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Photovoltaic Cooling System

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Abstract

The heart of the solar system is Photovoltaic (PV) panels generally it has a low energy conversion efficiency available in the market. PV panel temperature control is the main key to keeping the PV panel operate efficiently and increase the lifetime of it. This research presented the great influence of the cooling system in reduced PV panel temperature.

A cooling system has been developed based on water sparkles using a closed-loop water circuit open to the wind. Water is sprayed on the back side of the PV panel will extract the heat energy distributed and cool it down. The working operation of the water sprayers is controlled by the programmed Arduino, which is depending on the average value of PV panel temperature.

Trials were performed with and without cooling mechanism attached to the backside PV panel and a dirty panel with dust on it. The whole PV system was built in outdoor weather conditions. The project clearly shows how cooling mechanism improves the performance of PV panel at the hot climatic weather. In short, the reduction of PV panel temperature is incredibly important to keep its performance operated efficiently.

Dedications

We would like to dedicate this work for our great families ,friend and every single person who have supported us through our road of graduation . Also we can’t forget our beloved teachers in the faculty of engineering technology.

Acknowledgements

This Project and the research behind it would not have been possible without the exceptional support of our supervisor, Prof.Omar Badran. His Support , knowledge and exacting attention to detail have been an inspiration and kept our work on track. We acknowledge the efforts of all the faculty members who have taught us and all the staff at The Faculty of Engineering Technology who took care of us and our comfort during the study period.

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List of Nomenclatures:

G ……… Solar irradiance (W/m^2)

ρ_r ……… Reflectance

α ……… Absorptivity

NOCT ……… Nominal Operating Cell Temperature (°C)

T_{cell} ………. Cell Temperature (°C)

V_{wind} ……….. Wind Speed

Qc .... Heat loss by convection (W)

Q_E .... Heat loss by evaporation (W)

GHI .... Global Horizontal irradiation (W/m^2)

GTI .... Global Tilted Irradiation (W/m^2)

DNI .... Direct Normal Irradiance (W/m^2)

DHI .... Diffuse Horizontal Irradiance (W/m^2)

θz .... Zenith angle

ω .... Hour angle

L_{loc} .... Position of the current local meridian

L_{noon} ……….. Meridian's position at solar noon

δ .... Declination angle

p_s , p_d ……….. Partial pressures (Kpa)

e ………... Evaporation factor

r ………... Latent heat of evaporation (kJ/kg)

ρ ………. Density of the water (kg/m^3)

u ………. Velocity of the flow (m/s)

D ……... Pipe diameter (m)

μ ……... Viscosity of the fluid (Pa.s)

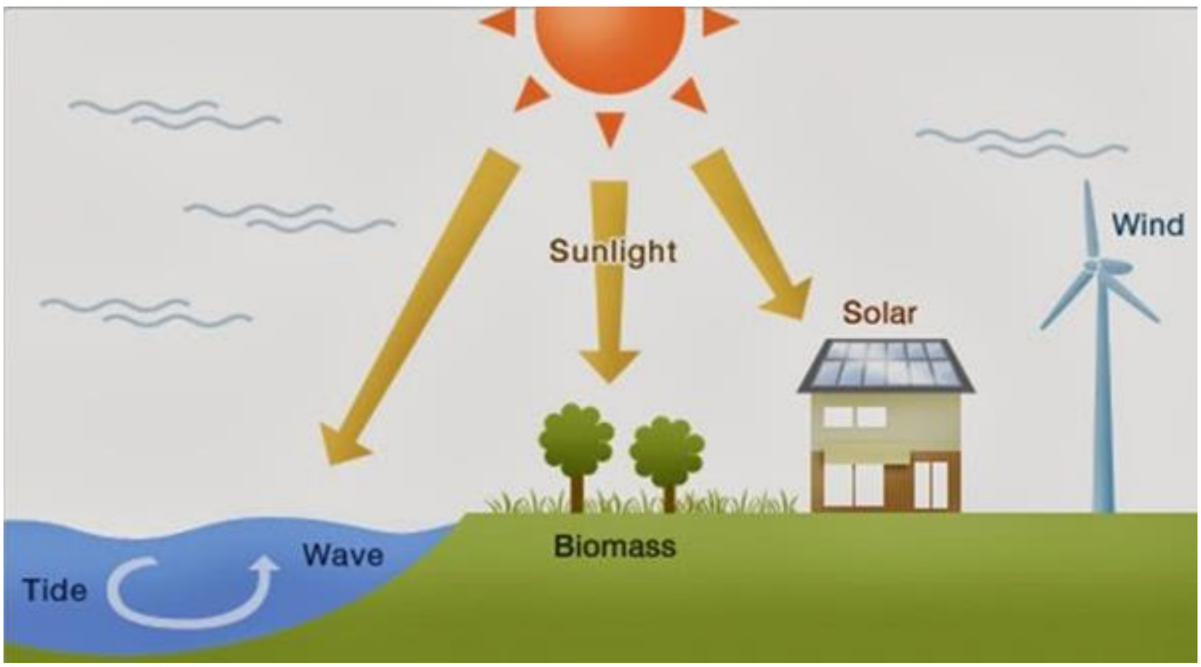
$\dot{m}$ ……... Mass flow rate (Kg/s)

C_p ……... Specific heat of the water equals to (4184J/kg.K).

Chapter 1 : Introduction

1.1 Solar Energy in General

Most of energy we use comes from the sun, and this energy is called solar energy where the sun is the ultimate source for energy generated from wind, solar and fossil fuels.

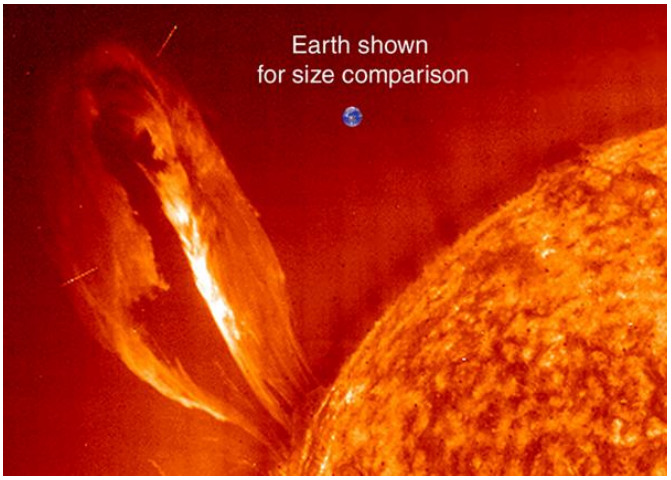


Figrue 1.1 : Types of renewable energy.

Heat from the sun drives the air current and water current that turns wind turbines and power hydro-electric dams. Meanwhile the rise of the sun also helps the plants grow they ultimately become wood, coal, and gas.

The sun is the direct energy, so why would not we use it instead of using coal, wood, natural gas, oil. since they are about to extinguish eventually “estimated time remaining for oil and natural gas are 50 years each and 115 for coal”. If we keep using it as the same rate as today we will not have enough to last next generations also they are polluting our planet and contributing to climate change .

On the other hand, The Sun energy will not be running out for about 5 billion Years , that makes it a renewable resource such as wind and water but even all the energy we could get from both of them added together is still less than 1% of the solar energy reaching the earth . It’s clear that the potential of solar energy massively outshines its competitors.
To understand the real power and potential of the sun , The sun is a massive flaming sphere of gases 330,000 times more massive than the earth , at its core 27 million Degrees Fahrenheit (about 15M Celsius) and because of that the sun gives a lot of energy in the space as heat and light called Solar Energy.



Figrue 1.2 : Size comparison between earth and sun.

1.2 Usage of Solar Energy

1.2.1 Solar Heating

The simple way to use solar energy is to heat air or water by using flat-plate collectors which captures solar energy and convert it to thermal energy. It is the most common device used in this area.

Flat-plate collectors consists of a black-ended metal plate, using one or two sheets of glass that is heated by the solar energy falling on it. Heating air or water in the fluid’s carrier, this flows past the back of the plate. The heat can be used directly or can be stored in a medium storage which is insulated to keep the heat inside.

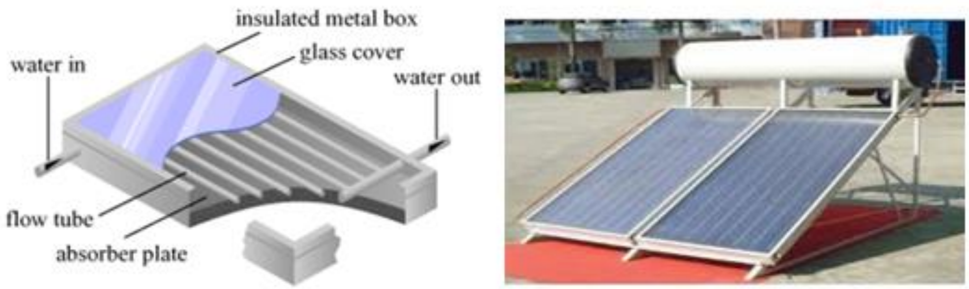


Figure 1.3 : Solar Heater.

1.2.2 Water Desalination

Water is one of the abundant resources on earth whereas it represents 75% of the earth's surface. Direct desalination systems use solar power to distillate salty water directly, Solar still uses green-house effect to evaporate seawater, It includes basin during which a constant salty water is within the V-shaped glass envelope .The bottom of the basin absorbs the sun rays that passes through the roof, These rays causes water to be heated and eventually starts to evaporate. The evaporated water is then condensed below the roof and runs down through, which conduct the distilled water to the reservoir.

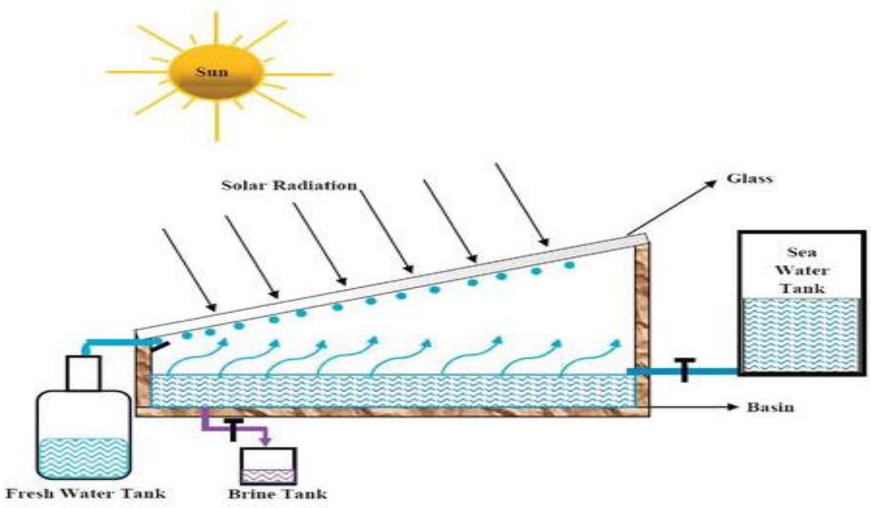


Figure 1.4 : Work principle of water desalination.

1.2.3 Photovoltaic (PV)System

Solar cells convert sunlight directly into electric power, solar cells used to power calculators and watches in the past and till now, but now there are more applications where we can use the sunlight. They are made from semiconducting materials almost like those used in computer chips. When the sunlight hit these materials, the solar power allows the electrons to cut loose from their atoms, allowing the electrons to flow through to generate electricity.

This process of converting light to electricity is known as the photovoltaic effect. The system is consisted of one or more solar arrays connected with an inverter and other electrical and mechanical hardware that use energy from Sunlight to supply electricity.

