People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

University of Kasdi Merbah Ouargla

Faculty of Hydrocarbouns and Renewable Energies and Earth and Univers Sciences.

Departement of Renewable Energies.

ACADEMIC MASTER THESIS

Field: Science Technology.

Speciality: Mechanical Engineering.

Option: Renewable Energy in Mechanics.

Presented by:

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Theme

Experimental study of the efficiency of solar photovoltaique panels cooled by water in arid climate Ouargla

Discussed publicly on: 12/06/2022.

Before the jury composed of:

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Academic year: 2021/2022

First of all, we thank Almighty God for giving us the breath of life, the courage, the will, patience, and health during these years of studies and it is thanks to God that this work was realized.

We would like to express our great gratitude to our supervisor Mr.NECIB Hichem who provided us with assistance and valuable advice to accomplish this work.

We would also like to express our gratitude to the laboratory staff at the level of the renewable energies department, without forgetting Mr.RACHEDI Mohammed Yacine, teacher at the University of Ouargla, who provided us with the photovoltaic panels.

We also thank the members of the jury for having reviewed this work.

Finally, we extend our sincere thanks to all the staff who helped us achieve this work.

I dedicate this work to my parents who raised me so I reached this part of my life, without forgetting my colleague Yasin Baba HAMMOU and Mr.Hichem NECIB for his blind trust in us, and miss Maissa AFFOUN for her help in every single word in this memory, and miss Ismahan DJEDIAI who gives help and hope to every student in the department, I would also like to dedicate this work to every single teacher who taught me anything and colleague I studied with in my study career and the faculty workers who gave us help by doings or a nice word without forgetting the jury members whom they will give us some helpful pieces of advice after hard questioning from them (Dr. Brahim GHARBI and Dr.Chouaib AMMARI), all my trust in your decision about our work.

Hacene KADI.

I dedicate this thesis to All who have taught us a letter in this mortal world, to my beloved parents who prayed for me and helped me in difficult times, to Mr.Hichem NECIB and for his advice, to my goofy friend MAICHA who had a generous insight into our work and stayed up late to help us improve it, and miss Ismahan DJEDIAI who gave help and hope to every student in the department. Without forgetting the jury members (Dr.Brahim GHARBI and Dr.Chouaib AMMARI), all my trust in your decision about our work.

I hope that one day I will be able to give back to them a little of what they have done for me, that God lends them happiness and comfort.

I also dedicate this work to my family, my sisters, my friends, and my companions throughout these 4years in Renewable Energies class, to all those who are dear to us, and finally to all those who use science for the happiness and prosperity of mankind.

Above all, we thank God the Almighty.

Yasin BABA HAMMOU.

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LIST OF FIGURES

NOMENCLATURE

Symbole	Designation	Unity
Tsol	Soiltemperature	[$°C$]
Ta	Air temperature	[$°C$]
S	Exchange surface	[m2]
λsol	Soil thermal conductivity	[W/m.K]
λair	Thermal conductivity of air	[W/m.K]
hcv	convective exchange coefficient	[w/m2. °k]
t	time	[s]
Cp	Specificheat	[j/kg.K]
u	Axial air velocity	[m/s]
r1	Inside radius of buried tube	[m]
r2	Outside radius of buried tube	[m]
r3	Radius of the adiabatic layer of the ground	[m]
L	Tube Length	[m]
x	Horizontal Coordinate	[m]
α	Thermal diffusivity	[m2/s]
ρ	Volumic mass	[Kg/m3]
R	Thermal Resistance	[m.K/W]
Q_v	Water flow	[l/s]
PMT	Panel max temperature	[$°C$]

EQUATIONS

GENERAL INTRODUCTION

General Introduction

Power is principal source of life to survive in the 21^{st} century, due to a high increase in energy consumption caused by fast advances in technology and the rapidly growing world population it's critical to obtain some reliable sources of energy. Despite having the fossil fuels that put the world at risk, renewable sustainable energies are the safest beneficial substitution for fossil power that is resulting in the melting of the arctic, drought, and increase in global heat [1], threatening the lives of all living organisms.

Sun emits a tremendous amount of heat power in the form of radiance on the world where it's known as solar energy [2], Renewable energies are the best solution to the world of the living organisms, where it has many technologies where the most common technology is photovoltaic solar technology, in the developing country Solar photovoltaic (PV) technology is the key driver for electrifying rural areas. Available solar energy can be converted directly into the direct current; this is a major advantage use of photovoltaic cells. Moreover, as compared to conventional energy production, operating solar energy is much easier and requires less manpower, the important application of the Solar Photovoltaic system is the Power supply to remote houses or villages, irrigation, and water supply. As compared to other power pumping devices which produce unbearable noise during operation, these solar cells produce no noise [3]. PV panels have no mechanically moving parts and maintenance and operating cost is also considered below. Furthermore, solar panels can be installed on both rooftops and the ground level without interfering with nearby lifestyles i.e. is another advantage of solar photovoltaic technology [4].

Photovoltaic technology is used to convert sunlight into electricity without taking any aid from a heat engine. Each cell of PV technology contains layers of a semi-conducting material. When light strikes the cell, electricity is generated as the cause of an electric field which is created across different layers of the semiconductor [4]. The quantity of electricity for a cell is determined by the intensity of the light striking it. The direct current generated by the PV cell can be converted to alternating current (AC) which can be stored for future use. Rating of PV systems is normally mentioned in peak kilowatts (kW) [5].

Photovoltaic (PV) modules are one of the most effective, sustainable, and eco-friendly systems, only a small portion of solar irradiation incident to these modules is converted into electricity (15-

20%). The rest of the irradiation is converted into heat, which overheats the PV module and reduces its performance [7]. So many researchers are trying to decrease the high temperature of PV models, especially in the arid, hot, and drought regions e.g. Ouargla, Algeria where the performance of the photovoltaic system (PV) decreases because of the high temperature of the PV panel in summer.

This work presents at the first chapter the solar field in Algeria and the history of photovoltaic technique from 1839 to 1958 and the progress of their efficiencies through these years, then the literature review chapter presents what some researchers over the globe from various regions experienced cooling photovoltaic solar panels with different techniques and methods and the results they got from their experiments. The experimental chapter presents the results obtained by cooled photovoltaic solar panel (PVT) and non-cooled photovoltaic solar panel (PV) which is considered as a reference, the results expose the effect of temperature increase on current (A) and voltage (V) on both panels so the electrical output power and electrical efficiencies. Cooling process based on cooling the (PVT) system with different flow rate (0.17 l/s, 0.037 l/s) and different panel maximum temperatures (PMT) 35°C and 45°C.

Renewable energy is the world future because it uses sustainable resources to provide power, photovoltaic technique is the most common type of renewable energies on the globe, this technique has an issue with heat (when the temperature raises it efficiency decreases) that experiment aims to decrease the photovoltaic panel temperature and raise it efficiency and which flow rate and PMT are the best to obtain more output power.

CHAPTER I: Solar field and photovoltaic history

1. Introduction

Although the sun is more than 150 million kilometers away, it remains the ultimate source of energy on the planet. The amount of energy released by it for one hour could be enough to cover the world's energy needs for a year [8].

Isn't this the ideal alternative to the energy problem facing the world? Clean energy is free and available anywhere on the planet. The fields of use of solar energy are diverse and varied:

- Thermal: produce heat for heating, drying, etc.
- Electricity: such as photovoltaic systems and thermodynamic plants, etc.

The photovoltaic system was detected, invented, and developed like any other scientific system through the decades to raise its efficiency and make it more proper. The photovoltaic system has a history and many different types and technologies.

2. The Sun

The sun is a gaseous sphere composed almost entirely of hydrogen. Its diameter is 1391000 km (100 times more than earth), and its mass is 2.1027 Tons.

All of the energy of the sun comes from thermonuclear and fusion reactions. They transform 564 106 tons of hydrogen into 560×10^{6} tons of helium every second. The difference of 4 million tons is dissolved in a form of energy ($E = mc^2$). It represents a total power of 361022KW. The earth is at a distance of 150 million km from the sun, receiving approximately a power of 1.8×10^{14}KW.

The sun is a structure made of many layers with different depths. The table and the figure underneath show each layer's name, depth, and temperature.

(Table I. 1) (Figure I. 1)

Table I. 1: The structure of the Sun [9]

Structure name	Structure thickness (Km)	Structure temperature (˚C)
Core	250 000	15 000 000
Radiation zone	244 160	10 000 000 to 500 000
Convection zone	199 751	500 000 to 6 400
Photosphere	500	6 500 to 4 500
Sunspot	1 000 to 50 000	4 000
Chromospheres	2 000	10 000 to 4 200
Prominence	200 000	/
corona	/	1 000 000 to 2 000 000

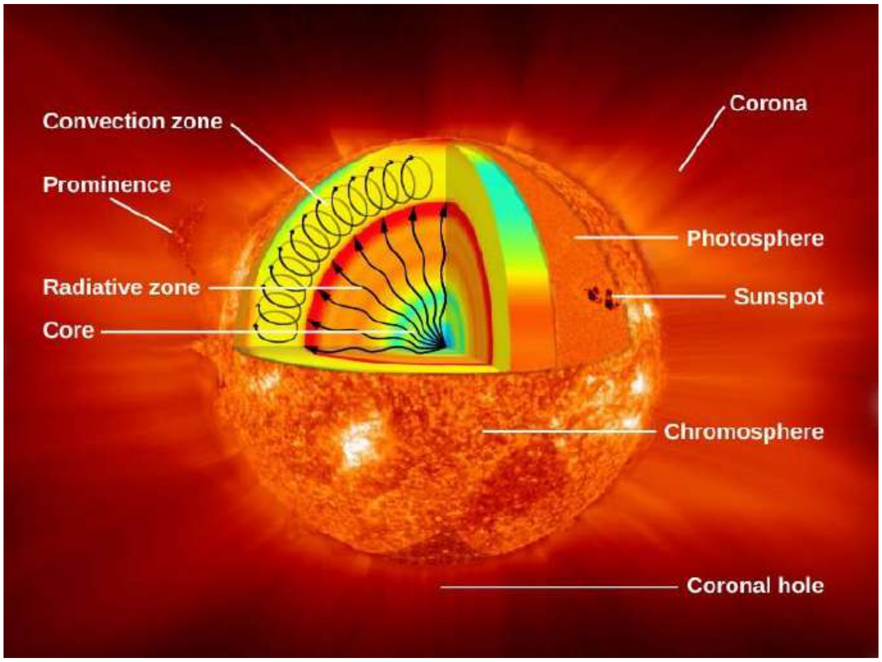


Figure I. 1: The composition of the sun [10]

3. Movement of the Earth around the Sun

The movement of the earth around the sun takes place in a plane called the plane of the ecliptic. The axis of the poles, which the earth rotates around, is not perpendicular to the ecliptic plane. The earth's center of gravity describes an ellipse with the sun at one focus, as shown in **Figure I. 2.**

The earth rotates on itself around the axis of the poles and the equatorial plane, perpendicular to this axis. So its rotation and tilt also cause the energy available at a given point to vary according to latitude, time, and season. It turns around the sun in 365 days, 5 hours, 48 min, and 40s ≈365.25 days [9].

The earth rotates with an average speed of 29.77 Km/s (maximum speed in winter 30.27Km/s and minimum in summer 29.77 Km/s). This movement is counter-clockwise and causes the cycle of the seasons [8].

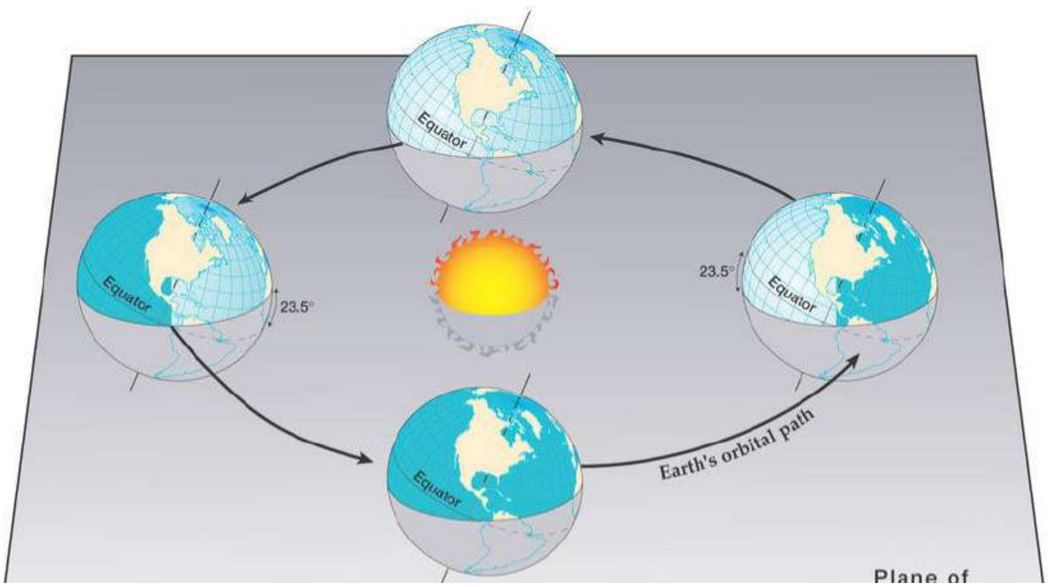


Figure I. 2: The distance between the Earth and the Sun [11]

4. The distance between the Earth and the Sun

The earth-sun distance varies daily according to the following mathematical relation:

$$DTS (J) = 1- 0.017 \cos[(360(J-2))/365] \text{ in AU} \qquad (1)$$

J: the day number in the year (counting from the 1st January till the day you want to count its distance)[8].

