of energy with panels provided an economic advantage. It also has an environmental impact by reducing carbon emissions that are harmful to the environment.

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RESUME

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