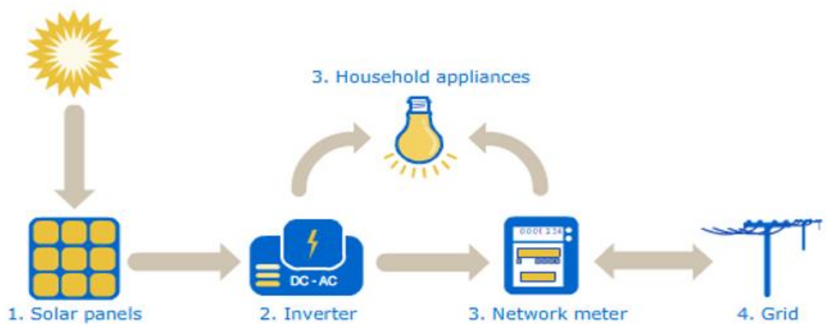


Figure 1.5 : PV system.

1.3 Renewable Energy in Jordan

Jordan like most countries has problems and difficulties that may be of national concern such as the increasement of renewable energy technology utilization. Where Jordan imports most of its fossil fuels to meet its energy needs, leaving it exposed to variations of fuel price. Jordan's demand for energy is growing at a rate of 3% annually.
Since Jordan is blessed with a lot of renewable energy resources, particularly solar and wind energies and these technologies are not that hard to implement, and they require less operating and maintenance costs. This means that we should reconsider the renewable energy sector. The most safely approach to address this issue is to

reduce the problems and difficulties linked with each of the above-mentioned factors.

1.3.1 Geothermal Energy

Geothermal energy is defined as heat from the earth's internal underneath the earth surface. Heat from the Earth plus the thermal energy is acquired by drilling water or steam wells same as when drilling for oil.

The first group relates to natural springs. These springs from the main surface appearance of geothermal energy of Jordan.

The second group of geothermal resources are these discovered while discovering oil and groundwater within the deep surface of the eastern deserts and along to eastern margin of the Dead Sea Rift. The location of almost all the thermal springs and the hot boreholes are dictated by their proximity to the Dead Sea cracks. Most of the springs have temperature around 45°C however in Zarqa Ma'in and Zara springs temperature reaches around 63°C.

One of the simplest types of geothermal plant is the dry steam power plant. The work principle of this type is to operate the turbine by using the steam from the tank. The steam will be collected from the production well and used to operate low-pressure turbines. Therefore, the working fluid is steam. After that the steam we used will condense and will be injected back through the injection well . The steam used in this type must be superheated and pressurized with a temperature approximately between (180°-350°C).

Thermal water of zara and zarq'a ma'in .

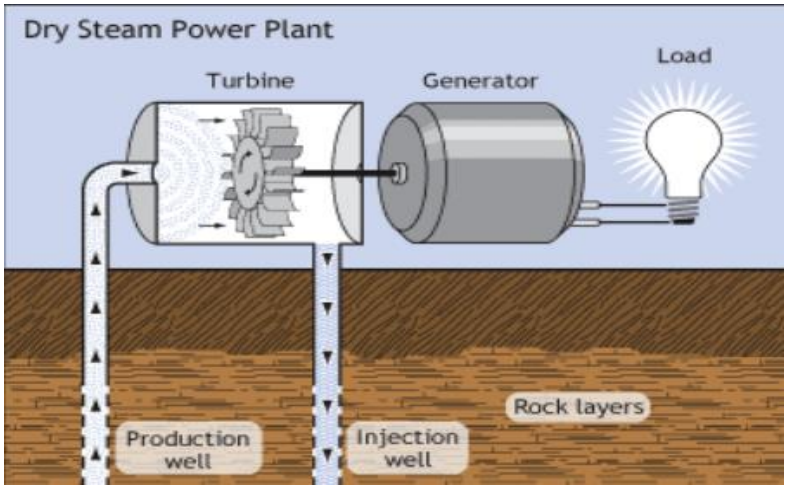


Figure 1.6 : Work principle of geothermal power plants.

1.3.2 Biomass

Biomass is basically made up from plants, animal material, such as sugarcane or corn crops, chips of wood, or even muck. As a renewable energy source, 70% of renewable energy around the world is obtained from biomass.

The most common way for biomass to generate electricity is direct combustion. The work principle is by burning the agricultural waste or wood to heat water which will produce steam which will eventually spin the turbine and produce electricity. Plants in Jordan: BioGas Planet at Rusaifeh landfill, Al Ghabawi-Zarq’a ,

Figure 1.7 : Biomass cycle.

1.3.3 Wind Turbine

Basic wind turbines are divided into two types either horizontal or vertical axis wind turbine. We can determine the amount of electricity produced by wind turbine by many way, but the most important factor is the length of the blades. Its work principle is by using the kinetic energy produced by the wind spinning the propeller-like blades to spin the generator and produce electricity.

Horizontal-axis wind turbines performs better than the vertical-axis wind turbine and that’s the reason why there are fewer vertical-axis wind turbines in use today and more horizontal.

Figure 1.8 : Windmill.

1.3.4 Hydropower

Hydropower in Jordan has no notable bodies of flowing water suitable for the construction of hydroelectric power stations. The only such plant is at the King Talal dam on the Az Zarqa River, with a capacity of 5 MW. Another hydroelectric generating facility employs a turbine to exploit the head of the cooling water taken from the sea to cool a thermal power station in Aqaba as it flows back to the sea. In 2012, these two stations together generated 61 GWh of electricity and were therefore the source of 0.4% of the electricity generated in the country as a whole.

1.3.5 Solar energy

The amplest rich supply of energy offered to the mankind is solar energy specially the electromagnetic energy emitted by the sun. A large research and development effort is afoot to develop economical systems to use solar energy and make it a significant sources of fuel energy, notably for heating and cooling systems. Solar energy is outlined as the transformation of energy that's present in the sun and is one among the renewable energies. Photons are the tiny packets of energy that enter into the atmosphere at daylight. Photons travel the ninety three million miles distance from the sun to Earth at the speed of light taking approximately eight and a half minutes. Once the sunlight passes through the earth's atmosphere, most of it is in the type of visible light and infrared radiation and to convert this energy into electricity we tend to use solar cells.

Two tendered PV projects, one totaling 2 MWp, financed by Spain in the Azraq area, and another totaling 65 – 75 MWp in Quweirah (Aqaba), financed through a fund of Abu Dhabi, were to be evaluated by the Ministry for Energy and Mining Resources (MEMR) in 2014.

1.3.6 Solar radiation

Solar radiation, electromagnetic radiation, including X-rays, ultraviolet and infrared radiation, and radio emissions, as well as visible light, emanating from the Sun. where is the availability of solar radiation data at a given locality is the most important parameter in assessment and study of solar energy conversion systems. Design and optimization of all solar systems requires detailed knowledge and adequate information of the solar radiation characteristics of the location in which the systems are to be used. For the above reasons and because of the increasing interest in solar energy applications in Jordan, it is important to study and evaluate the behavior of the measured global solar radiation data throughout the year. The measured values of solar radiation parameters are very limited in Jordan and are available at only a few places in the country.

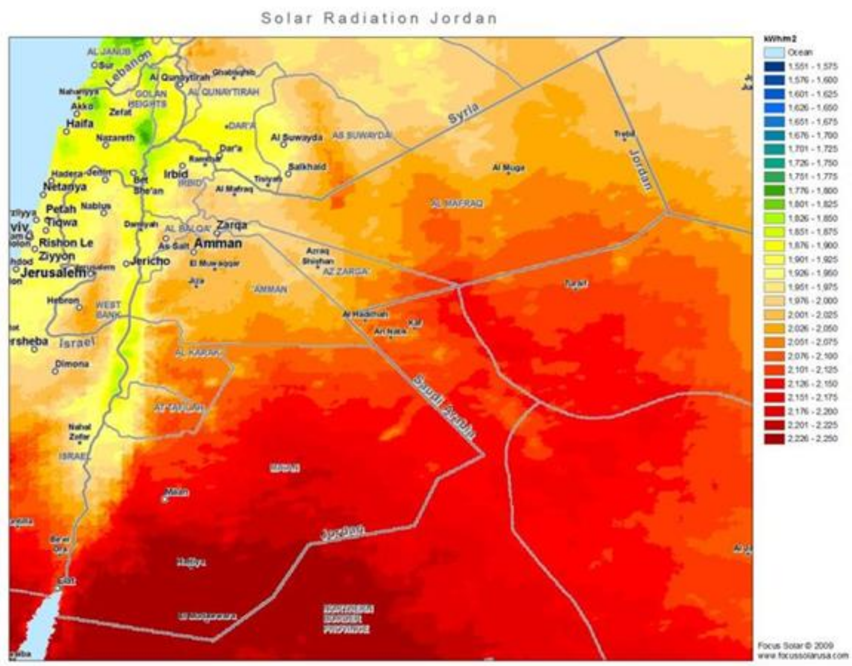


Figure 1.9 : Solar radiation distribution in Jordan.

1.4 Main Components of Solar Energy

In addition to the solar panels, there are different necessary parts of a photovoltaic system. These parts which usually accounts for over half the system price and most the of the maintenance includes inverters, combiners, disconnects, mounting, wiring, circuit breakers, electrical meters and solar battery storage units.

1.4.1 Solar Panel

When you think about solar energy, the primary factor that comes up on your mind is that solar panels collect clean renewable energy within the shape of sunlight and convert that light into electricity which can be used to generate power for electrical loads.

solar panels are consisted of multi solar cells that are themselves contain layers of silicon, phosphorous (which provides the negative charge), and boron (which provides the positive charge).

Figure 1.10 : Solar panel.

1.4.2 How does it work

Solar collector (panel) absorbs the photons and in doing so initiates an electrical current. The resulting energy generated from photons hitting the surface of the solar collector allows electrons to be released out of their atomic orbits and released into the electrical field excited by the solar cells which then pull these free electrons into a directional current. This process is called the Photovoltaic Effect. An average home has more than enough roof area for the necessary number of solar panels to produce enough solar electricity to supply all of its power needs. Excess electricity generated goes onto the main power grid, paying off in electricity use when the sun goes down.

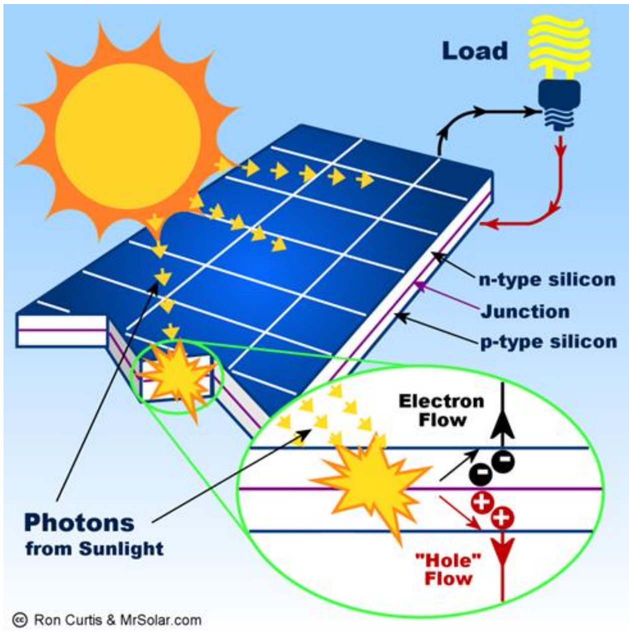


Figure 1.11 : Work principle of solar panel.

In a well-balanced grid-connected configuration, a solar panel generates power during the day that is then used in the home at night. Net metering programs allow solar generator owners to earn money if their system produces more power than what is needed in the home. In off-grid solar applications, a battery, charge controller and in most cases, an inverter are necessary components. The solar panel provide direct current (DC) electricity through the charge controller to the battery bank. The power is then ejected from the battery bank to the inverter, which converts the DC current into alternating current (AC) which will be used for non-DC appliances. Assisted by an inverter, solar panel arrays are often sized to satisfy the most demanding electrical load requirements. The AC current usually used to power loads in homes or commercial buildings, recreational vehicles and boats, remote cabins, cottages, or homes, remote traffic controls, telecommunications equipment, oil, and gas flow monitoring and more.