5. Solar constant

The value of solar radiation "Ic" received by a surface perpendicular to the rays of solar cells placed at the upper limit of the Earth's atmosphere (i.e. about 80 km altitude) varies during the year with the Earth/Sun distance. Its average value "I0", called the: solar constant, is around 1354W.m^{-2}. As a first approximation, it's possible to calculate the value of "Ic" according to the number of days in a year "NJ" by the mathematical relation [9]:

$$Ic = I0 \, [1+0.033 \times \cos[(0.984 \times NJ)]] \qquad (2)$$

The sun continuously discharges a massive amount of radiant energy into the solar system. The Earth intercepts a small part of the solar energy radiated in space. An average of 1367 watts reaches every square meter of the outer edge of the Earth's atmosphere (for an average Earth-Sun distance of 150 million km). That is called the solar constant. It is equal to 1367W/m², as shown in the added figure. **(Figure I. 3).**

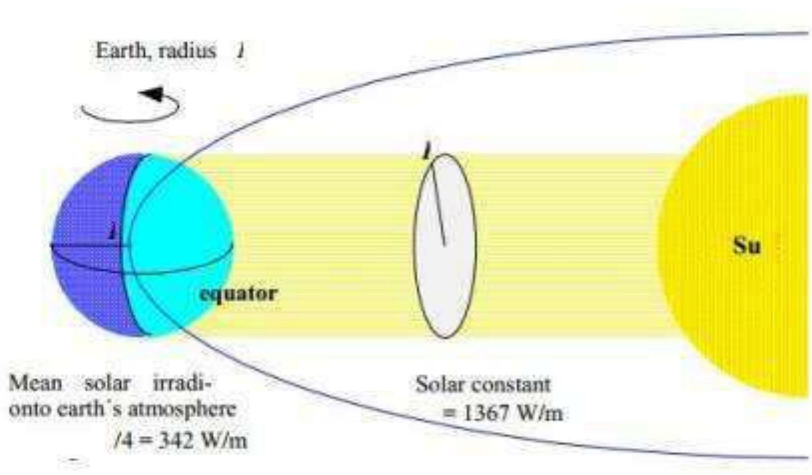


Figure I. 3: The Sun constant [9]

6. The main types of radiation

The Sun emits particles called photons in very generous quantities. It's called solar radiation. These streams of photons, also called radiations or rays, travel through space at the speed of 300,000 km/s (speed of light) and reach the earth at different wavelengths. Can be distinguished by their wavelength's different types of rays: this is the solar spectrum [9].

Generally, the shorter the wavelength, the greater the danger to living things. Although longer wavelengths also have their hazards, very short wavelengths, such as X-rays and gamma rays, can easily damage living tissue. Mainly reaches us:

- ❖ Ultraviolet (UV), from 200 nm to 400 nm, invisible, without heating, cause cell damage.
- ❖ Visible light, from 400 to 800 nm, visible, they allow us to distinguish shapes and colors.
- ❖ Infrared (IR), from 800 to 1400 nm, invisible, heat solid matter orgas that they encounter.

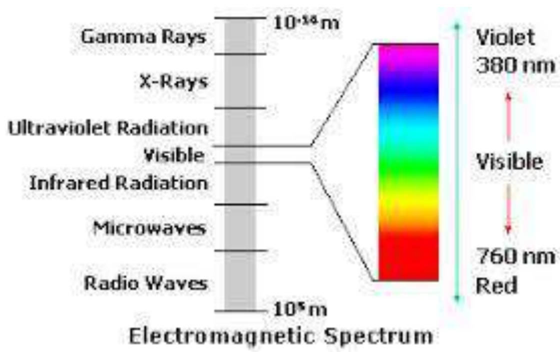


Figure I. 4: Representation of visible and invisible rays [13]

7. Illumination or Irradiance

Illumination is the power received by a surface and expressed in W/m^2 (watt per square meter). The S.I. (international system of units) recommends using the symbol G [9].

Note that, in addition to the effects of the atmosphere, solar irradiation depends on:

- ❖ Orientation and inclination of the surface.
- ❖ The latitude of the place and its degree of pollution
- ❖ The time of year and the moment considered during the day.
- ❖ The nature of the cloud layers.

8. The Solar field in Algeria

Among the countries that have a significant deposit worldwide, there is Algeria. Following a satellite assessment, the German Space Agency (ASA) concluded that Algeria represents a critical solar potential in the entire basin Mediterranean. The Algerian solar potential is the equivalent of 10 large natural gas deposits that would have been discovered in the Algerian SAHARA. The distribution of solar potential by climatic region at the level of the Algerian territory is represented in Table.02 according to the sun rays received annually.

Table I. 2: Different levels of sunshine in Algerian regions [9] [12]

Region	Region coastal	Top strays	Desert (Sahara)
Area (%)	4	10	86
Hourly average sunshine(hour/year)	2 650	3 000	3 500
Average energy received (kWh/m^2/year)	1 700	1 900	26 500

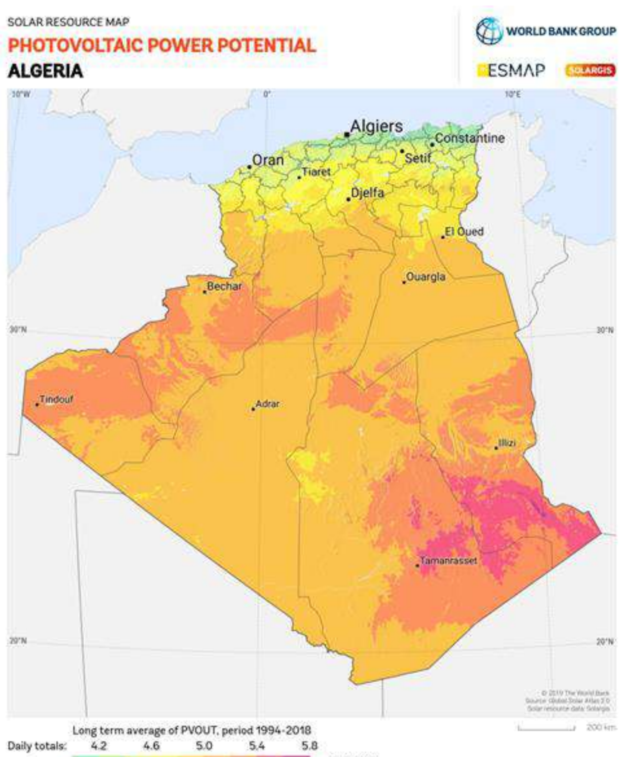


Figure I. 5: Algeria map of the average annual irradiation in kWh/m²/day on a horizontal plane [14]

9. Photovoltaic history

Scientists for more than 15 decades have admitted the photovoltaic effect. It was identified in 1839 by Alexandre -Edmond Becquerel. In 1946 Russel Ohl invented the solar cell made of silicon [8]. The table below shows the development of photovoltaic technology through the years. **(Table I.3)**

Table I. 3: Year wise progress of PV technology from 1839 to 1958 [4]

Year	Development
1839	Antoine – Cesar Becquerel discovered production of voltage on exposing solid electrode immersed in electrolyte. This effect was named as photovoltaic effect[9].
1876	Selenium cell was firstly manufactured by W.G Adams and R.E. Day by observing photovoltaic effect in solid selenium.
1883	Charles Fritz built first true photovoltaic cell which had an efficiency of loss than 1%. He used thin layer of gold for coating semiconductor selenium[6].
1904	First paper was published on the photoelectric effect by Albert Einstein.
1927	Using copper and copper oxide new type of cell was developed which had an efficiency less than 1%[9].
1941	The silicon photovoltaic cell was developed by Russel Ohl[9].
1954	Efficiency of 4% was achieved in silicon photovoltaic cellat Bell laboratories by Chapin et al, which was soon increased to 6% and 10%[10].
1958	This was the first time when PV cells were used in space

10. Photovoltaic Solar cells types and technologies

There are many kinds of solar cells, wafer-based cells accounts for 90 % of solar cells. The thickness of wafer-based silicon solar cells is approximately 180-200 μm [11].

The majority of types of silicon material required for the production of solar cells are single-crystalline, multi-crystalline, amorphous silicon [4], cadmium-telluride [4] [12] and copper-indium-gallium-sulfide [13] [14]. The classification of solar cell technologies is shown in **Figure I.6** Based on manufacturing material and level of commercial maturity, PV cell technologies can be categorized into three generations [4]

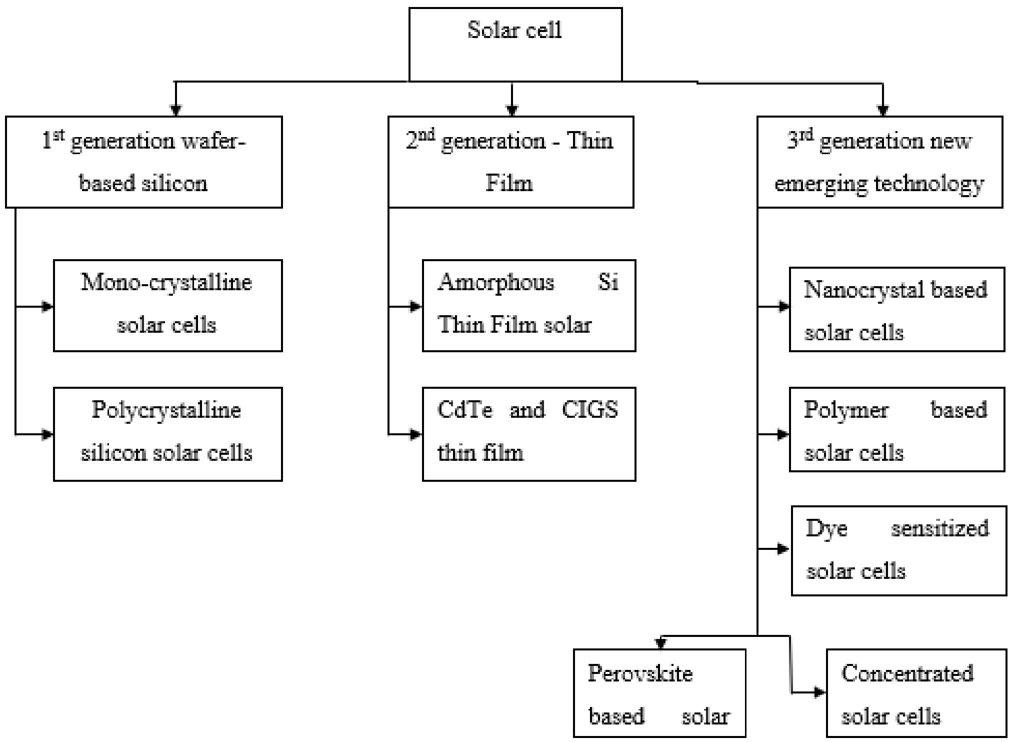


Figure I. 6: Classification of solar cell technologies [2][4][14]

10.1. First generation of Solar cells

Silicon wafers are used for the development of first-generation solar cells. Due to high power efficiencies, this technology is the oldest but most popular technology [3]. The first-generation solar cells are further categorized into two sub-groups [2][13][14]:

- Single/Mono-crystalline silicon solar cell.
- Poly/ Multi-crystalline silicon solar cell.

10.1.1. Single/Mono crystalline silicon Solar cell

The first silicon solar cell was developed at Bell Laboratories in 1954 by Chapin et al [10]. It already had an efficiency of 6% and rapidly increased to 10%. The main application for many years was in space vehicle power supplies. Solar cell technology benefited greatly from the high standard of silicon technology developed originally for transistors and later for integrated circuits. This is also applied to the quality and availability of single-crystal silicon of high perfection. In the first years, Czochralski (Cz) grown single crystals were the only ones used for solar cells. This material still plays an important role [15].Czochralski process is used to manufacture mono-crystalline solar cell [14][16][17]. During this Czochralski process, Si crystals are cut from big-sized ingots. Precise processing is required while manufacturing the large single-crystal hence making this process of “recrystallizing” more expensive. Although the efficiency of monocrystalline silicon solar cells lies between 14% – 18% [18], the leading company Sun Power Corporation (2015), manufactured the modules having an efficiency of 20.4% which was measured by NREL (2015) [19].

10.1.2. Polly crystalline silicon Solar cell

Polycrystalline material in the form of fragments is obtained from highly purified poly silicon and placed in a quartz crucible located in a graphite crucible and melted under inert gases by induction heating [15]. Several different crystals are mixed to form polycrystalline silicon solar cells. The process of this type of solar cell is done by cooling a graphite-filled mold which makes it more economical. These cells are currently the most popular types of solar cells [3]. Despite this, these cells are inexpensive to fabricate but related to mono-crystalline silicon solar panels. These cells have an efficiency of about ~ 12 %-14% [4].

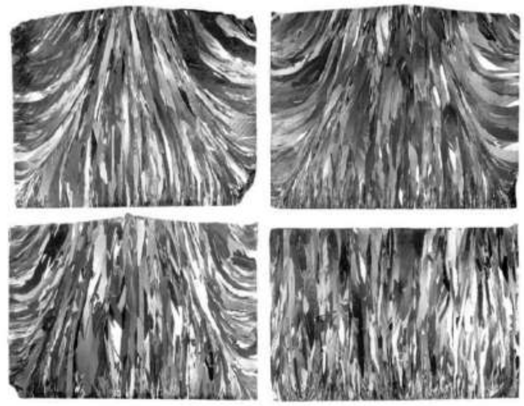


Figure I. 7: Cross-sections of multi-crystalline Si-blocks were cooled down under different conditions [15]

10.2. Second generation of Solar cells

These are based on thin-film PV technologies and include three primary families: amorphous (a-Si) and micro morph silicon (a-Si/ μc-Si), cadmium –telluride (CdTe), Copper –Indium –Gallium –Di -Selenide (CIGS). The first considerations concerning thinner silicon wafers for solar cells were made by Wolf and Lofersky while simulating the ideal parameters for record-high efficiencies [15]. This solar cell generation is more economical when compared to the first generation silicon wafer solar cells [4]. A light-absorbing layer of first-generation solar cells and thin-film solar cells are of order 350 μm and one μm thickness, respectively [20]. Most of the available thin-film PV technologies were assessed by Powalla and Dimmler (2001), especially the Cu (In, Ga) Se2 (CIGS) based technology [4][21].

10.2.1. Amorphons silicon thin film (a-Si) Solar cell

The first publications on amorphous silicon (a-Si) relevant for solar cell fabrication appeared after the late 1960s [15]. These cells can be prepared at low processing temperature; therefore, it uses low-cost polymer and other flexible substrates [4]**.** During the fabrication process backside of the substrate is coated with doped silicon. These types of solar cells have the color of dark brown on the reflecting side while a silverish color on conducting side**.** Unstable efficiency is the main limitation of these cells**.** Figure.08 depicts the schematic of the Amorphous Silicon Solar Cell. Most companies are manufacturing this kind of module in the range of 5.9-9 %. Station Corporation of USA manufactured a-Si modules with the highest efficiency of 13.8% [19].