1.4.3 Inverter

An inverter is an electrical device which receives electrical current in the form of direct current (DC) and converts it to alternating current (AC). For PV systems, this means the DC current from the solar array is fed through an inverter which converts it to AC. This way we can operate most electric devices or interface with the electrical grid. Inverters are very important for nearly all solar energy systems and they are the most expensive component after the solar panels themselves. The conversion efficiencies of most inverters are 90% or higher and contain many safety features including ground fault circuit interruption and anti-islanding. These features tend to shut down the PV system when there is a loss of grid power.

1.4.4 Batteries

For PV systems, the necessity for energy storage leads most of the people to battery banks. With the exception of petroleum-based fuels, batteries are currently the foremost practical and cost-effective way to store enough energy for human use. luckily, you'll be able to incorporate batteries into just about any PV system.

1.4.5 Charge Controllers

The main role of a charge controller in a PV system is to properly control the charge from the PV array into the battery bank by controlling the current and voltage from the array into the batteries. without a charge controller, the PV array would be able to send all its current into the battery bank with none regard for the batteries' needs. The batteries will become overcharged and eventually ruined. Charge controllers regulate the voltage and current sent to the batteries throughout the charging method. every charge controller has multiple stages that it regulates completely different voltage and current levels.

1.4.6 Mounting

the mounting structure which fixes the solar array to the ground or rooftop. Typically constructed from steel or aluminum, this set up mechanically fix the solar panels in place with a high level of precision. The system is designed to stand firm against extreme weather events such as hurricane or tornado level wind speeds and/or high accumulations of snow. Also, the system is used to ground the solar array to prevent electrocution.

1.4.7 Other components

The remaining components of a solar PV system include combiners, disconnects, breakers, meters, and wiring. A solar combiner works by combining two or more electrical cables into one larger one. Combiners involve fuses used for protection and are used on all medium to large solar arrays. Disconnects are switches which allow for manual disconnection of an electrical wire. Usually used on either side of an inverter "DC disconnect" and "AC disconnect" these devices provide electrical isolation when an inverter needs to be installed or replaced. Circuit breakers is used to protect electrical systems from over current or surges. They are designed to trigger automatically when the current reaches a specific amount, also breakers can be operated manually. An Electric meter measures the amount of energy that passes through it and is used by electric utility companies to measure and charge customers. For solar PV systems, a special bi-directional electric meter is used to measure the incoming and the outgoing energy from the solar PV system. The wiring or electrical cables transport the electrical energy from and between each component and must be properly sized to carry the current. Wiring exposed to sunlight must have protection against UV exposure, and wires carrying DC current sometimes require metal sheathing for added protection.

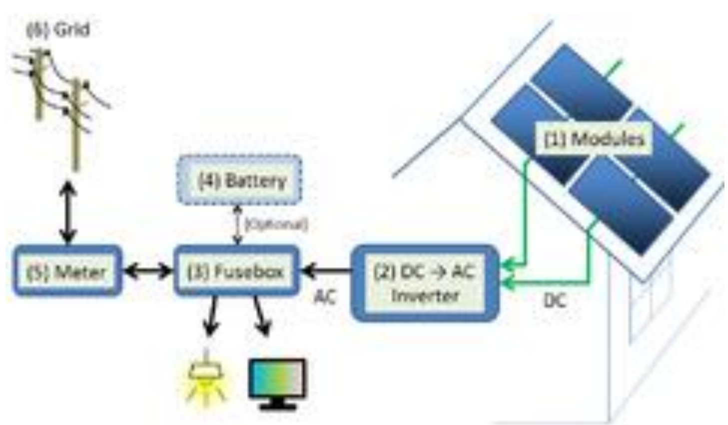


Figure 1.12 : On-grid PV system.

1.5 Advantages & disadvantage PV system

Advantages

• While using PV to produce electricity environment will not be harmed , there is no pollution that gets into the air or water unlike other sources that provides electricity nor endanger animals , deplete natural resources or human health.

• Photovoltaic systems operate in total silence and nothing visual.

• Small-scale solar plants can take advantage of unused space on rooftops of existing buildings.

• PV cells were originally developed so we can use it in the outer space , where repair is extremely expensive, if not impossible.

• Solar energy is a locally available renewable resource. It does not need to be imported from across the world. This reduces environmental impacts associated with transportation and reduces our dependence on imported oil. And, unlike fuels that are mined and harvested, when we use solar energy to produce electricity we do not deplete or alter the resource.

• A PV system can be constructed to any size based on energy requirements. Furthermore, the owner of a PV system can enlarge or move it if his or her energy needs change. For instance, homeowners can add modules every few years as their energy usage and financial resources grow. Ranchers can use mobile trailer-mounted pumping systems to water cattle as the cattle are rotated to different fields.

Disadvantages

• Some toxic chemicals, like cadmium and arsenic, are used in the PV production process. These environmental impacts are minor and can be easily controlled through recycling and proper disposal.

• Solar energy is somewhat more expensive to produce than conventional sources of energy due in part to the cost of manufacturing PV devices and in part to the conversion efficiencies of the equipment. As the conversion efficiencies continue to increase and the manufacturing costs continue to come down, PV will become

increasingly cost competitive with conventional fuels.
• Solar power is a variable energy source, with energy production dependent on the sun. Solar facilities may produce no power at all some of the time, which could lead to an energy shortage if too much of a region's power comes from solar power.

1.6 Parameters That Affect's Solar Panels

1.6.1 Effect of radiation

Photovoltaic power is affected by incident irradiation. PV module short circuit current (Isc) is linearly proportional with the irradiation, while open circuit voltage (Voc) increases exponentially with the maximum value with increasing the incident irradiation, it varies slightly with the light intensity.

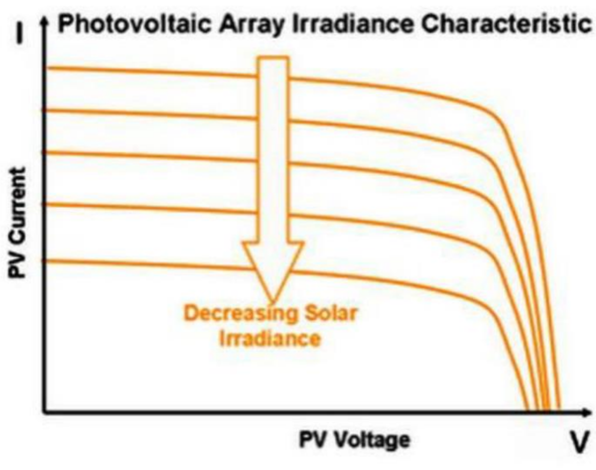


Figure 1.13 : Photovoltaic array irradiance characteristics.

1.6.2 Effect of Temperature

Higher temperatures do not mean that the production of solar panels will increase, its actually the opposite since it manages to drop the voltage, power and therefore the efficiency. when we talk about high temperature, we mean the extreme type which causes the drop.

Solar panels are rated at 25 ˚C so when the temperature increase 1 ˚C higher that the rated temperature it decay's (0.25%-0.5%) of the output which means in hot days panels will have less production of power.

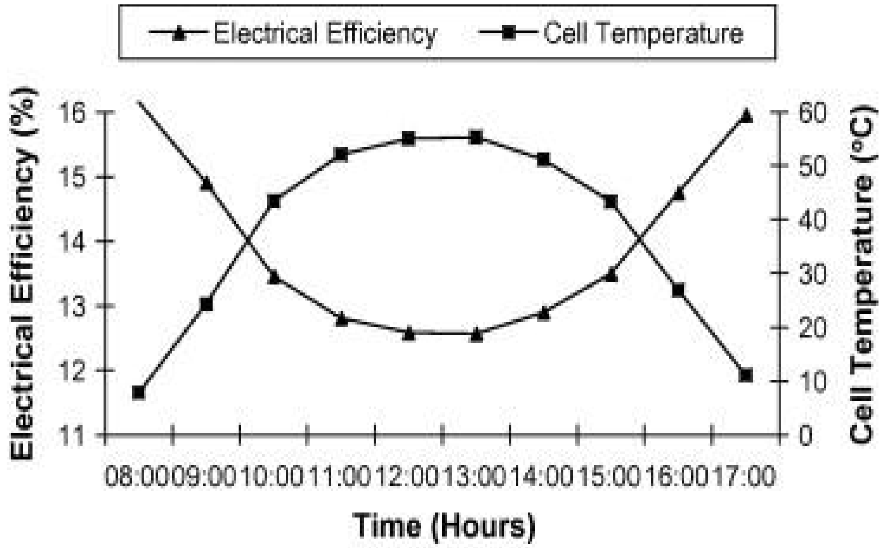


Figure 1.14 : Cell temperature effect on electrical efficiency.

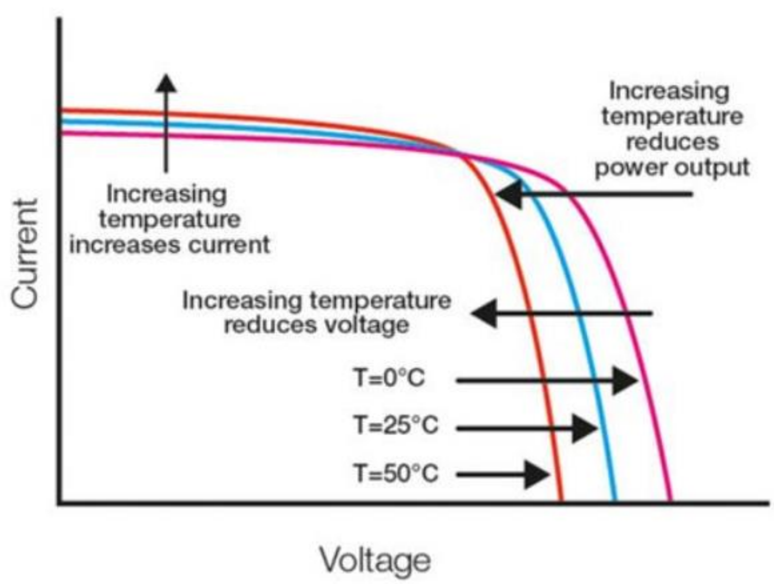


Figure 1.15 : Temperatures influence on the output voltage and current curve for PV performance.

1.6.3 Maximum power point (MPP)

Maximum power of the PV module equal to the current at maximum power point (IMP) multiplied to the voltage at maximum power point (VMP), it is the maximum possible power at Standard Test Condition (STC). Referring to Figure 1.16, the "knee" of the I-V curve represents the maximum power point (PMPP) of the PV module system. The maximum electrical power is generated at STC. The usable electrical output power depends on the PV module efficiency which is related to the module technology and manufacture.

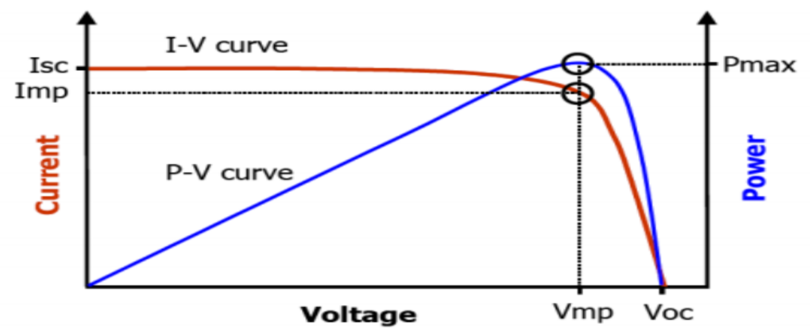


Figure 1.16 : I-V curve for maximum power point of a PV system.