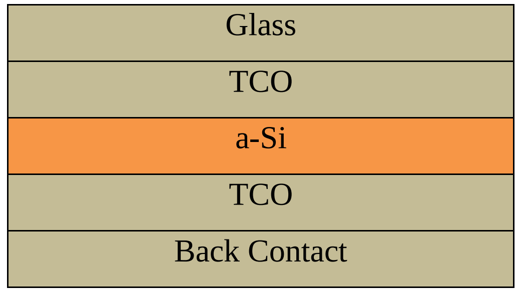


Figure I. 8: A schematic of Amorphous silicon [4]

10.2.2. Cadmium Telluride (CdTe) thin film Solar cell

The history of CdTe-based cells is a story about an adventurous search for the appropriate structure on a track full of obstacles and traps. As in the case of CdS, first attempts have been made with CdTe single crystals. At the RCA Labs, indium was alloyed into n-type CdTe crystals resulting in an alloy-tye p-n junction with 2.1% conversion efficiency. At the same time, CdTe-cell efficiencies of even 4% were oublished in the USSR and submitted for publication [15]. From an economic point of view, Cadmium telluride (CdTe) is one of the remarkable types among thin-film solar cells, which is less expensive and economically feasible. p-n junction diode is formed between layers of cadmium sulfide. The manufacturing process is as follows: firstly, the CdTe-based solar cells are synthesized from polycrystalline materials, and glass was chosen as the substrate. Secondly, deposition is done. i.e. using different economical methods, the multiple layers of CdTe solar cells are coated onto a substrate. Its efficiency usually lies in a range of 9.5-11%[4][18].

10.2.3. Copper Indium Gallium Di-Selenide (CIGS) Solar cell

It is a semiconductor that comprises four elements, i.e. Copper, Indium, Galium, and Selenium [13]**.** CIGS has achieved an efficiency of about ~10% -12%. Technology-based on CIGS solar cell forms one of the apparent thin-film technologies due to its high efficiency. The process of CIGS is done by the following techniques: sputtering, evaporation, electrochemical coating technique, printing, and electron beam deposition [4][14].

10.3. Third generation of Solar cells

These include technologies that still need demonstration and research, like concentrating PV (CPV) and organic PV cells. Most of the developed 3rdgeneration solar cell types are [2][4]:

- Nanocrystal based solar cells
- Polymer-based solar cells
- Dye-sensitized solar cells
- Concentrated solar cells

11. Conclusion

This chapter shows that Algeria has immense and costless energy that provides efficiency for more than one country. The hourly average sunshine in the whole country reaches approximately 11 000 hours per year, and the average power received from the sun is up to 31000 kWh per square meter per year. This chapter exposes the history of solar cells and the different technologies throughout the years. These technologies are divided into three generations: 1st generation wafer-based silicon, 2nd generation Thin-Film, and 3rd generation new emerging technology. In addition, to some technologies efficiencies of these three generations and the most economical types.

CHAPTER II: LITERATURE REVIEW

1. Introduction

The photovoltaic technique is the most common technique worldwide to produce electricity using the sun's irradiance. A big part of this irradiance will transform into heat, which will affect the PV panel, i.e the increase in the temperature of the PV panel decreases its efficiency. After some researches about cooling photovoltaic solar panels using water, a conclusion was raised: there are three frequent techniques used to cool down the PV panels using water. Talking about top cooling of PV panel, bottom cooling, cooling both sides of the PV panel, or using other materials and fluids to cool the PV panel.

2. Top Cooling

Moharram et al [22], presented a cooling system based on water spraying on the top of the PV panel (Figure III.1) using a numerical software to determine when to start cooling, i.e when the PV panel reaches the maximum allowable temperature of 45˚C, to decrease its temperature to normal operating temperature 35˚C. This cooling experiment took place on 1day in June and 1day in July 2012 in a hot arid region. The cooling process is repeated every 15 min, approximately, where the cooling period of the photovoltaic cells was 5 min each time. Using a controlled water flow rate of 29 l/min, the cooling rate for the solar cell is 2˚C/min. The results show that every 1˚C of temperature rise causes a drop in the efficiency and the power output by 0.5%. The PV panel yields the highest output energy if the cooling of the panels starts when the temperature of the PV panels reaches the maximum allowable temperature (MAT) of 45˚C.

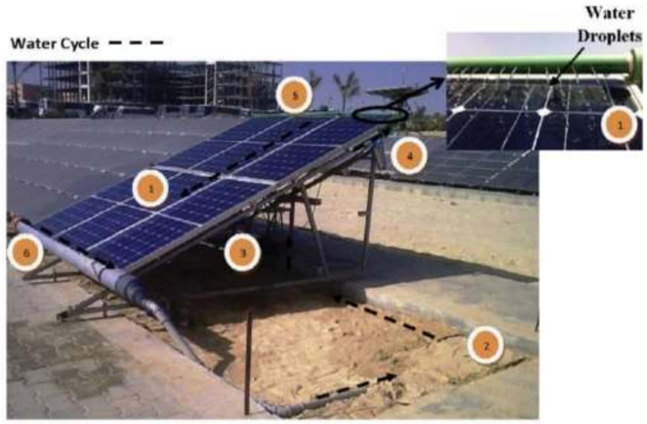


Figure II. 1: Experimental setup: 1.PV module, 2.tank, 3.pump, 4.filter, 5.nozzle and 6.drain pipe [22]

Sukarno et al[23], in March 2016 at the University of Malaysia Sabah, discussed the comparison of the output and the efficiency between a continuous cooling system by water, a cooling system every one hour, and a non-cooling system of a solar photovoltaic panel. The results of this experimental research: the efficiency of the panels was 16.7%, 14.4%and 13% for the continuous cooling system, cooling every one hour, and for the non-cooling system as well the maximum output power reached 68.8W, 65.11W, and 59.06W respectively.

Figure II. 2: Experimental setup of cooling system [23]

Figure II. 3: Experimental setup of non-cooling system [23]

Govard hanan et al[24]presented an experimental study entrenched in changing the mass flow rate using two water tanks. See Figure III.4. A storage tank is placed under the PV panel, and an intermediate tank is placed over the PV panel. The water goes up to the intermediate tank by a water pump, the mass flow rate can be controlled by a valve. Water flows on the PV panel from the intermediate tank. The results of these three experimented mass flow rates (5.3, 3.8, and 2.3 kg/min) showed that the 5.3 kg/min mass flow rate is the best. It yields an efficiency of 15% and maximum output power of 23W compared to the conventional PV panel. This cooling reduces the PV panel temperature by 30% compared to the ordinary panel.

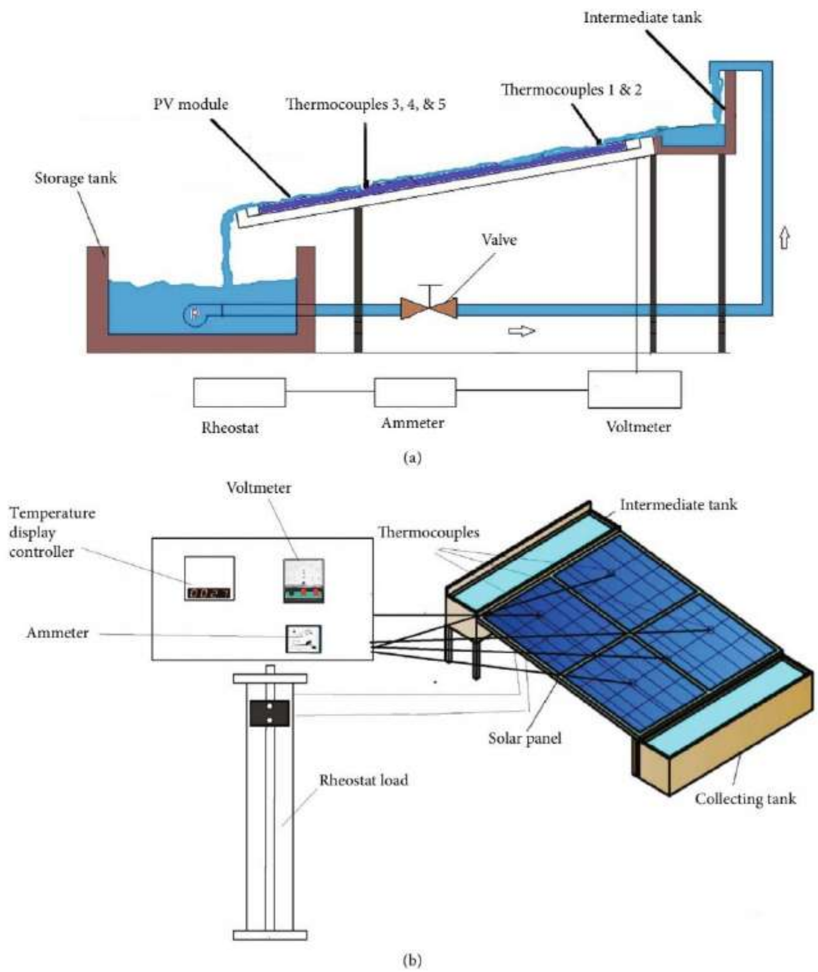


Figure II. 4: Experimental setup where (a) is side view and (b) is top view of the experimental setup [24]

Hosseini et al [25],reduced the PV module surface temperature and reflection losses through a thin-film water flow. A cooling system on the top surface using a tube with a slit installed at the top of the PV panel is considered a feeding tube as Figure III.5 shows. The water is collected at the bottom of the PV panel and passes through the finned tube which is used as a heat exchanger to cool water. Then water will be pumped back to the feeding tube at the desired temperature level to flow on the panel surface. It was found that the maximum temperature difference of 18.7 ˚C is observed, and the temperature difference between the top and bottom sides of the PV model was almost 1.5 ˚C. This temperature reduction has caused a noticeable improvement in electrical efficiency, such that for some hours the relative difference is more than 33%.

Figure II. 5: Front view of solar photovoltaic panel equipped with water film producer [25]

Figure II. 6: Pumping system and the heat exchanger of experimental combined Photovoltaic/Thermal (PV/T) system [25]

Abdolzadeh and Ameri [26],examined the performance of a 225W PV module by spraying water on the top surface. The effect of spraying water is inspected with module efficiency, module temperature, and pump flow rate. It showed that a higher pump flow rate was required in the middle hours since the temperature rise was high. The system with water spraying achieved a 12.5% increase in module efficiency. The following figure shows the experimental setups of this study.

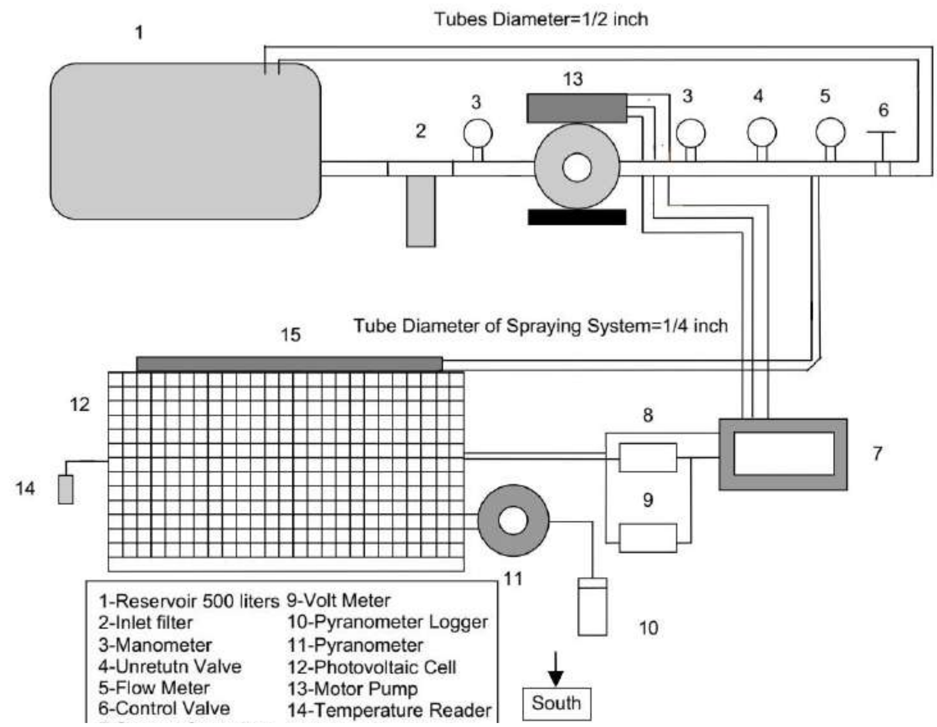


Figure II. 7: Layout of pumping system test stand with spraying system [26]

In the United Arabic Emirates, where the temperature lifts from 40˚C to 60˚C in the summer, Sequeira et al [27], experienced the influence of cooling the solar photovoltaic panel with water by developing a cooling system as the figure underneath shows. The maximum allowed temperature is 35˚C, i.e the system starts cooling when the PV model reaches the maximum allowed temperature. The results showed PV panels yield the highest output energy if the cooling of the panel begins when the temperature of the PV panels reaches the maximum allowed temperature. The maximum allowable temperature is a compromised temperature between the output energy from the PV panels and the energy needed for cooling. It is possible to attain 8.9 watt-hour energy output using the proposed cooling system compared to without using a cooling system.