1.6.4 Maximum Power Points Tracking

Maximum power point tracker is an electronic converter which converts DC to DC and optimizes the match between the solar array and the battery or utility grid. it tries to keep the panel voltage close to its Maximum Power Point when both the temperature and radiant intensity are changing. And this results in increasing of efficiency.

1.6.5 Dust

Dust has great effect on panel performance and some studies showed that the reduction of peak power produced by the panels is up to 18% which can be considered high.

1.7 Energy conversion efficiency

Energy conversion efficiency can be expressed as the percentage of power converted and collected when solar cells are connected to electrical circuit. In order to increase energy conversion efficiency, we need to reduce the reflection of incident light and if we manage to do that, we will have increasement in the efficiency.

Chapter 2: Literature Review

In these papers, the development in cooling techniques and temperature reduction of photovoltaic (PV) panels are analyzed and discussed. It is known that a reduction in the panel temperature will produce an increase in PV efficiency, so in previous years different cooling method have been discussed and tested experimentally. The efficiency decreases with the increase in temperature, with a magnitude of 0.5 %/°C. Several cooling type, mostly based on air cooling and active water, as these are the not complex techniques. Other cooling methods include state-variation material cooling, conductive cooling, etc..

Growing in electrical efficiency according on cooling techniques, size and type of the module, geographical location, and the season of the year, and often identify with a increase of 3-5 % in overall efficiency. At the end, a point of view on the other cooling method for PV solar panels will be shown in these papers.

2.1 Air Cooling PV System

The solar energy from sun it is the mother of energy in the universe, the one example of use this energy, the photo voltaic panel it gives us energy range from about (150 to 300 w) it is good, but the problem starts when the temperature increases to the limit effect on this output and efficiency where heat can reduce the efficiency from 10% to 25%. So, to solve this problem we use one type of cooling it is air cooling. The principle of this type of cooling is based on increase the surface of area or increase the flow of air through the body to reduce the temperature we can expand the surface area exposed to the cooled air use the fins.

To occur the air-cooling process, the ambient air temperature should be lower than the body temperature, based on second law of thermodynamic which is say it is not possible for heat to flow from a colder body to warmer body without any work having been done to accomplish this flow.

The technic of heat transfer in this method of cooling is by convection where the heat transfer from the hot object to the colder the colder surrounding as law:

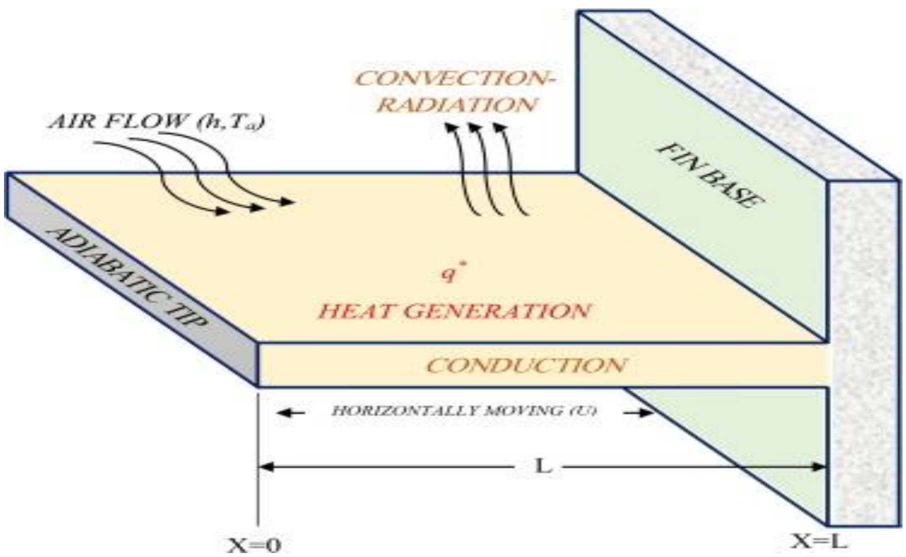


Figure 2.1 : Heat transfer through a fin.

There are 2 type of air cooling : passive air cooling where it gives high limit of natural convection and heat dissipation by using heat spreader like heat sinks to absorb or dissipate heat. The positive points of passive cooling are the lower energy required and lower financial cost making it appropriate choice for cooling PV panels. And active air cooling includes forced air by fan or blower, fans are used when natural convection is insufficient the main disadvantage of active cooling it requires the use of electricity and therefore it is higher costs, compared to passive cooling.

In addition to these methods, we use the heat sink which is consist of perforated fins and attached to the back of PV panels ,the result showed substantial decrease in operating temperature of the PV panels.

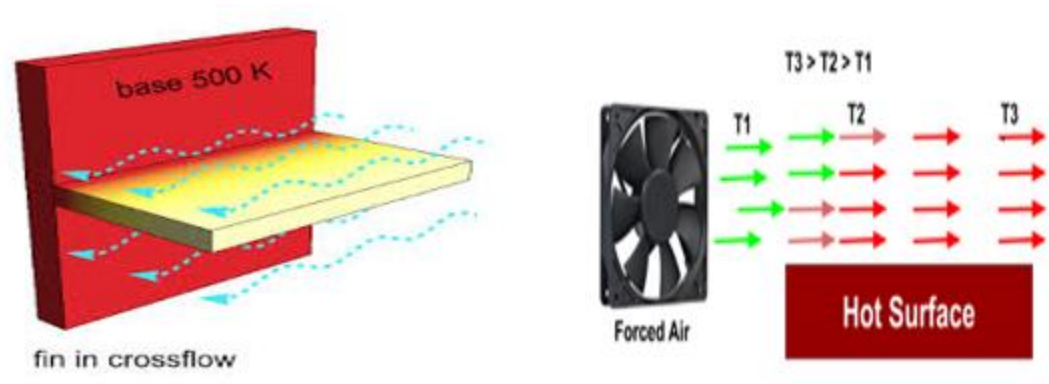


Figure 2.2 : Effect of forced cooling on fins.

Zainal Arifin et al [1]. find out that with air flow velocity 1.5m/s and temperature of 35C^0 under heat flux of 1000W/m^2 showed decrease in PV panel average temperature from 85.3C^0 to 72.8C^0. As a consequence of decreasing it`s temperature ,the heat sink increased the open circuit photovoltage and maximum power point of the PV panels by 10% and 18.67%, respectively.

Characteristics	Active cooling with heat sink	Active cooling without heat sink
Voc (Volt)	20.9	19
Isc (Ampere)	2.5	2.53
Pmpp (Watt)	35.4	29.83
FF	0.677	0.621
η (%)	11.11	8.51

Adam M. Palumbo [2]. Youngstown state university in his thesis talk about the effect of Forced Convection (active cooling) with fins on the PV panel temperature surface and this is the result of his experiments:

I (W/m^2)	V(m/s)	Ts(C^0)
1000	1.12	49.519
1000	1.37	45.977
1000	2.54	36.793

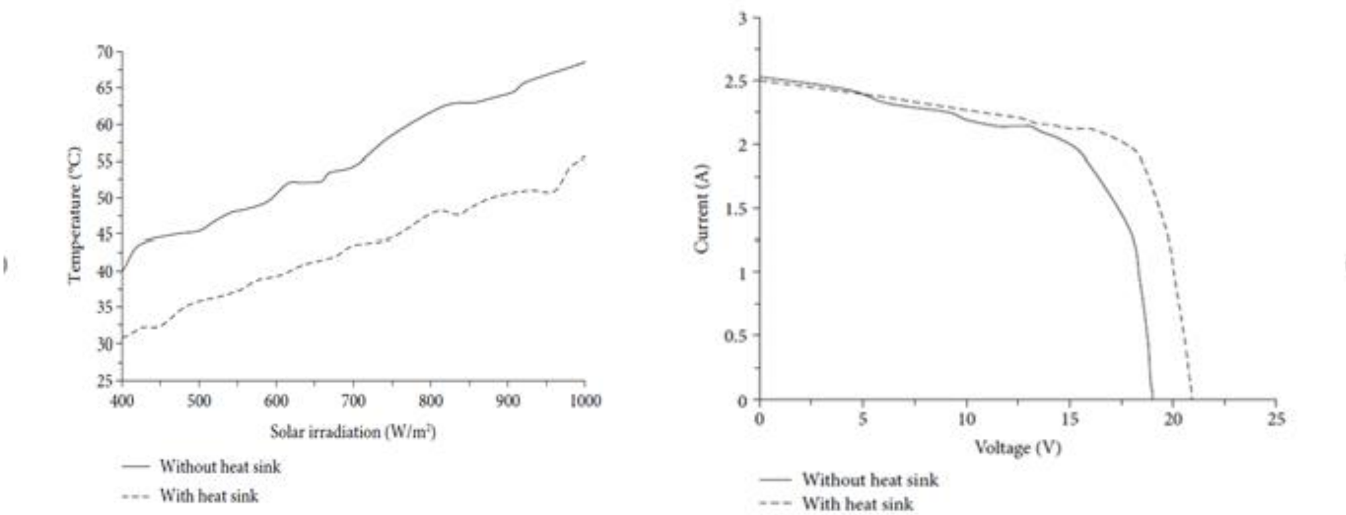


Figure 2.3 : Heat sink influence on current, voltage and temperature.

Cuce et al. [3]. worked on an experimental study on polycrystalline PV cells in grip conditions. Two PV cells were used: one with aluminum fins as a heat sink, with thermal dough applied and one without a heat sink. Illumination was diversified from 200 to 800 W/m2. The growing in electric efficiency of 9 % has been obtained through usage of passive cooling with a heat sink.

R. M.Hernandez et al. [4]. has shown that the deepness of flow channel below PV cells has great influence on passive cooling, for larger PV surface (1.95 m2). It has been shown that, for a length-to-deepness ratio of 0.085, the PV module heats increase by 5-6 °C when compared with a PV module on a uniform mount. It has been noted that the temperature variation growing with the increase of insolation. On the other hand, passive flow channels can have the reverse impact on PV cooling.

Wael Al-Kouz et al. [5]. find out the normal efficiency of the solar panels before cooling was between 10% to 15% at 42 _C. After cooling, the temperature of solar cells reduced to 20 C and the efficiency increased by 7%. Moreover, the output power was rise by 30% with maximum efficiency of 32.5% at noon time.

Sunarno A.Rakin et al. [6] find out the result was as following: The measured temperatures, voltage ,currents and powers of proposed cooling system are much better than the compared system which is heat sink only and water cooling only .it's able to perform best among the measured panel .In term of the average surface temperature ,the proposed cooling system the proposed cooling system 12.66% lower than basic solar panel ,solar panel with heat sink and solar panel with water. Consequently, it produces 21.49%, 4.66%,8.34% higher output voltage. Likewise , the load current increases about 21.27%, 3.73%, 7.50% subsequently than the compared panel. Finally, the output power of panel with the proposed cooling system achieves 47.71% higher than the plain solar panel. It shows how achievement cooling system can do. The performance comparisons are plotted as following figures:

Parameters	Basic Solar Panel	Heat-sink	Water	Proposed Method
Average Surface Temperature (°C)	53.33	51.83	51.17	46.58
Average Output Voltage (Volts)	9.83	11.42	11.03	11.95
Average Load Current (Ampere)	1.91	2.24	2.16	2.32
Average Power (Watts)	18.82	25.68	23.91	27.80

Figure 2.4 : Performance comparison between different cooling techniques.

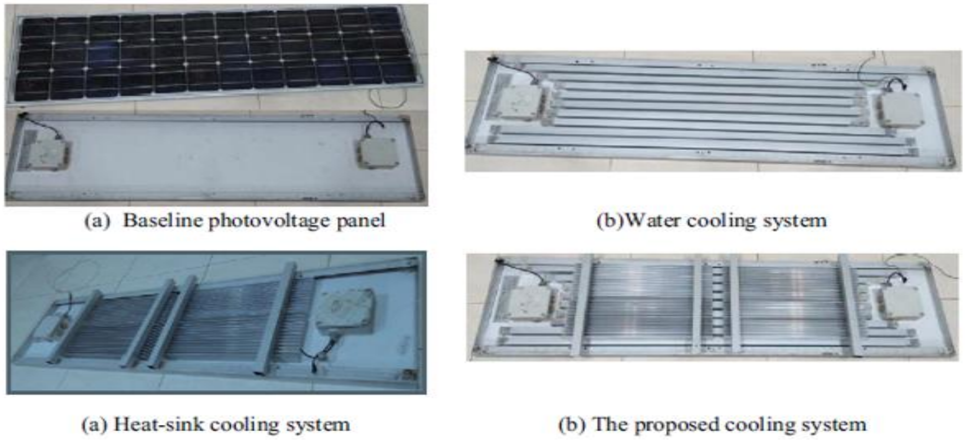


Figure 2.5: Passive cooling construction.

Popovici et al. [7] inspected numerically the temperature dropping of the PV panels during a clear day of summer by using variation arrangements of wall heat sink of air and passive cooling. It was found that the highest temperature of the panel for angle 45° was lower than that for angle 135°.The study found that the highest power produced by PV panel in case of using heat fins was grew by 6.97% and 7.55% comparing to the other refernce case, for angles of the ribs from 90° and 45°, respectively.

Farhana et al. [8] studied experimentally the operating temperature variation for the PV module with and without active cooling system to understand the electrical performance of the PV panel, two multi-crystal silicon solar modules with 13% of top efficiency at standard condition (25°C, 1000 W/m2) were used in the test. One of the modules was used as a reference and the other an aluminum was mounted at the bottom of the PV panel as a heat sink and a DC brushless fan was mounted on the heat fins.

Temperature for the PV panel with and without cooling system was higher than perimeter temperature by 30% and 70% . subsequently, the open circuit voltage (V_{oc}) of the PV module with cooling system was little higher than PV panel without cooling system.

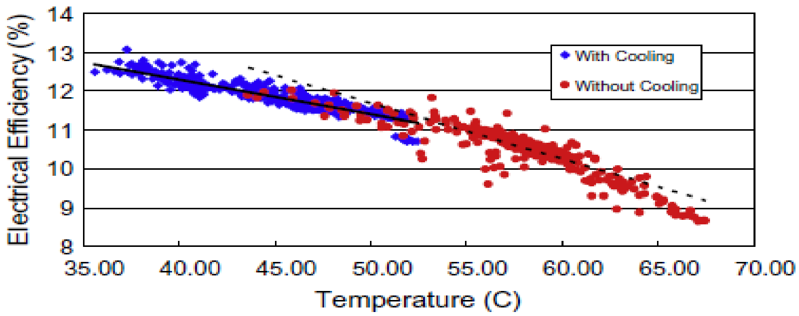


Figure 2.6 : Temperature effect on electrical efficiency.

Dubey, Sandhu et al. [9] conducted studies on two types of PV modules, glass to glass and glass to tedlar , the studies were made with and without duct under the panel, the duct dimensions are (0.605 m x 1.0 m x 0.04 m) and the PV tilt angle was 30 degree, this test was made in New Delhi, India under its latitude and climate. It is found that the glass-to-glass modules with duct gives higher electrical efficiency also higher outlet air temperature amongst all cases. Since the percentage difference between electrical efficiency of glass-to-glass type PV modules with and without duct is 0.66% which can be considered to be very high if it is used in large PV plants also the annual average efficiency of glass-to-glass type PV module with duct is 10.41% and 9.75% without duct. We notice that the overall electrical efficiency of the photovoltaic (PV) module can be increased by reducing the temperature of the PV module by withdrawing the thermal energy associated with the PV module.

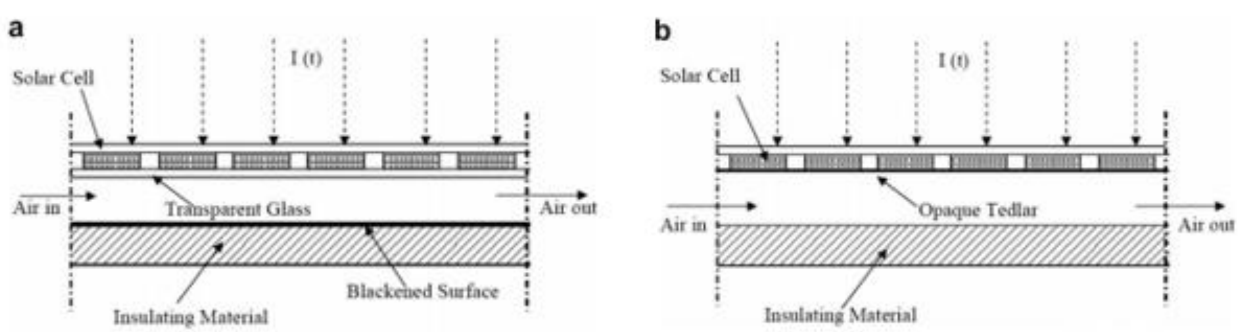


Figure 2.7: (a) Cut sectional view of glass-to-glass PV module with duct. (b) Cut sectional view of glass to tedlar PV module with duct.

Shahsavar, Salmanzadeh et al [10]. (2011) studied the integrated photovoltaic panels coupled with air thermal collectors. The idea was that he connected the PV system with mechanical ventilation system of the building. The Principle of work was that the Exhausted air from mechanical ventilation during the summer cools PV units and in winter the cold air preheated under warm panels is used for enhancing space heating system in the building. This model was tested for the Kerman city located in Kerman province in the south of Iran. It was found that using ventilation system for cooling PV panel increased electricity production by 7.2 % during the year. Moreover, annually calculation for an area of $10m^2$ of PV panels indicates that 3400 kWh of energy was recovered to the space heating system. For the same area it was found that 56 kWh of additional electricity was generated by PV panels using cooling system.

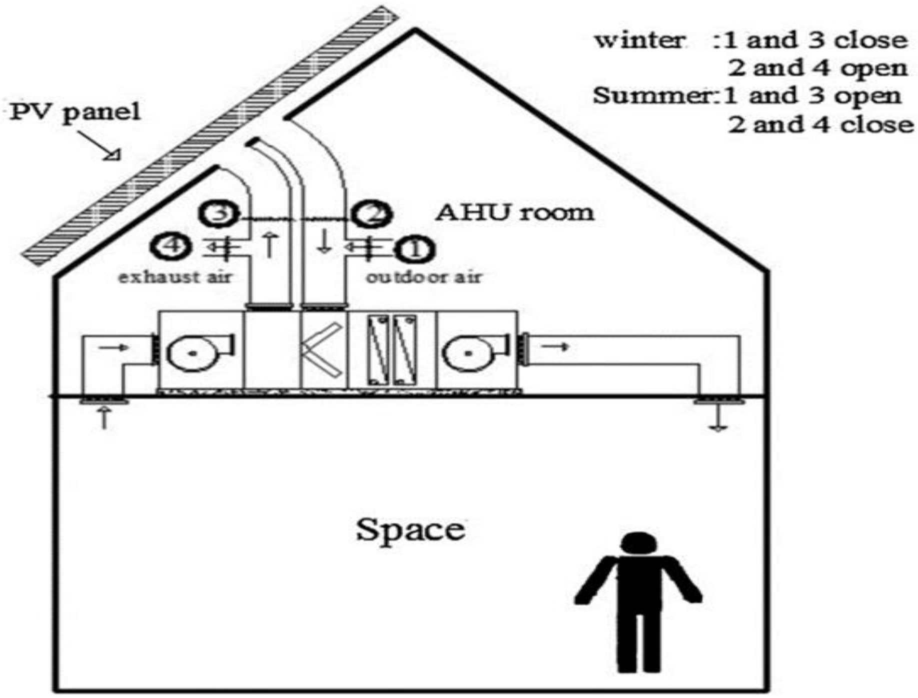


Figure 2.8 : PV coupled with air thermal collectors.

2.2 Nano-Based Cooling

Heat transfer fluids are a critical parameter that affects the size, costs of heat exchangers. However, the available coolants (water and oils) have low thermal conductivities, which make many limitations to the development of heat transfer to reaches high performance cooling. The need for development of new types of fluids which enhance the heat transfer capabilities attracted the attention of many researchers. modern nanotechnology developed nanoparticles to have unique thermal and electrical properties that should help improve heat transfer. A "nanofluid" is a fluid with suspended very fine nanoparticles that increases the heat transfer properties compared with the original fluid. Nanofluids are the new generation of heat transfer fluids. The efficiency of the fluid will be improved by enhancing the thermal properties for it, especially the thermal conductivity, and the nanofluids will have a greater thermal conductivity than the base fluids.

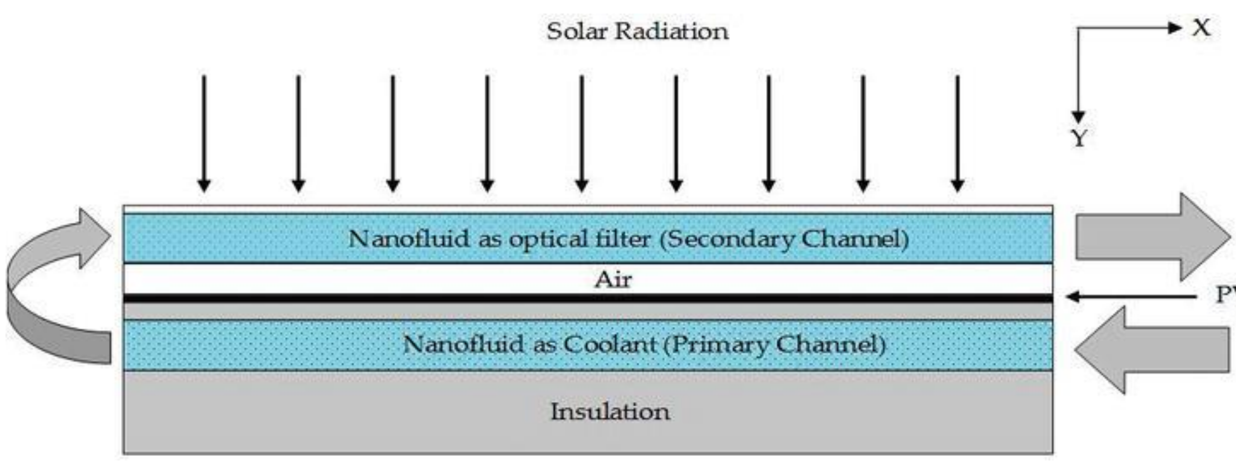


Figure 2.9 : Construction of nanofluid cooling for PV.

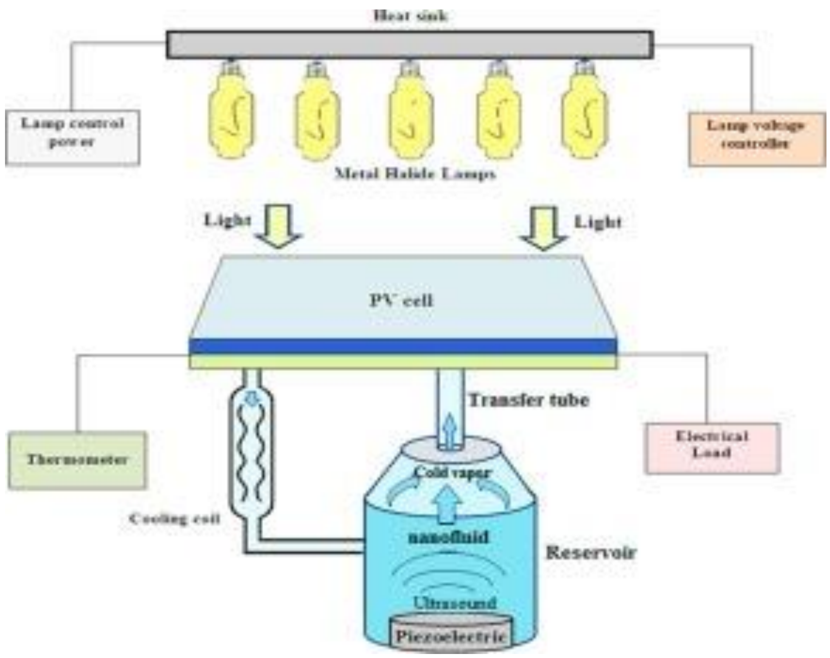


Figure 2.10 : Nanofluid cooling technique for PV cell.