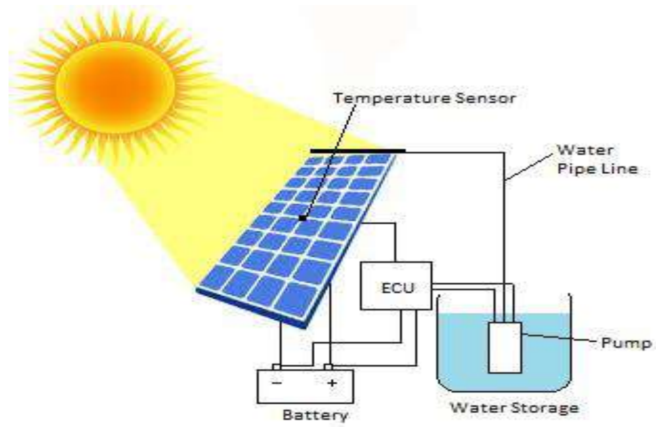


Figure II. 8: Experimental cooling system setup [27]

3. Bottom Cooling

Rahman et al [7],experienced the effect of cooling the PV panel and discussed various parameters like dust, humidity, and irradiation intensity which are the influencing parameters in the efficiency of the PV module. The authors used a heat exchanger on the backside of the PV module to cool it. The outlet water of the PV module gets into the radiator to cool it down and then gets pumped back to the heat exchanger by a water pump, as shown in the figure below. The experiment results showed that the efficiency of the PV module is directly proportional to the cooling water flow rate and reduction in module temperature and inversely proportional to the devaluation in humidity and dust accumulations. The results were compared between a PV module with cooling and one without cooling for different irradiance. It was found that the module efficiency decreases 0.06% for every 1°C rise in module temperature. Due to the effect of cooling, the output power increased to 8.04W and efficiency increased to 1.23%.

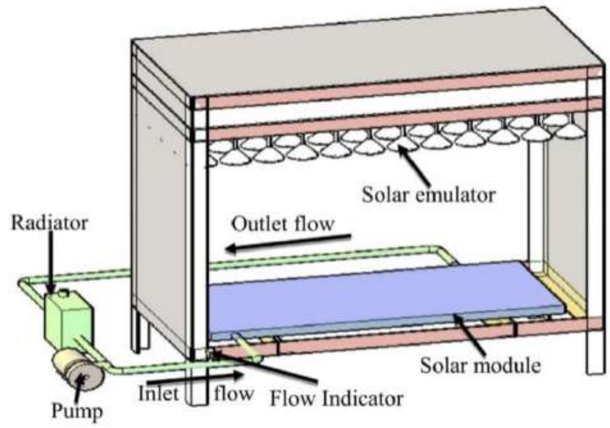


Figure II. 9: Schematic diagram of experimental setup [7]

Bahaidarah et al[28],developed a numerical model to predict the effect of electrical and thermal parameters on the performance of the PV module. An experimental study on the act of the PV module using bottom cooling by water was also conducted, as the figure below shows. The numerical model results that were found are in good agreement with experimental data. The effect of mass flow rate was studied with module temperature and found that the increase in mass flow rate reduces the temperature rise. The active water cooling systems reduce the surface temperature of the module by 20%, with an increase in PV efficiency by 9%. Also, the energy collection with the hybrid (water-cooled) PV system is higher (nearly 4times) than the PV-only system (non-cooling).

(a)

(b)

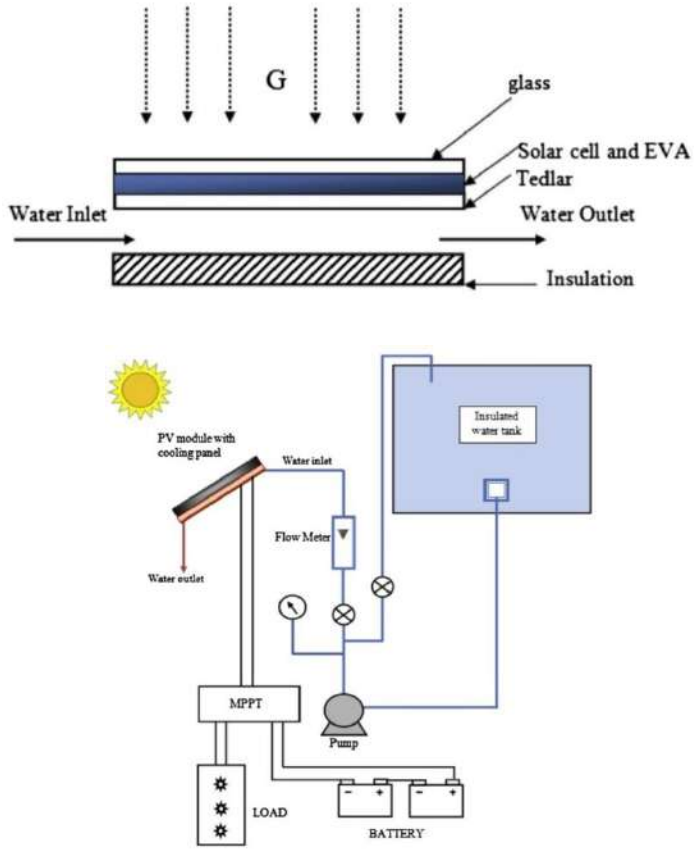


Figure II. 10: (a) Cross sectional view of water cooled PV/T system

(b) schematic diagram of the experimental setup[28]

Chandrasekhar et al [29],experimentally investigated the electrical and thermal performances of a PV module with a cooling system by cotton wick structure, with a 7 mm diameter, and spiral shape placed at the bottom of the module, as the figure below indicates. The free end of the cotton wick was dipped with three different types of fluid in a reservoir (water, Al2O3/water nanofluid, CuO/water nanofluid). By results comparison, the wick structure with water was more efficient in cooling the module than the other two fluids, where it obtained maximum power of 47.5W and 44.6W for nanofluid. The module temperature was decreased to 45°C by cooling with a wick structure with water.

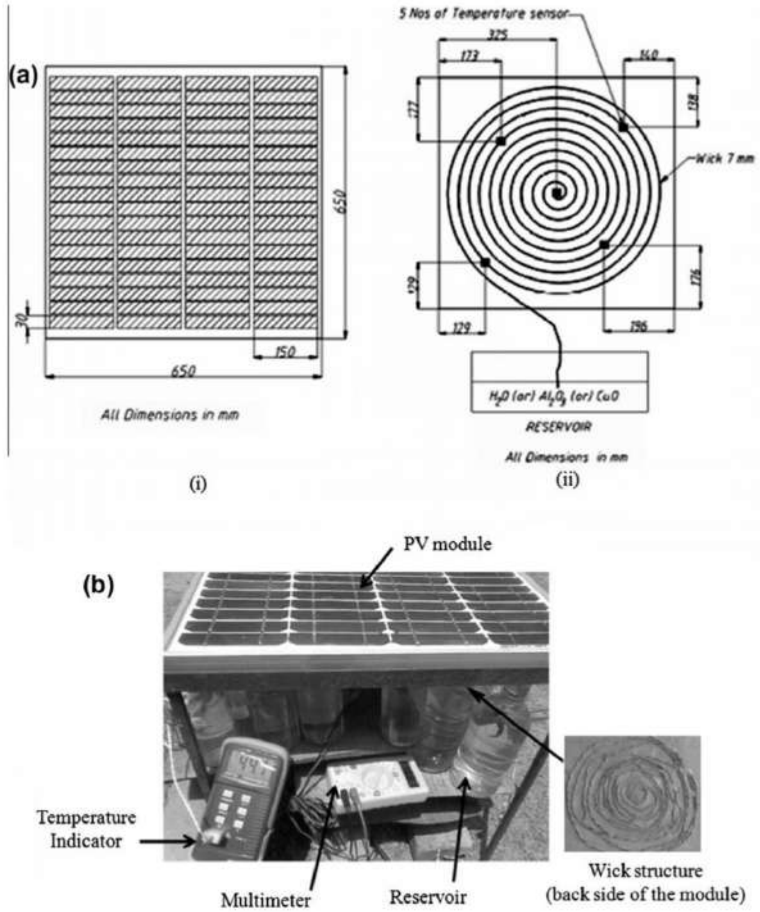


Figure II. 11: (a) Schematic of (i) front side of the PV module and (ii) back side of the PV module with wick structure

(b) Photograph of the experimental PV module[29]

An experimental study made by Bahaidarah [30] aims to cool the PV panel by using jet impingement on the backside of the PV model on the aluminum substrate. The study reveals that by employing jet cooling, the net power improved up to 49.6%with a conversion efficiency of 82.6%. The Figure below shows the geometrical parameters of a jet cooling model for PV.

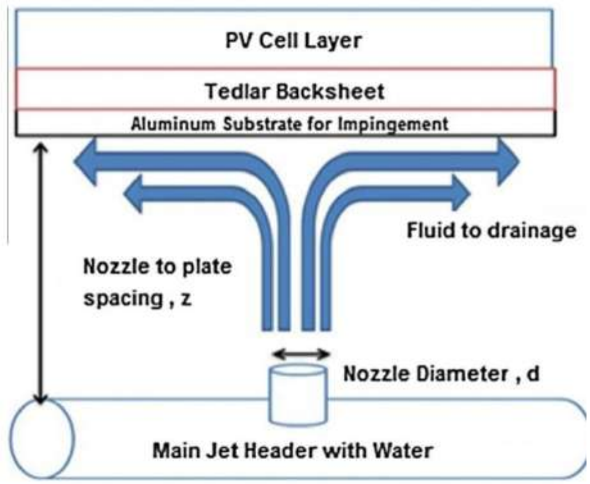


Figure II. 12: Schematic for geometrical parameters of jet cooling model for PV [30]

HaiAlami[31] examined the effect of evaporative cooling on the efficiency of PV modules. This method involved incorporating a synthetic clay layer at the bottom of the PV module with a gap in between them. The evaporating of the thin film of water through the gap reduces the module temperature. The thickness of the clay layer was imposed for investigation, and the variations in thickness as 2 mm, 4mm, and 6mm. The thickness of 2mm was found to be more efficient in recovering heat from the module. The PV module with the cooling system produced a maximum increase of 19.4% in the output voltage and maximum output power of 19.1% more than the module without cooling. The figure down shows the experimental setup.

Figure II. 13: Experimental setup of cooling the PV module [31]

4. Top and Bottom Cooling

An experimental setup of cooling both sides of the PV panel with water spray was elaborated by Nizetic et al [32], to investigate the water spray cooling effect on the PV panel. The total power output increased to a maximum of 16.3%, and the total efficiency increased by 14.1%, the module temperature was decreased to a minimum of 24°C.

(a)

(b)

Figure II. 14: (a)Schematic layout of the specific experimental setup

(b) The front and backside of the PV panel with the specific water nozzle system [40]

Shan et al[33]stimulated the dynamic performance of the PV module with different fluid (air) flow configurations. There were five configurations used in this analysis: without fluid flow (conventional), fluid flow on the top, fluid flow at the bottom, simultaneous fluid flow on both top and bottom, and fluid flow at the bottom and on the top in series mode, on analyzing the results, the fluid (air) flowing on the top and bottom in series mode produced higher temperature difference compared with the conventional PV module.

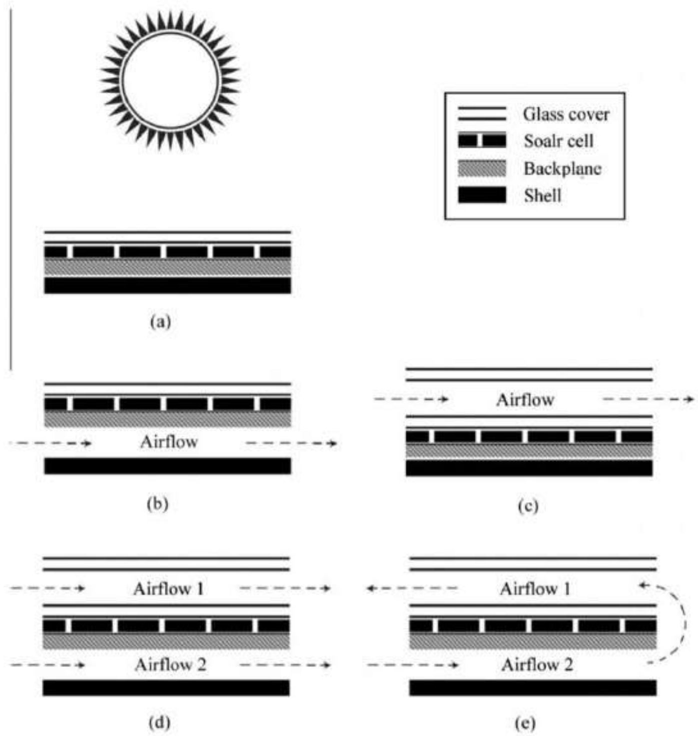


Figure II. 15: Sectional view of the PV/T systems with different configurations [33]

5. Conclusion

This chapter shows that the rise in temperature of the photovoltaic (PV) model decreases its efficiency. Researchers have done plenty of experiments and simulations to cool down the temperature of the PV model by using many fluids. The most efficient fluid to cool the PV panel is water, after using many technologies, including many other fluids.

CHAPTER III: EXPERIMENTAL PHASE

1. Introduction

Solar radiation received by photovoltaic systems is converted to some extent into electricity, but most of it is converted into heat, which drastically reduces the electrical efficiency produced by the system when the temperature exceeds 35 °C and 45 °C. The main purpose of this chapter is to determine the influence of temperature on thermal and electrical characteristics by cooling the PV models using water.

2. Description of the system PV/T

In this experiment, a cooling system was developed using water to increase Its efficiency as seen in **Figure III.1**. The system consisted of directly pouring the water on the PV panel when it reaches an inappropriate temperature that reduces the efficiency and life duration of the modules significantly and stops the effect of overheating. Ouargla is known for its high solar irradiation area with long sunny days which makes it perfect for photovoltaic power generation. However, it also got one of the highest ambient temperatures (which usually reaches43 °C or even more) resulting in overheating and reducing power generation efficiency. Water is an excellent conductor of heat, by using it the heat transfers from our modules to the water rapidly and efficiently. The experiment was tested outdoors in the summer, one of which was cooled by water and the other exposed to the sun and dust.

Figure III. 1: Experimental test setup front view

3. Experimental Process

To achieve results and get a clear comparison between cooled and uncooled PV, 2 PV modules were used with a maximum output power of 50W, both modules facing south with a fixed latitude tilt for the location of the city of Ouargla (30°)[42] as **Figure III.2** underneath shows, One module with the cooling system proposed, while the other was taken as a reference, The modules were installed on the rooftop of the Kasdi Merbah University of Ouargla , The experiment were carried out on sunny days in May 15th, 29th, 31st and 1st June, 2022 from 8:20 a.m. to 4:00 p.m. local time taking results every 20 minutes.