Researcher	Type of cooling system	Cooling agent	Cell temp	Electrical Performance
Rostami [11]	Nano-fluids and ultrasonics PV module	Atomized CuO Nano-fluid	PV temp decreases to 57.25%	Power up to 51.1%
Sardarabadi [12]	PVT system	AL2O3-,TiO2,ZnO in deionized water	ZnO/Water. Outlet temp -3.11C	50% increase in power
Hussein [13]	PVT system	AL2O3-water nano-fluid	Panel temp decreases from 79C to 35C	ZnO/water electrical efficiency 6.46%

2.3 Cooling PV System Using Heat Exchanger and Spray Cooling

Over time researchers found out that water cooling is move efficient that air cooling even if it is more expensive and a lot of researches were made on a certain method of water cooling which is called “spray cooling “.

Spray cooling is basically sprinkling water on the panel’s surface or the use of channels for a working fluid to cool the panel, some studies showed that spraying water on the front of the panel would cause a reduction in the amount of solar energy accepted by the panel also the amount of cooling water is quickly decreased, and this result made it damaging to reuse the cooling water so a researcher suggested sprinkling water on the rear of the panel to prevent temperature increase, but as the water is reused the temperature of the reused water will increase and its efficiency will decrease, so the idea is that the reused water needs a cooling source to go back to its original low temperature , and that’s when the heat exchanger comes to work.

Jakhar et al.[14] used earth water heat exchanger (EWHE) to cool the reused water and lower its temperature so it would keep on cooling the PV panel and the results showed an improvement in efficiency. But the (EWHE) required large spaces for installation, so the idea was to find a suitable heat exchanger and the one which was suitable was the U-shaped borehole heat exchanger (UBHE) which was cheaper and required less space to install it.

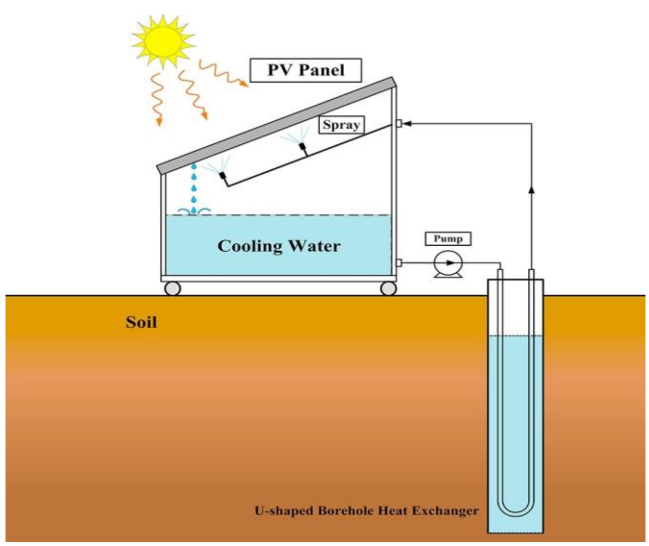


Figure 2.11: Spray cooling with UBHE heat exchanger.

The UBHE set up includes digging a vertical well to set the (UBHE), and then filling the well with water or soil. The reason why we used water or soil to fill the well is because of their good heat transfer effect. At first cooling water from (UBHE) is used to cool equipment and then the waste heat is transferred into the soil, and then the cooled water is used for cooling equipment again and then the cycle completes.

The results of using this system for example in a plant factory that uses panels would increase the efficiency by 14.3%, and its equipment costs are recovered in approximately 8.7 years using this system.

Operation cost	**Average solar intensity (W/m2)**	**Operation time (s)**	**Pump working time (s)**	**Average power output (W)**	**Average net power output (W)**	**Conversion efficiency (%)**
Without cooling system	875.9	2,040	-	33.0	33.0	6.77
Cooling system without (UBHE)	875.3	3,600	2,880	37.4	33.4	6.87
Cooling system with (UBHE)	871.2	3,600	1,235	37.5	35.8	7.38

Chapter 3: Theoretical aspect

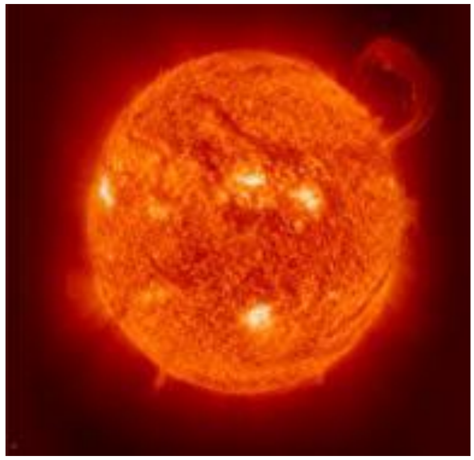


Figure 3.1 : A picture for sun taken by NASA.

3.1 Aim of project

As we seen in many researches such as Erdem Cuce et al. paper we notice that they inspected the several aspects and effects of heat and temperature diversity on the performance of solar PV panels. There is a great deal of research about ameliorating the power output efficiency of solar panels by using passive cooling straight heat fins and they are growing the efficiency power of the solar panel by 9% using the passive cooling with fins.

in our project we hope to increase the efficiency of the power over 9% with minimum costs as much as possible, according to the data we collected from our country such: global horizontal irradiation, global tilted irradiation, wind speed and perfect tilt angle. we will be using multiple types of cooling using heat fins, we will design the appropriate wavy, straight and without heat fins, taking in the account the passive and active cooling.

All the energy available at Earth's comes from the sun. The sun gets its energy from the process called nuclear fusion. This process occurs in the sun's core, where temperature and pressure are very high. During the sun's life, energy comes from the fusion of hydrogen nuclei. In this process four hydrogen nuclei are fused to forming a helium nucleus. Energy is released duo to the helium nucleus has a slightly lower mass than the four original hydrogen nuclei.

Einstein's formula {$E = mc^2$ or Energy = mass × the speed of light squared} explains why energy is released. This energy makes its way to the outer regions of the sun and is radiated or emitted away in the form of energy, known as the electromagnetic radiation. A particle of electromagnetic radiation is known as the photon. Electromagnetic radiation, known as radiant energy (or radiation).

3.2 Radiation modeling

3.2.1 Solar radiation components

The global horizontal irradiance (**GHI**) falling to the Earth's surface and it consists of the diffuse horizontal irradiance (**DHI**) from the sky and direct normal irradiance (**DNI**) from the sun.

GHI = DHI + DNI*cos(θ)

where **θ** is the solar zenith angle.

GHI is measured by a pyranometer which have a hemispherical view, mounted horizontally. DHI measured by a pyranometer shaded from the direct sun beam also DNI is measured by a pyrheliometer which have a narrow view that only measures the beam is directly from the sun. To measure DNI its important to have high accuracy automatic sun tracker. Using the radiometer sensitivities (calibration factors) the output signals can be converted into irradiance in W/m^2.We can see the GHI in Jordan as the figure below:

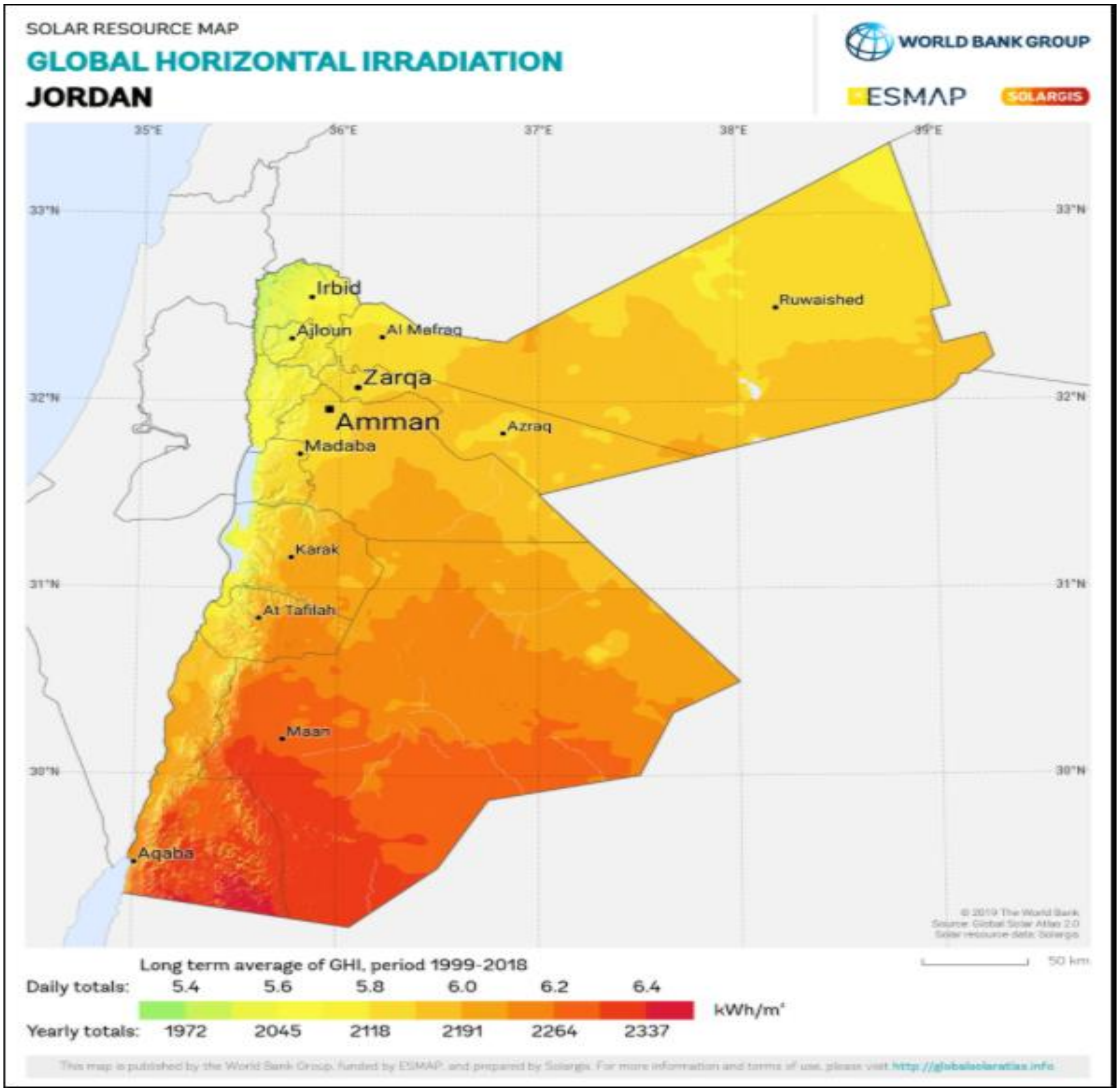


Figure 3.2 : Global horizontal irradiation in Jordan.

GHI is the basic driver for flat-plate solar systems e.g., PV. However, outside the intertropical zone, your solar collectors will be pointing to the equator line at a significant tilt angle. For that, what you will need called GTI (global tilted irradiance) for that specific tilt. If the tilt is low mean system designed to deliver its highest output during summer, GTI is not very different from GHI.