Therefore, our PV panels was mounted on white sprayed metal PV solar panel mounting brackets designed specifically for the modules used in the **Figure III.1**, the purpose of the white spray was to decrease heat conduction and protect it from oxidising, the mounting dimensions are (56cmx85cm) to fit to the panels with the ability to adjust the tilt angle for experimental purposes, The mount was lifted at a height of 80 cm away of the ground to isolate it from unnecessary heat exchanges and away from eachothers for the same exact goal.

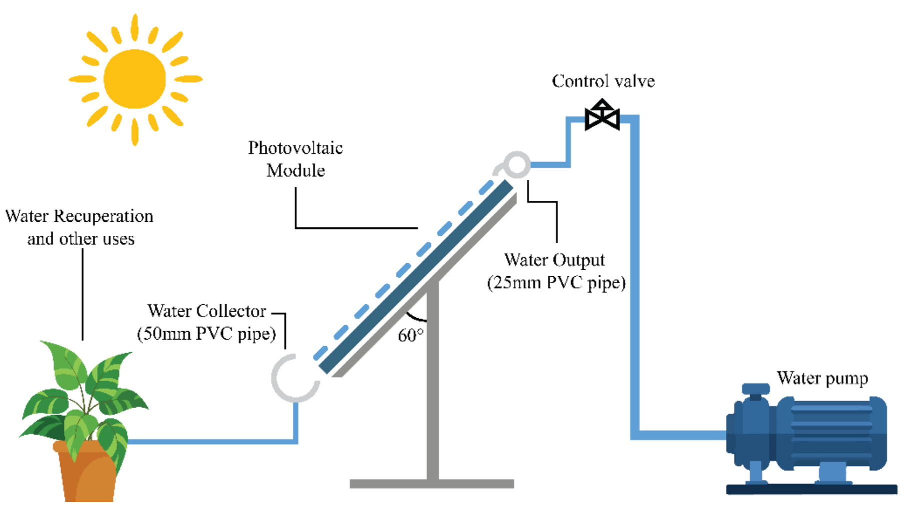


Figure III. 2: Schematic diagram of experimental process of the cooling system

3.1. PV/T section

In the PV/T section, the water was transported through a 25m long water hose using an electric water pump, and then destributed over the panel via 7 transparent flexible narrow pipes inserted in a hole for each, leaving a 25 mm PVC pipe that is attached to the main water hose, the consistency of water diffusion was difficult to regulate due to low water flow, but was managed by slowly spreading the water in closing all 7 outlets and releasing them 1 by 1, or building up good water pressure before opening the plastic ball valve that used to systematically regulate the speed of water flow, the 25 mm PVC pipe was purposly attached to the metal mount away from set PV/T module to eliminate shading it when the sun takes a specific angle.

The water that utilized to cool the module is collected in a larger 50 mm PVC pipe and then discharged along a second water hose which is then stored for other purposes or used for watering plants (the volume of water that used to enhance our modules was not taken into account).

The whole experiment was divided into 4 tests examined over 4 days as follows:

- Day 1 : PMT=35° ; $Q_{v/max}$ =0.17 l/s
- Day 2 : PMT=35° ; $Q_{v/min}$ = 0.037 l/s
- Day 3 : PMT=45° ; $Q_{v/max}$ =0.17 l/s
- Day 4 : PMT=45° ; $Q_{v/min}$ = 0.037 l/s

Q_v : Water Flow.

PMT : Panel maximum temperature

The cooling system launches manually each time the panel reaches it PMT to reduce energy consumption by the pump an dto calculate system efficiency on both temperatures with the variation in water flow Q_v .

3.2. PV section

In the PV section, a duplicate module was mounted in the same strategic way without cooling and isolated from one another, the section was exposed to all natural effects like dust and overheat, measured in the same way at the same time using simillar units presented afterwards,

4. Measurement system

4.1. Photovoltaic Solar Panel

Figure III.3 presents the PV module that is composed of monocrystalline silicon cells which are covered with clear glass and assembled with a metal frame, the active area of the solar irradiation collection has a cell area is 0.4482 m^2, where the main electrical characteristics of the PV panel are mentioned in the **Table III.1** underneath.

Figure III. 3: Photovoltaic Solar panel

Table III. 1: Electrical characteristics of the PV panel

Module type	50 P(36)
Maximum power	50 W
Maximum voltage (Vmax)	17,98 V
Maximum courant (Imax)	2.7 A
Voltage open-circuit (Voc)	21.87 V
Courant short-circuits (Isc)	3,04 A
Dimensions	830*540*28 (mm)
Weight	6 (Kg)
Tolerance	3 %
System operating voltage	1000 V
Standard test condition, AM1	1000W/m^2, 5,25°C
Cells	36Pcs, 156*63 monocristallin Silicon

Table III. 2: Technical Specifications of Measurement Equipments

Parameter	**Instrument Model**	**Range**	**Accuracy**
Solar irradiation	Solarimeter 1307SI	0 - 2000 W/m2	± 5 %
Temperatures	OMEGA RDXL4SD K-type thermocouples	-50.0 – 999.9°C	± (0.5 + 0.4 %)
DC - Current	GWINSTEK GDM-356	0.02 – 20 A	± (5 + 3 %)
DC - Voltage	INGCO DM750 DIGITAL MULTIMETER	0.6 – 1000 V	± (3 + 0.5 %)
Load resistor	ECO1/2-10	0 – 10 Ω	± 10%

4.2. Electrical scheme

Entire electrical component used for both modules to calculate all variations of both voltage and electric current.

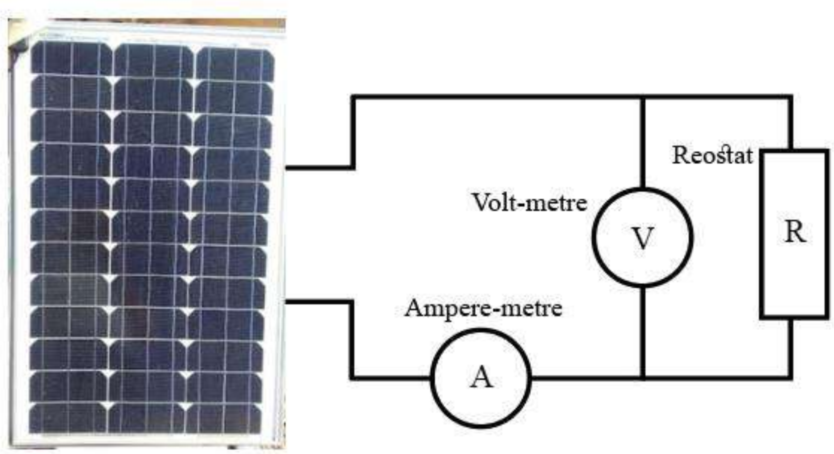


Figure III. 4: Electrical scheme of experimental process of measuring system

5. Results and discussions

The experimental tests were carried out by controlling the water flow velocity at different PMT thresholds and calculating the increase of energy production also thermal efficiency to specify which of the mentioned 4 test will be more successful and advantageous from one another in the region of Ouargla.

5.1. The variation of global illuminance

The progress of solar irradiation and ambient temperature during the test days are displayed in **Figure III.5,** the 4 test days were almost completely clear and had practically the same daytime insolation curve behavior, the highest recorded values of around 1000 W / m2 at 13:00, skipping the random natural down spike when it got cloudy for a short while (took into consideration).

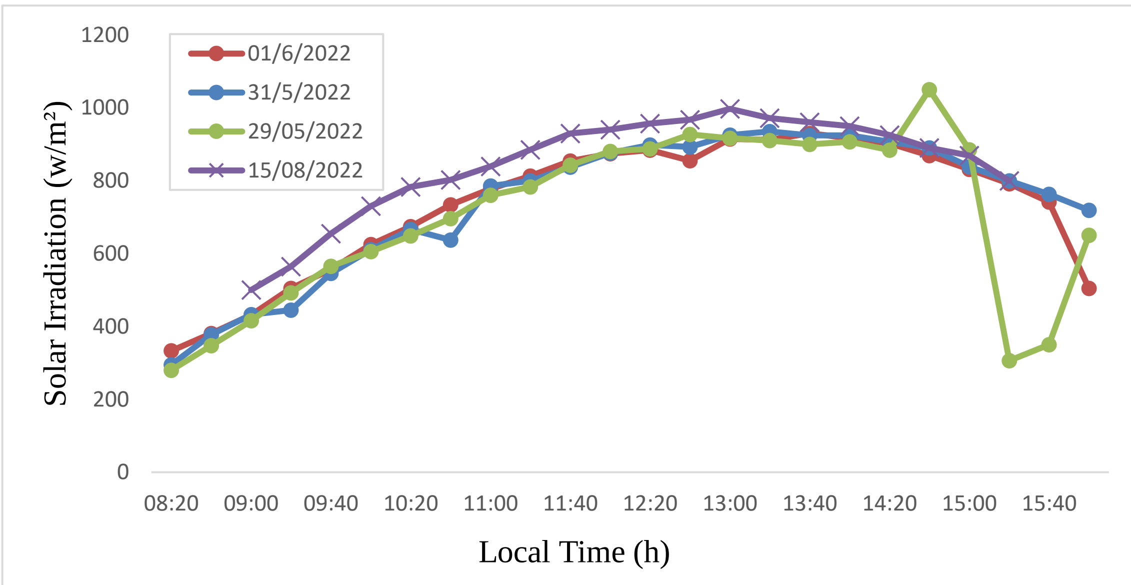


Figure III. 5: The variation of global illuminance during the 4 days

5.2. The variation of ambient temperature

There was a slight difference in the ambient temperature as shown in **Figure III.6** the maximum temperature reached 42,8 °C, 41.9 °C, 44.8 °C and 45.6 °C on May 15, 29, 31 and 01 of June 2022 respectively.

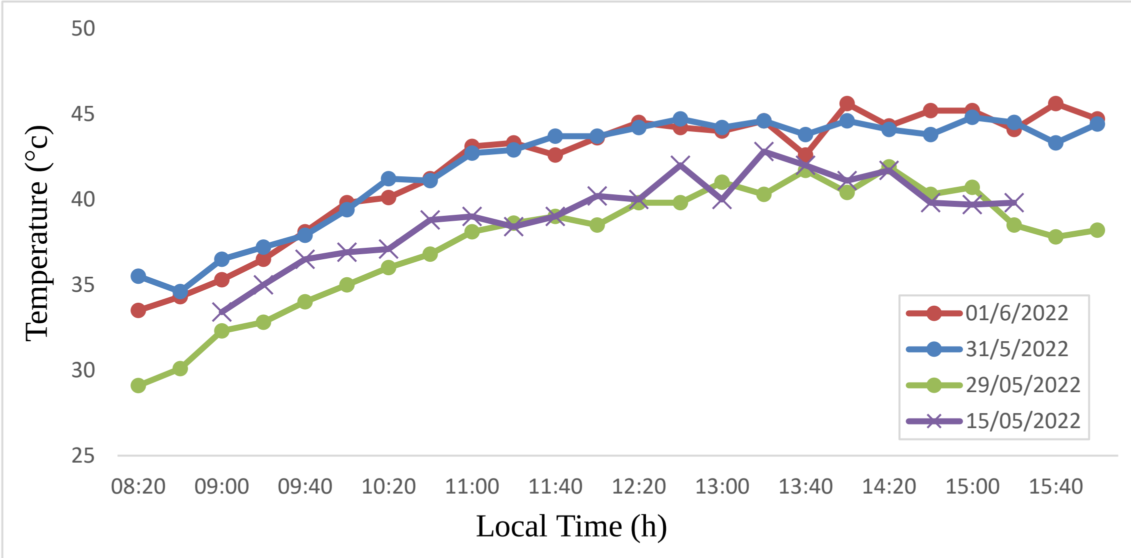


Figure III. 6: The variation of ambient temperature during the 4 days

5.3. Effect of cooling and thermal units

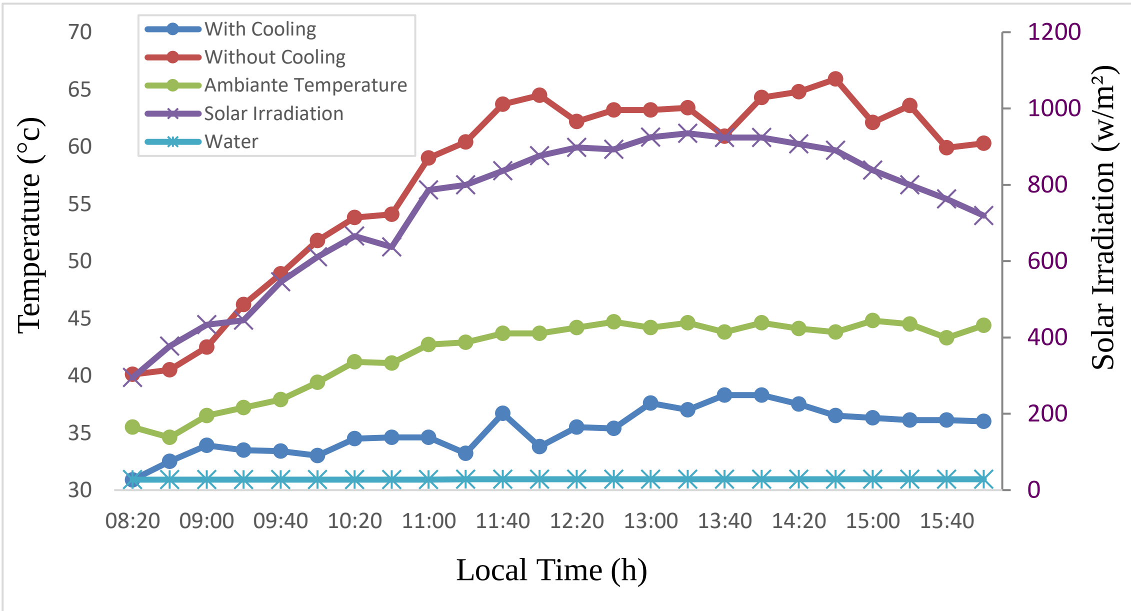
To investigate the effect of the developed cooling system on the thermal performance of a PV module, three K-type thermocouples **Figure III.6** were installed at same locations on the rear face of each module (cooled and reference modules) and one on the front face of the PV reference. However, the difference between back and front temperature was negligible (difference of 2.5%). Therefore, only the back thermocouples were kept to achieve similar results.

Temperatures of the two tested modules are registered at a 20-minute interval from 8:20 to 16:00 during the day and the water temperature was always around 28 °C throughout the whole experiment.

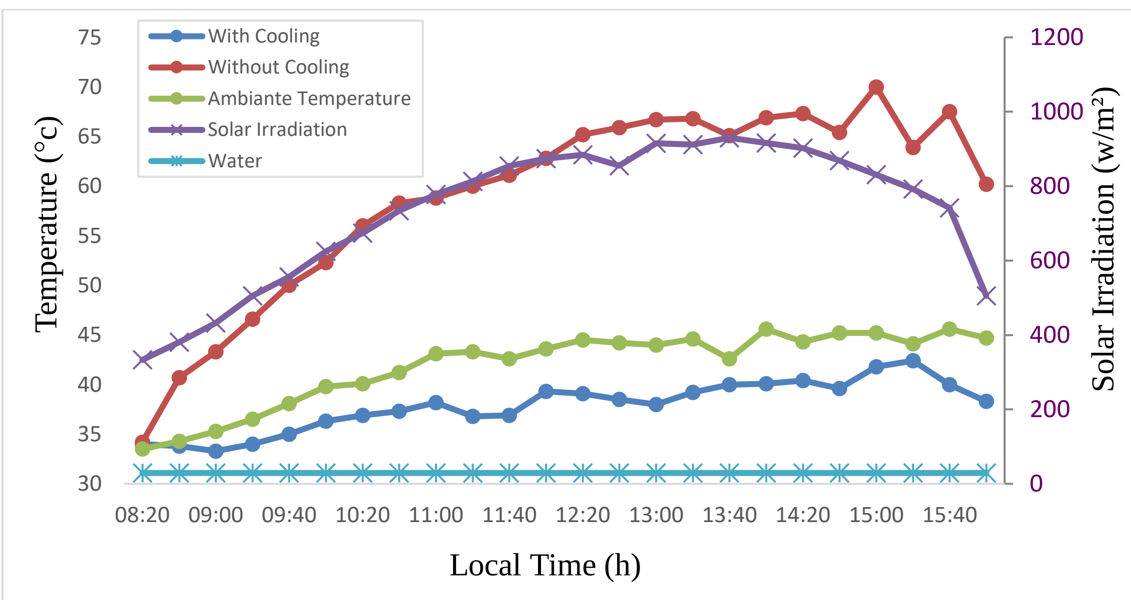
Notice that $Q_{v/max}$ is 4.6 times stronger than $Q_{v/min}$.

5.4. Panel Maximum Temperature of 35 °C

All measured temperatures are shown in **Figure III.7** shows the distribution of temperature as a function of time.



Day 1: $Q_{v/max}$



Day 2: $Q_{v/min}$

Figure III. 7: Temperatures registered at PMT 35 °C

Observations:

- **Day 1:** The temperature of PV system and the ambient temperature recorded the highest ones between 14:40 and 15:00 having 65.9 °C and 44.8 °C respectively. at the other hand, the temperature of the PV/T module reached its maximum 38.3°C between 13:40 and 14:00 achieving 47.60% heat diffusion and 37.70% throughout the day comparing to reference the module having difference of 26°C.

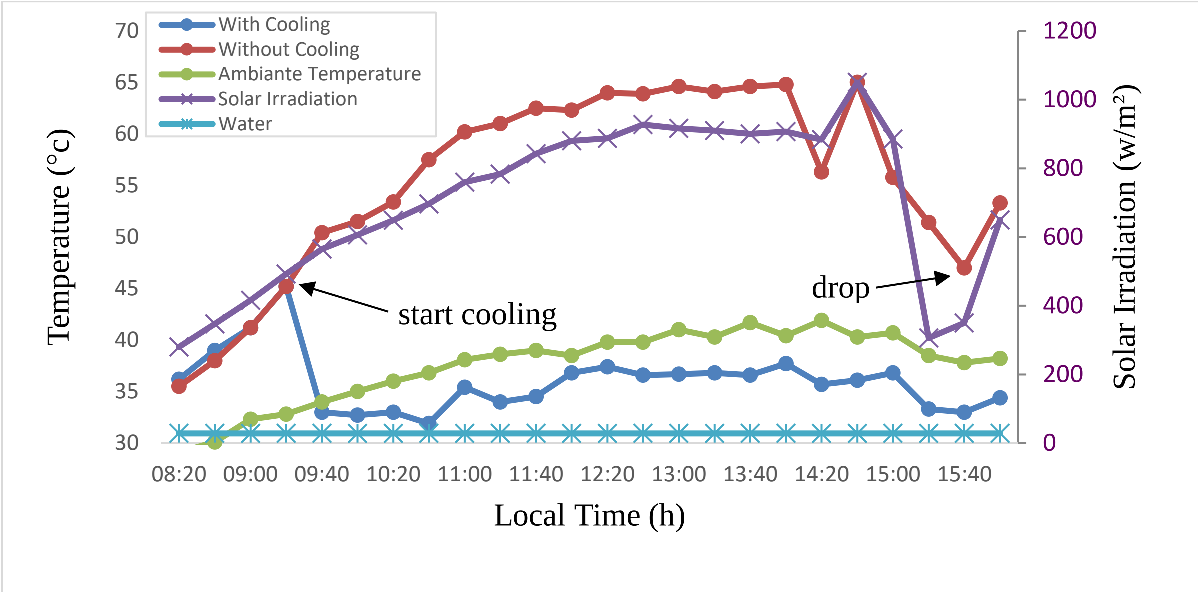
Due to high temperature at 8:20 am, the cooling system was already working at the registration shift

- **Day 2:** Shows temperature variations during day 2, particularly having the same curve behavior, though the ambient temperature recorded the highest ones between 15:00 and 14:00 having 70 °C and 45.6 °C respectively. PV/T module reached its maximum 42.4 °C at 15:20 achieving 43.02% heat diffusion and 34.34% throughout the day comparing to reference module and having difference of 21.5 °C.

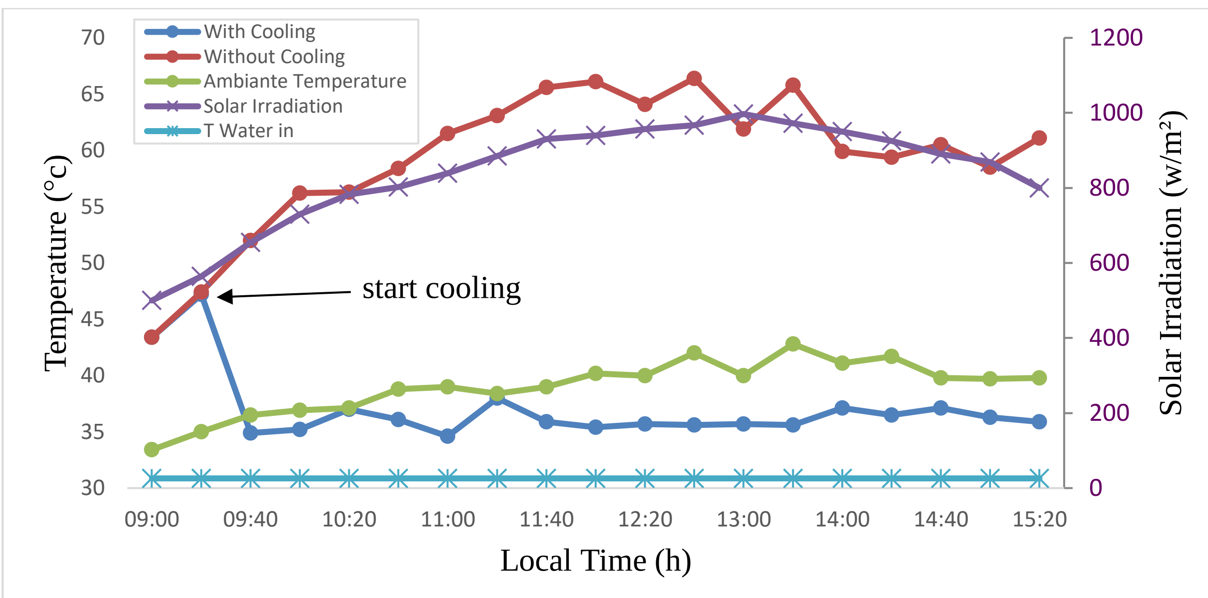
Calculating the entire day, it was observed that the rear temperatures of the two modules being the same at 8:20 due to the temperature not reaching 35 °C yet, giving the same result at that particular time only, the rest of the day had incessant cooling.

5.5. Panel Maximum Temperature of 45 °C

All measured temperatures are shown in **Figure III.8** shows the distribution of temperature as a function of time.



Day 3: $Q_{v/max}$



Day 4: $Q_{v/min}$

Figure III. 8: Temperatures registered at PMT 45 °C

Observations:

- **Day 3:** The temperature of PV system and the ambient temperature recorded the highest ones between 12:40 and 13:20 having 65°C and 41.9 °C respectively. at the other hand, the temperature of the PV/T module reached its maximum 37.7° C at 14:00 and 45.2 °C, achieving 44.8% heat diffusion and 32.96% throughout the day comparing to the reference module having difference of 27.1 °C

- **Day 4:** The temperature of PV system and the ambient temperature recorded the highest ones between 14:40 and 15:00 having 66.4 °C and 42.8 °C respectively. at the other hand, the temperature of the PV/T module reached its maximum 38 °C at 11:20and 47.2 °C, achieving 42.32% heat diffusion and 30.90% throughout the day comparing to reference module having difference of 23.5 °C.

5.6. Thermal comparison

The results obtained in the **Figure III.10** were clear, with the maximum flow efficiency exceeding the lower being 37.7% and 34.34%, respectively throughout the day. So, the stronger water flows, better is the effect of cooling (to some extent).

The intensity of solar irradiation and ambient temperature strongly affects the temperature of the PV module, as shown in **Figure III.8** Day 3 having a huge downward peak at the time of a small cloud circumventing.

The time needed to heat up and cool down back again to it PMT are calculated in Table III.3 according to its ambient temperature.

Table III. 3: Time taken to heat and cool the PV/T module

	9:30		11:00		13:40		16:00	
	heating	cooling	heating	cooling	heating	cooling	heating	cooling
35°C	4.3 min	1.58 min	5 sec	1 min	0	0	0	0
45°C	10 min	1.5 min	6 min	2 min	4.25 min	3 min	7 min	3 min

Max water flow rate

	9:30		11:00		13:40		16:00	
	heating	cooling	heating	cooling	heating	cooling	heating	cooling
35°C	1.3 min	2.5 min	0	0	0	0	0	0
45°C	7 min	4 min	5.3 min	4.56 min	2 min	6.2 min	4 min	7.2 min

Min water flow rate

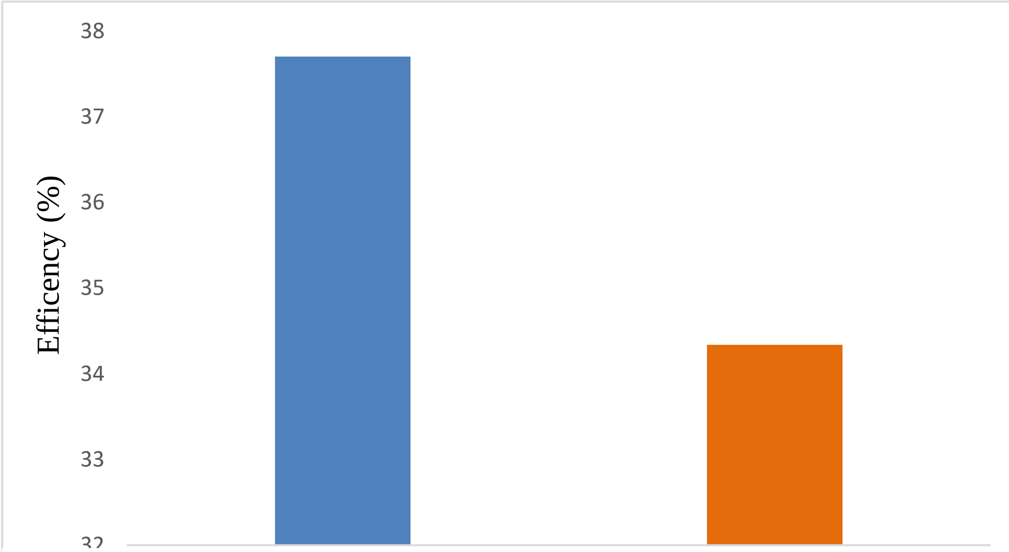


Figure III. 9: Cooling efficiency from different Water Flows

5.7. Effect of cooling on electrical units

The electrical characteristics of the two tested PV modules (with and without cooling) were measured in terms of current (I) and voltage (V). The output power (P) and the peak output power (Pp) and electrical efficiency (η) of each module were calculated as follows:

$$\mathbf{P = I \times V} \qquad (1)$$

$$\mathbf{Pp = Isc \times Voc} \qquad (2)$$

$$\boldsymbol{\eta = P\ (A \times G)} \qquad (3)$$

Where (G) is the incident solar irradiation and (A) is the PV module's surface area.

The variations of short-circuit current (Isc) with ambient temperature for tested PV modules (with cooling and without cooling) are shown in **Figures III.10**, to discuss the increase in temperature and dust accumulation affect on the non-cooling module (PV system) comparing to the clean and cooled module (PVT system),that shows the increase in temperature does not effect on the short-circuit current (Isc) at variance to dust accumulation that effects on PV system decreases the short-circuit current by 3.6% than PVT system. The **Figure III.11**, presents the effect of temperature increase on the open circuit voltage (V) with time on tested PV modules (with cooling and without cooling) that shows the decrease in voltage for PV system (without cooling) with ambient temperature increase, the PVT system improved in voltage by an average of 13.4%, and **Figure III.12** show the peak electrical output power variation with temperature increase with time for PV and PVT system the average electrical improvement of PVT system is 10.53Watts that equal to 16.79% comparing to PV system.