On the contrary, at high latitudes or if the system is designed for a maximum output during winter, the tilt must be high and GTI will be obviously different from GHI.

	Recommended measurements
Small PV power plant	GHI and GTI

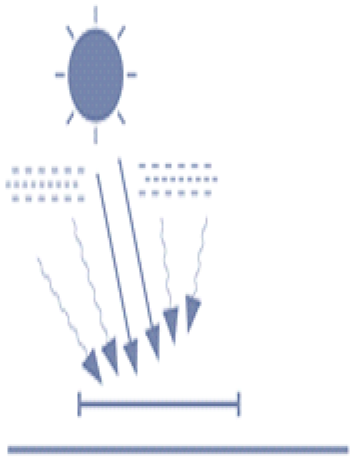
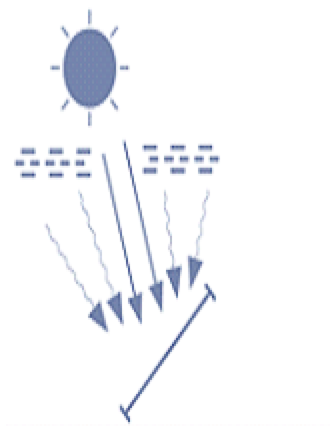
Type of radiation	Description	Measurement instrument
GHI Global Horizontal Irradiation 	Its total amount of radiation received from above by a horizontal surface on plane. This value includes Direct Normal Irradiation (DNI) and Diffuse Horizontal Irradiation (DHI). Application: Fixed PV installations Comparisons with solar data bases to perform MCP (Measure Correlate Predict) evaluations	Pyranometer (horizontal) Reference cell
GTI Global Tilted Irradiation 	Its total amount of direct and diffuse radiation received from above by a tilted surface on plane. GTI is an approximate value for the irradiation yield calculation of fixed installed tilted PV panels. Applications: Fixed PV installations	Pyranometer tilted with the same angle as the solar module Reference cell

Figure 3.3 : GHI and GTI comparison.

Day, august	GTI fix tilt(w/m^2)	GHI (w/m^2)
1, Aug	1024	1032
3, Aug	1047	1032
5, Aug	1021	1003
7, Aug	1045	1021
9, Aug	858	855
11, Aug	1008	978
13, Aug	1033	995
15, Aug	1029	987
17, Aug	1040	993
19, Aug	1067	1010
21, Aug	1079	1016
23, Aug	1048	981
25, Aug	1069	994
27, Aug	1054	978
29, Aug	1020	941
31, Aug	1045	957

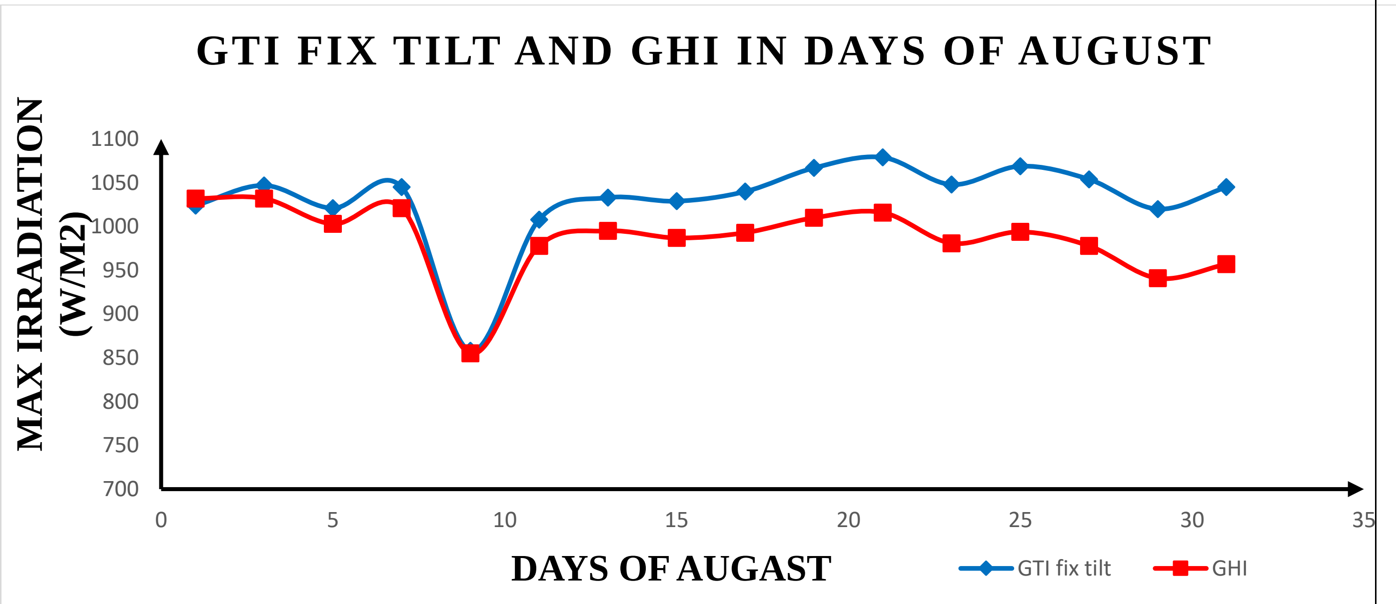


Figure 3.4 : Max irradiation in the days of august.

September	GTI fix tilt (w/m^2)	GHI(w/m^2)
1, Sep	1073	944
3, Sep	1012	924
5, Sep	998	909
7, Sep	1021	919
9, Sep	1009	904
11, Sep	933	837
13, Sep	1010	888
15, Sep	976	864
17, Sep	938	829
19, Sep	953	830
21, Sep	951	822

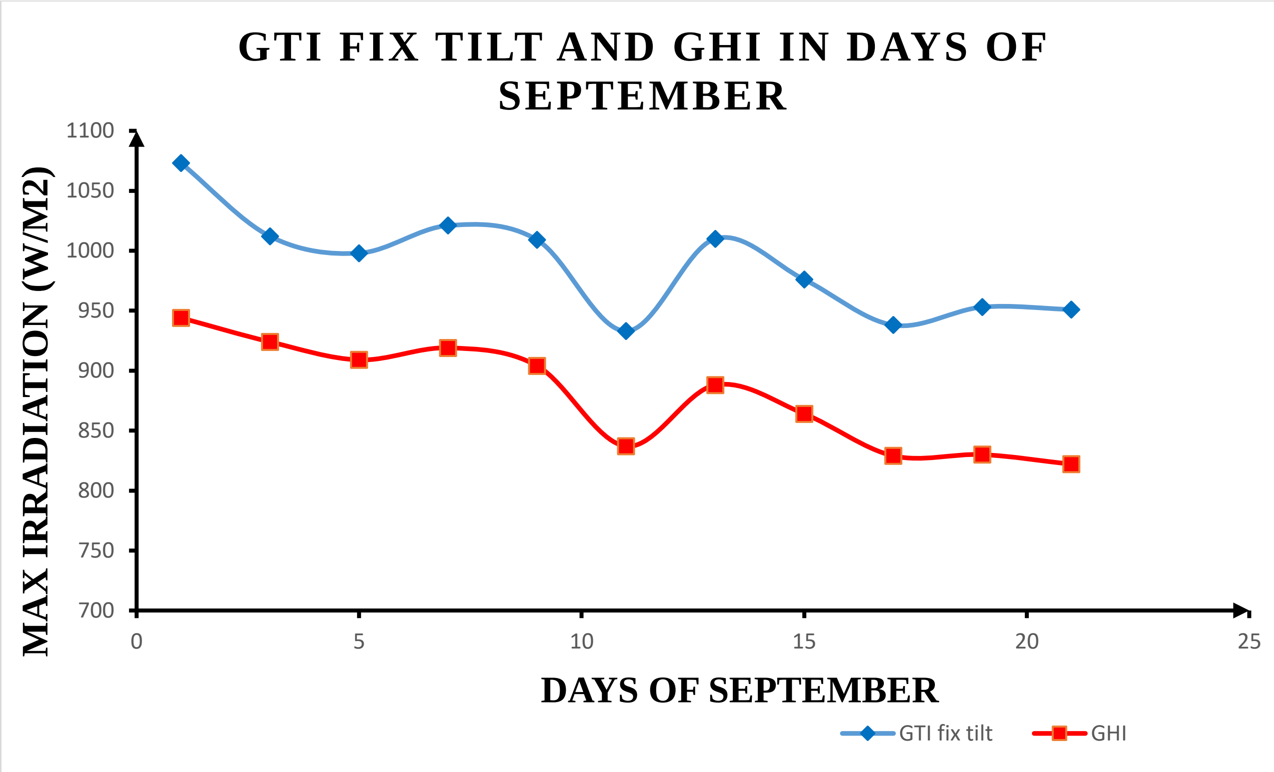


Figure 3.5 : Max irradiation in the days of September.