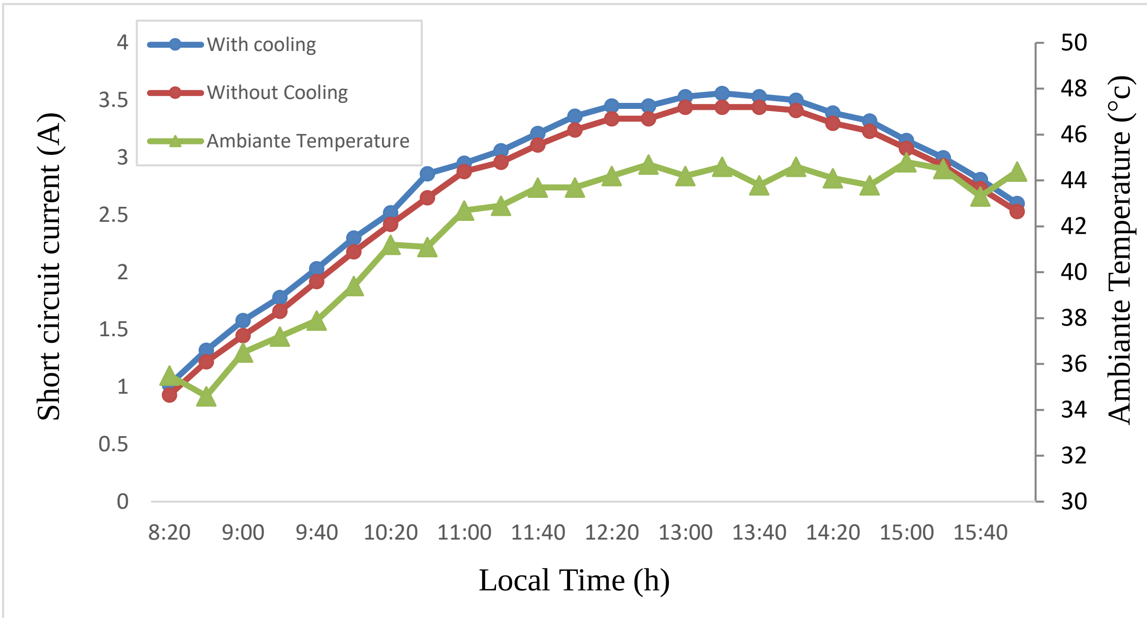


Figure III. 10: The variation of short-circuit with the temperature increase and dust accumulation

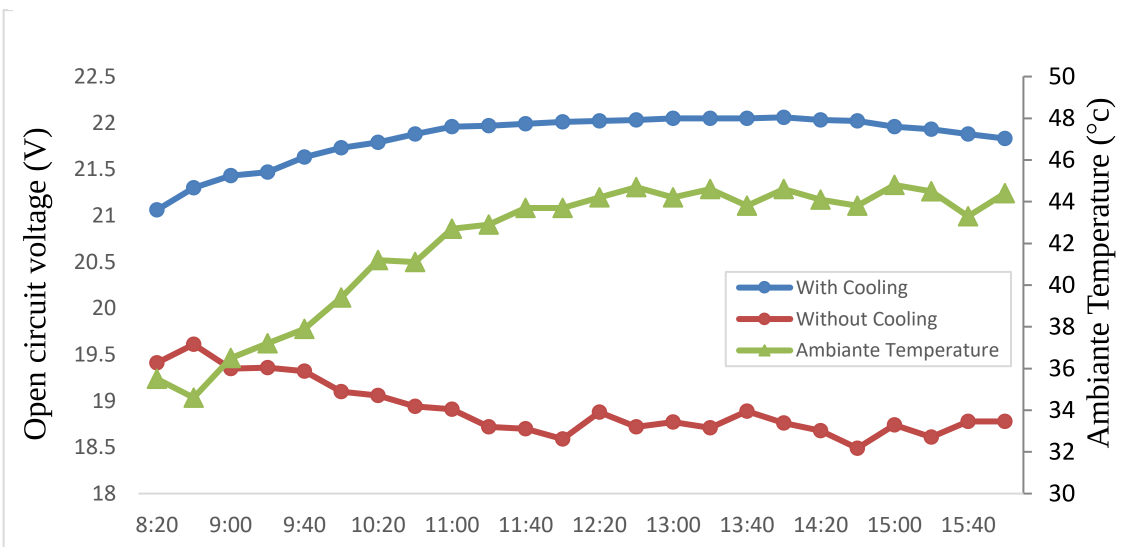
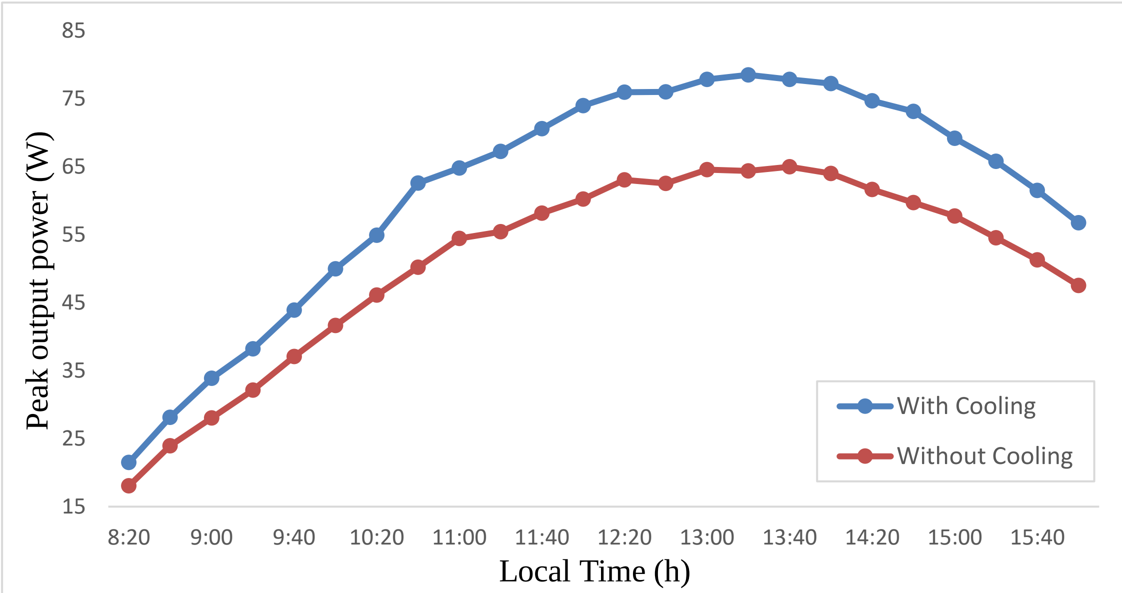


Figure III. 11: The effect of temperature increase on the electrical output power (W) with time



The **Figure III.13, Figure III.14, Figure III.15 and Figure III.16** investigate the peak output power variation with voltage as well as the temperature effect on PV system output power at the experimental days (day1, day2, day3 and day4) respectively, it is obviously from figures underneath the temperature increase decreases PV system voltage so the output power.

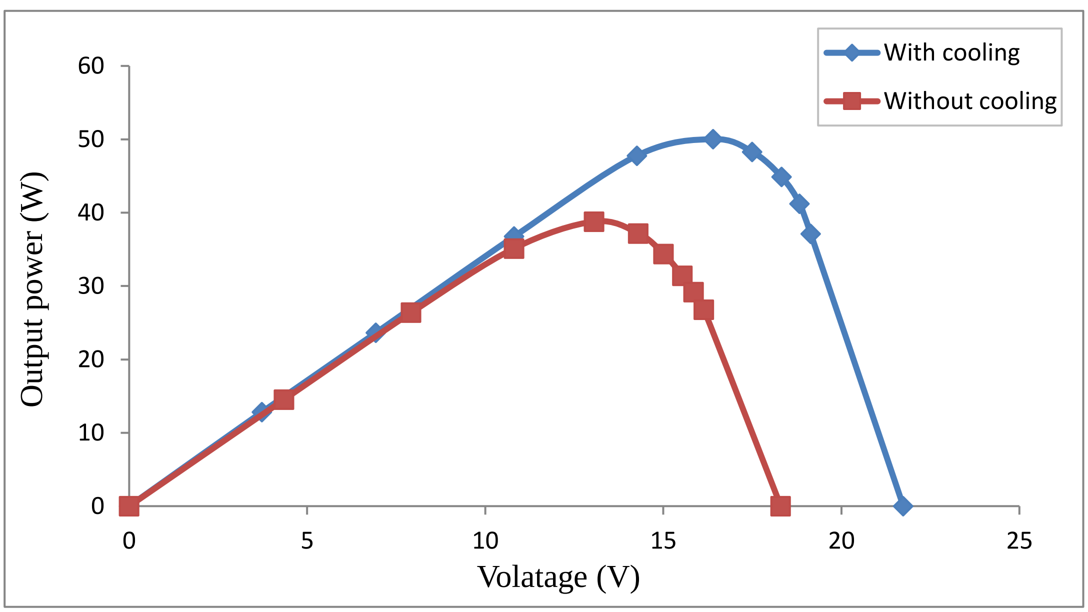


Figure III. 13: Output power and voltage variation for Day 1

Day 1: At this part of the experiment as shown in **Figure III.13** the output power as well the voltage increased for PVT system (with cooling) by 10.53Watts and 2.93 Volts i.e 16.79% and

13.4% respectively, the temperature of PV system (without cooling) was 60.9°C and PVT system (with cooling) decreased to 38.3°C.

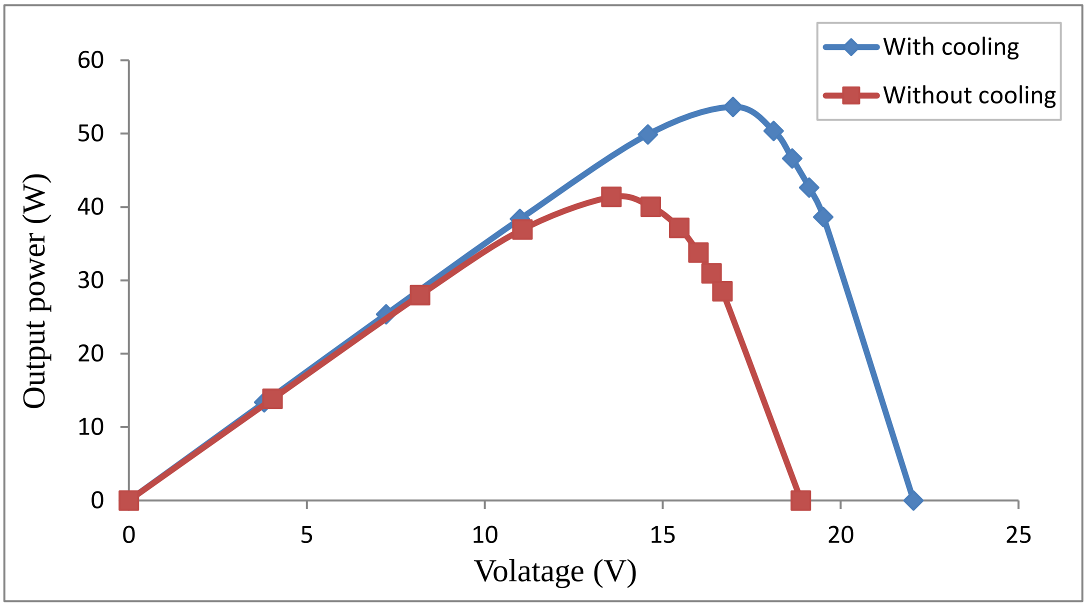


Figure III. 14: Output power and voltage variation for Day 2

Day 2: At this part of the experiment as shown in **Figure III.14** the output power as well the voltage increased for PVT system (with cooling) by 10.03Watts and 2.81 Volts i.e. 16.70% and 13.07% respectively, the temperature of PV system (without cooling) was 65.1°C and PVT system (with cooling) decreased to 40°C.

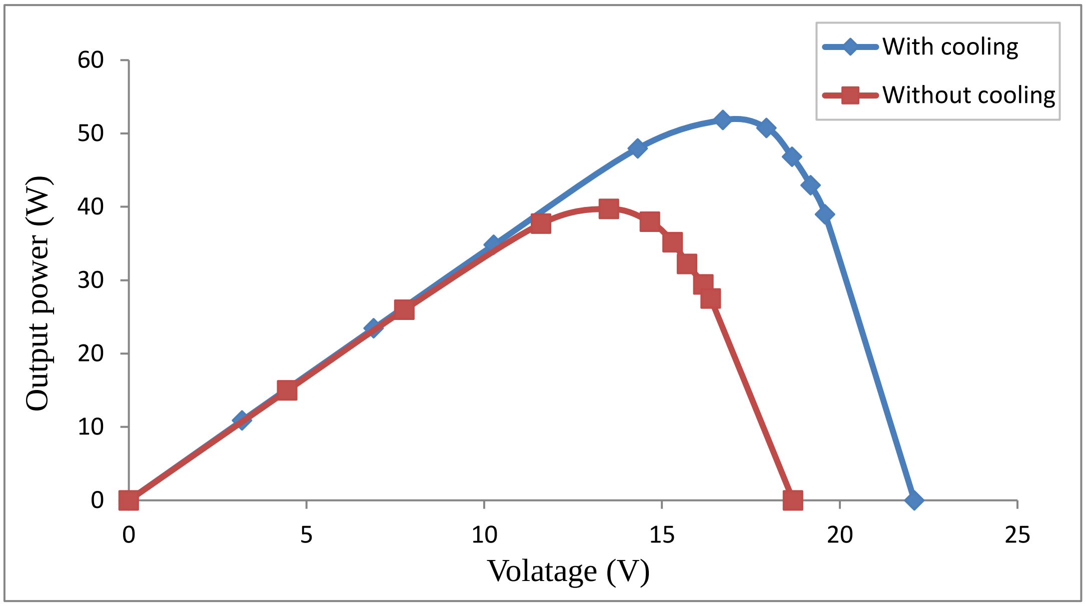


Figure III. 15: Output power and voltage variation for Day 3

Day 3: At this part of the experiment as shown in **Figure III.15** the output power as well the voltage increased for PVT system (with cooling) by 9.21Watts and 2.61 Volts i.e. 14.57% and 12.07% respectively, the temperature of PV system (without cooling) was 69.6°C and PVT system (with cooling) decreased to 36.6°C.

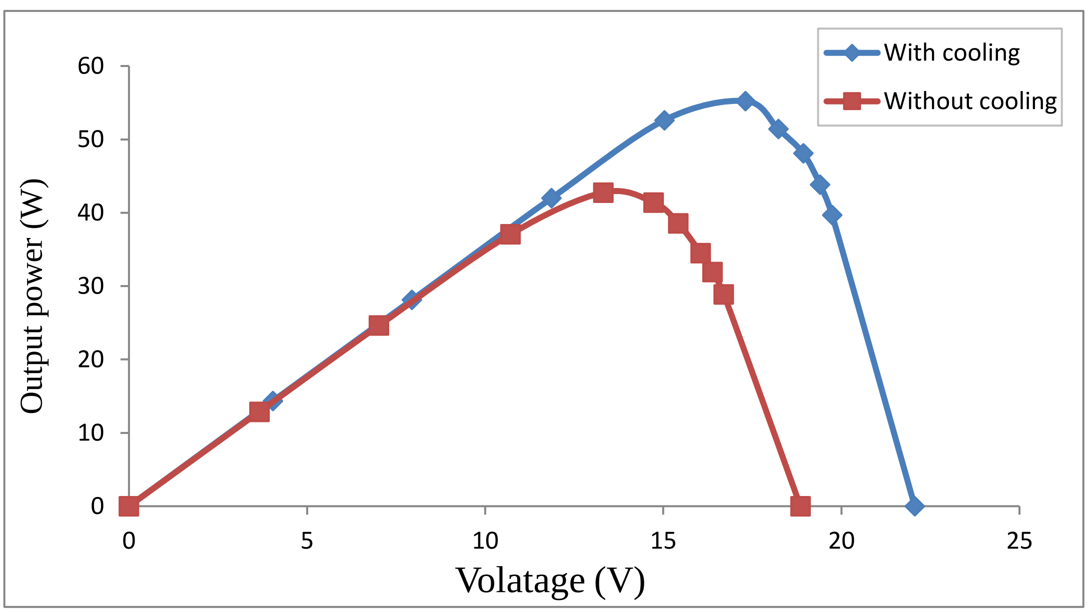


Figure III. 16: Output power and voltage variation for Day 4

Day 4: At this part of the experiment as shown in **Figure III.16** the output power as well the voltage increased for PVT system (with cooling) by 10.39Watts and 3.08 Volts i.e., 15.80% and 14.04% respectively, the temperature of PV system (without cooling) was 61.9°C and PVT system (with cooling) decreased to 35.7°C.

5.8. Comparison between the electrical efficiency and improvement from day 1 to day 4

To investigate the comparison of the electrical efficiency from the 1st day to the 4th **Figure III.17** shows that the 1st day has the highest efficiency then the 3rdday these registered high efficiencies are consequence of the high flow rate, then the 2nd day than the last, the first two days are better than the last two days due to the continuous cooling (all the day).**Figure III.14** discuss the electrical improvement from the 1st day to the 4th, considering the PV system (without cooling) as a reference to PVT system (with cooling) where the 1stand 3rddayare the best for an improvement equal to 19.79% and 18.83% respectively then the 2nd day with an improvement of 18.34% which is better than the last day which has an improvement of 15.94%.

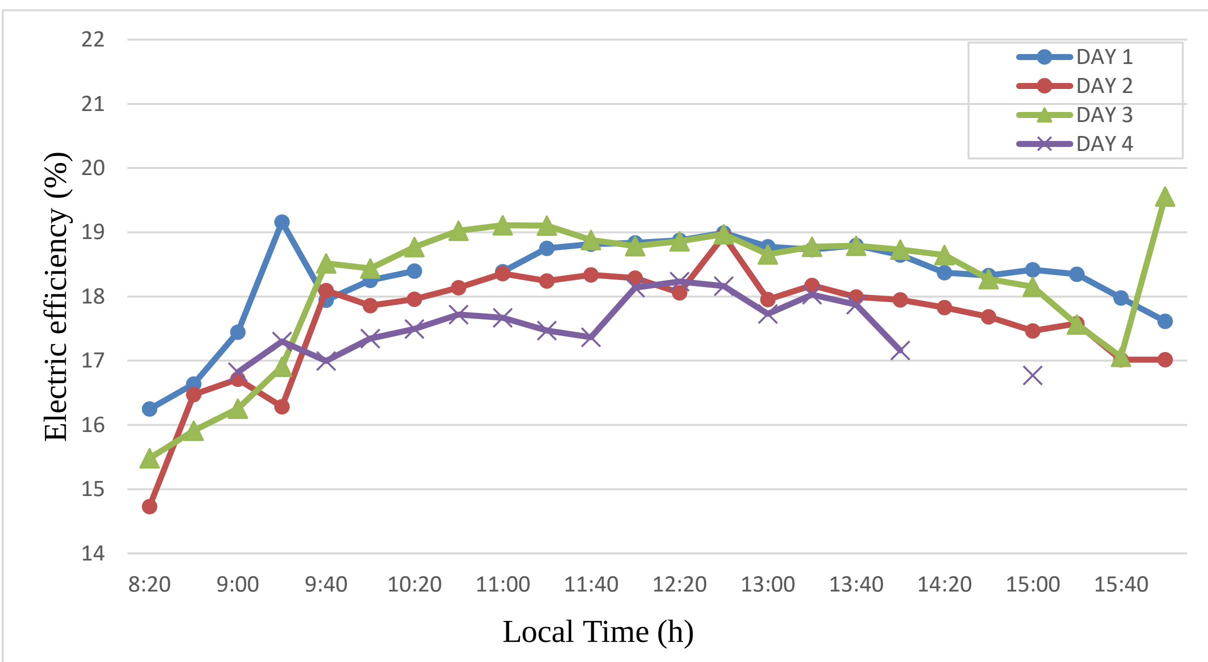


Figure III. 17: Electrical efficiency comparison from the 1st day to the 4th day

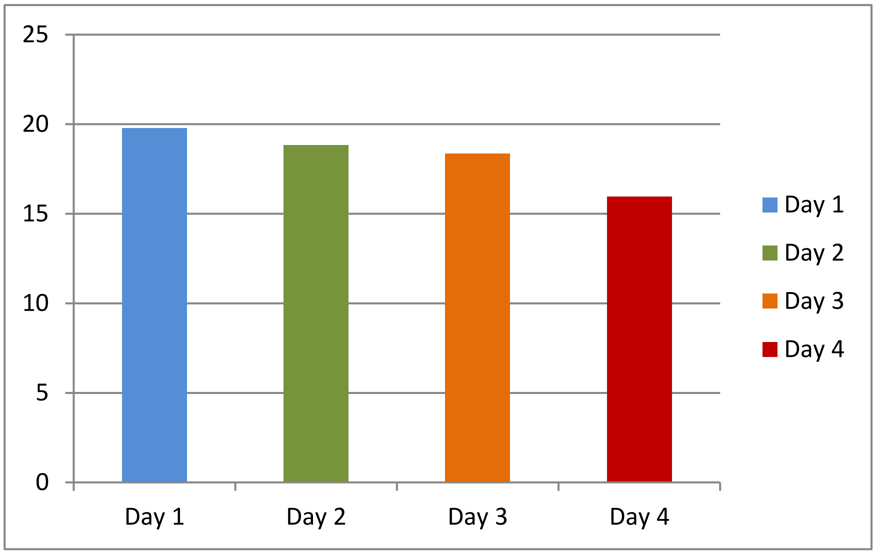


Figure III. 18: Electrical improvement comparison from 1st day to 4th day

6. Conclusion

This experiment discuss the efficiency of flow rate variation (Q_{vmax}= 0.17 l/s, Q_{vmin}=0.037 l/s) at Panel Maximum Temperature (PMT) 35°C and 45°C for PVT system (with cooling), side by side to PV system (without cooling) which the last one is considered as a reference for the first system, where the results show which flow rate and PMT are the best to use at this period of the year, the flow rate (Q_{vmax}) 0.17 l/s obtained 17% and 15% output power enhancement than PV system for 35°C and 45°C respectively with taking in consider the reduction in temperature by 37.4 % and 34% for the PVT system, i,e providing total (thermal and electrical power) output power 434 Watt for 35°C and 286 Watt for 45°C, as for the water flow rate (Q_{vmin}) 0.03 l/s obtained an enhancement in the output power of 16% and temperature reduction over than 20°C for both PMT and total usable power over than 80% where the PV system its total usable power is 14%. Looking to results it is clear to consider the flow rate 0.17 l/s is more efficient than 0.03 l/s as for 35°C is the most effective PMT during the experiment days than 45°C.

The increase in temperature does not effect on the short-circuit current (Isc) contrary to dust accumulation that effects on PV system by decrease the short-circuit current by 3.6% than PVT system, and for the voltage (V) it decreases with the temperature increase, contrary to the current it does not get effect by the temperature increase.

Note: volume of water used was taken into account.

GENERAL CONCLUSION

General Conclusion

Sun is the known by its power where the human used it to fulfill his needs of power from its irradiation by using the photovoltaic technique which is invented in 1800s and got developed through the years, but that technique has issues with the sun heating. A lot of researchers over the globe figured out that the photovoltaic panel efficiency get lower and lower by the increase in the panel temperature, most of them used cooling with water (due to his high thermal conductivity and his availability on the globe) with different techniques (on the top surface or back surface) by spraying water on the panel, a jet of water or flowing water on it…ect.

In this experimental study which is based on using water to cool the photovoltaic solar panel by varying the flow rate (0.17 l/s and 0.03 l/s) on the PVT system and establishing a maximum temperature for that system (don't letting the panel temperature raise over 35°C and 45°C) PMT, side by side there is another system (PV system) is considered as a reference to the PVT system, both panels are installed facing south with 30° this experimental was made in four days to get plenty of data for each flow rate with each PMT the results can be concluded in points underneath:

For 0.17 l/s flow rate with 35°C PMT (day 1):

- Output power gain reach to 11 Watts that equals to 17 % of power for PVT system comparing to the PV system.
- Temperature reduction of 22.25°C it means 38% of heat regarding the PV system as a reference.
- Total usable output power (thermal power 368 Watts and electrical power 65.5 Watts) of 433.5 Watts that can be considered to present 87% of used power by sun.

For 0.03 l/s flow rate with 35°C PMT (day 2):

- An output power gain of 17 % for PVT system which is 10 Watts.
- Reducing PVT temperature by 34% so it is used for otherwise such as bathing (thermal power of 550 Watts) to become the total power of that system equal to 610 Watts (electrical power of 59 Watts).

For 0.17 l/s flow rate with 45°C PMT (day 3):

- Power gain of 15% due to the temperature reduction (34%) for PVT system.

- Total output power of 286 Watts that represents 81.60% of solar radiation that can be used.

For 0.03 l/s flow rate with 45°C PMT (day 4):

- Electrical power gain of 15.89 % while cooling the PVT system.
- Heat reduction of 30% that obtained thermal power over than 700 Watts to get total power of 83% (60 Watts for electrical output power).

The 1st day and the 3rd day registered the best efficiencies during the experiment days then the 2nd and the 4th day respectively, these high efficiencies of the first and the third day are due to the high flow rate used in the experiment that means the more temperature reduce from the PVT system the more improvement registered. 35°C PMT registered better electrical efficiency than 45°C for the maximum and the minimum flow rate due to the continuous cooling (PVT cooling starts at 11:00 till the end of the day), through experience, it was found that PMT and the flow rate depends on the year's season. If the lowest PMT used in the summer that will consume a lot of energy to start the water pump for cooling the system, that system if it is used in a solar station can provide electrical output power improvement able to supply more other houses with electric power.

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ملخص

تستثمر الجزائر و تعزز مجال الانتقال الطاقوي و الطاقات المتجددة من خلال إنشاء عدة محطات كهروضوئية, معظمها في المناطق الحارة, أجريت هذه الدراسة رفع الكفاءة اللوح الشمسي في في الأوقات الحارة عن طريق تغيير درجة الحرارة القصوى للوح و معدل تدفق الماء (35° درجة مئوية و 45° درجة مئوية/ 0.17 لتر/الثانية و 0.037 لتر/ الثانية), عند درجة حرارة 35° مع استعمال أعلى معدل لتدفق الماء سجل اكبر تحسن في الطاقة الكهربائية ب10.53 واط الذي يعادل 16.79% مقارنة بالنظام الغير مبرد و إنخفاض درجة الحرارة بمقدار 22.25° ما يعادل 37.7%كما لوحظ من خلال التجريب أن تراكم الغبار يخفض شدة التيار بنسبة 3.6% و لا تؤثر ارتفاع درجة الحرارة عليه على عكس فرق الكمون.

الكلمات الدالة: الطاقة الكهروضوئية ؛ التبريد السلبي ؛ تراكم الغبار ؛ تحسين الاداء.

Abstract

Algeria is investing and strengthening the field of energy transition and renewable energies through the establishment of several photovoltaic stations, most of them are in hot regions. This study made to raise the PV efficiency in hot times by changing the panel maximum temperature (PMT) and water flow rate (35°C and 45°C/ 0.17 l/s and 0.037 l/s), 35°C PMT with highest flow rate registered an electrical improvement of 10.53W which means 16.79% comparing to the non-cooling PV system and temperature reduce of 22.25°C that equal to 37.7%. It was also observed through experimentation that dust accumulation reduces the current intensity by 3.6% and the increase in temperature does not affect on it, unlike the voltage.

Keywords: photovoltaic energy; passive cooling; dust accumulation; improve the performance.

Abstrait

L'Algérie investit et renforce le domaine de la transition énergétique et des énergies renouvelables à travers l'implantation de plusieurs centrales photovoltaïques, la plupart se trouvent dans les régions chaudes. Cette étude visait à augmenter l'efficacité du PV en période chaude en modifiant la température maximale du panneau (PMT) et le débit d'eau (35°C et 45°C/ 0,17 l/s et 0,037 l/s), 35°C PMT avec la plus haute le débit a enregistré une amélioration électrique de 10,53 W, soit 16,79 % par rapport au système PV sans refroidissement et une réduction de température de 22,25 °C, soit 37,7 %. Il a également été observé par expérimentation que l'accumulation de poussière réduit l'intensité du courant de 3,6% et que l'augmentation de la température n'a pas d'effet sur celui-ci, contrairement à la tension.

Mots clés : énergie photovoltaïque ; refroidissement passif ; accumulation de poussière ; améliorer les performances.