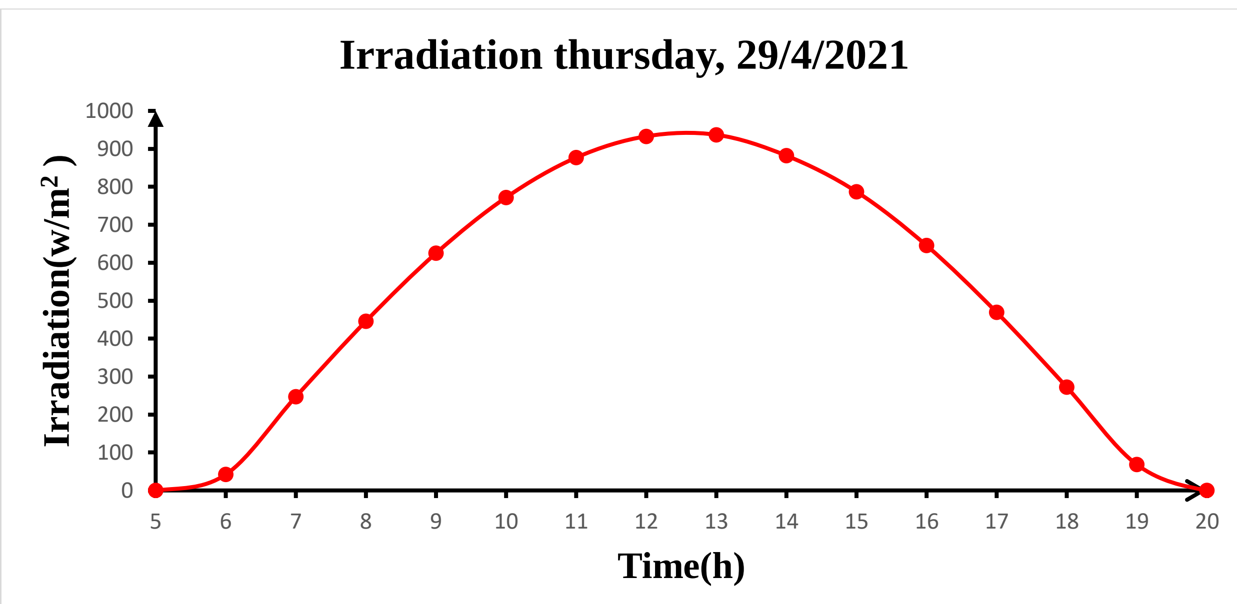


Figure 3.6 : Irradiation through day , Thursday ,29/42021

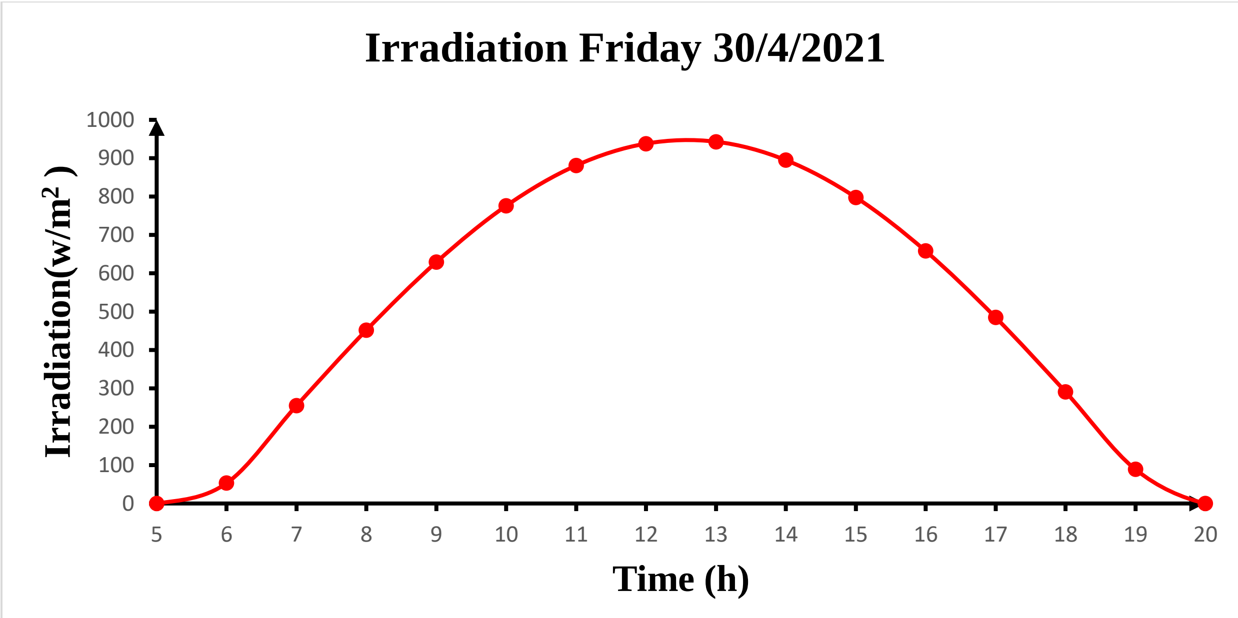


Figure 3.7 : Irradiation through day , Friday ,30/4/2021

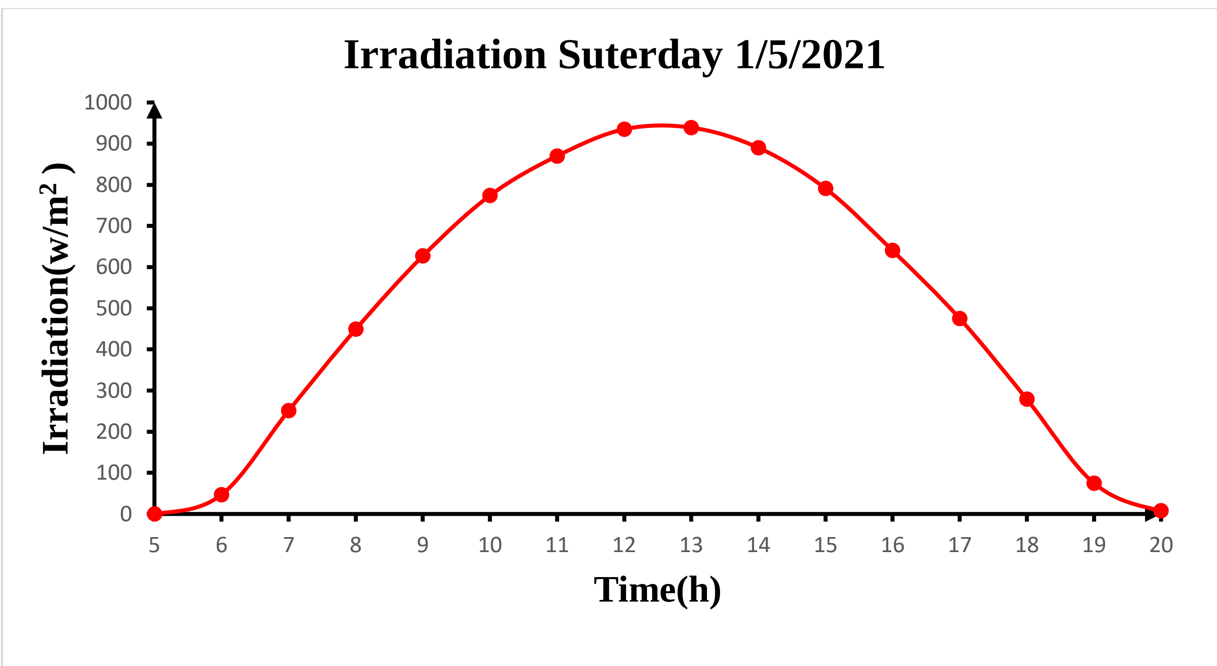


Figure 3.8 : Irradiation through day , Friday ,1/5/2021

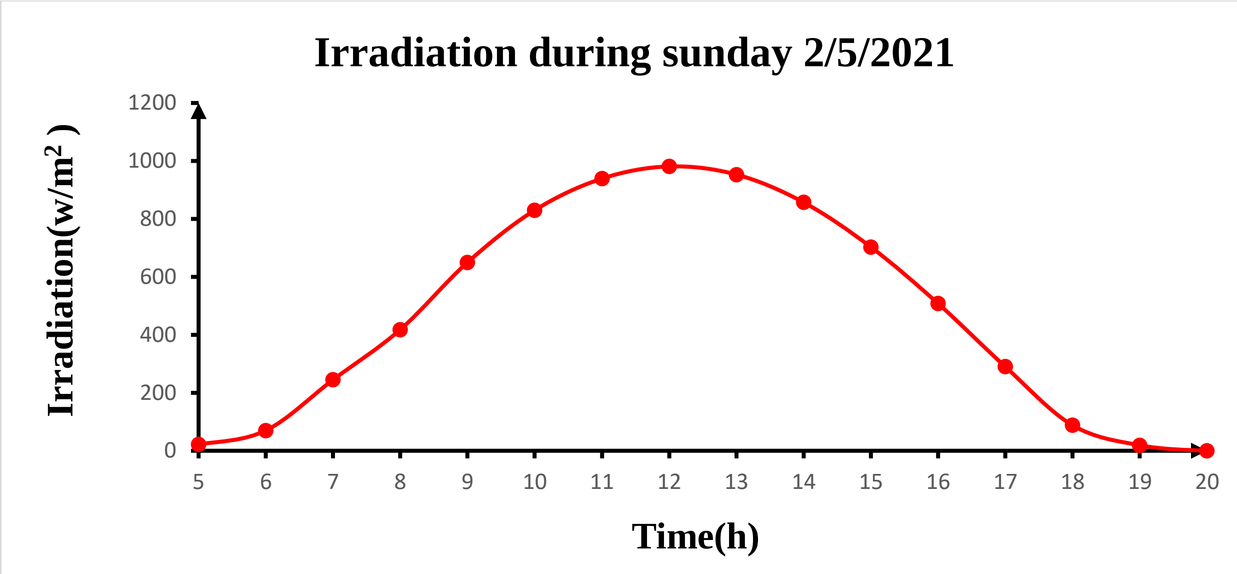


Figure 3.9 : Irradiation through day , Saturday ,2/5/2021

3.2.2 Effect of clouds and other local variations in the atmosphere

The final effect of the atmosphere on incident solar radiation is because local variations in the atmosphere. Depending on the type of cloud cover so the incident power is severely reduced.

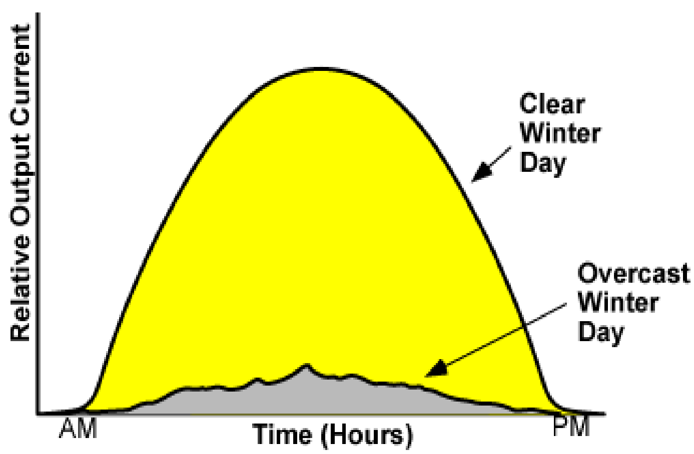


Figure 3.10 : Cloud influence on output current of PV system.

3.2.3 Atmospheric Effects

Atmospheric effects have lots of impacts on the solar radiation at the Earth's surface. The major effects for PV applications are:

I. A reduction in the power of the solar radiation because absorption, scattering and reflection in the atmosphere.
II. A change in the spectral content of the solar radiation because greater absorption or scattering of some wavelengths.
III. The diffuse or indirect component into the solar radiation.
IV. Local variations in the atmosphere [such as water vapor, clouds and pollution] which have additional effects to the incident power, spectrum and directionality.

These effects are summarized in the figure below.

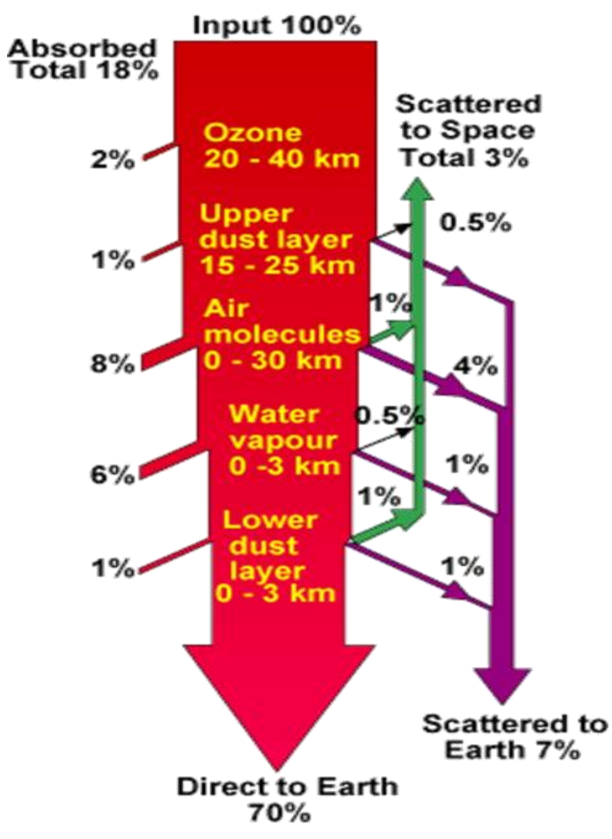


Figure 3.11 : Atmospheric effect on PV system.

3.3 Optical modeling

3.3.1 The zenith angle

θz is the angle between the normal to the horizontal plane at a specific location, and the incident beam radiation. The geometric components involved in finding an expression for θz are outlined.

The figure shows the local horizontal plane at arbitrary location on Earth. The plane is defined by its inclination with respect to the celestial equator, which is the projection of Earth's equator on the celestial sphere. The angle between the equator plane and the normal vector of the local plane (v) is equal to the latitude φ of the location.

Over the course of the day, Earth rotates with respect to the celestial sphere, making a complete cycle in one day. This movement is indicated by the hour angle ω, which is the angle between the position of the current local meridian L_{loc} of Earth (as projected on the equator plane) and the meridian's position at solar noon, L_{noon}. The Sun's position on the celestial sphere is further defined by the declination δ, which is the angular displacement of the Sun from the equator plane. The incidence angle θz can now be found as the angle between the vector u, which points from the center of the celestial sphere to the Sun's position, and the normal vector v of the horizontal plane.

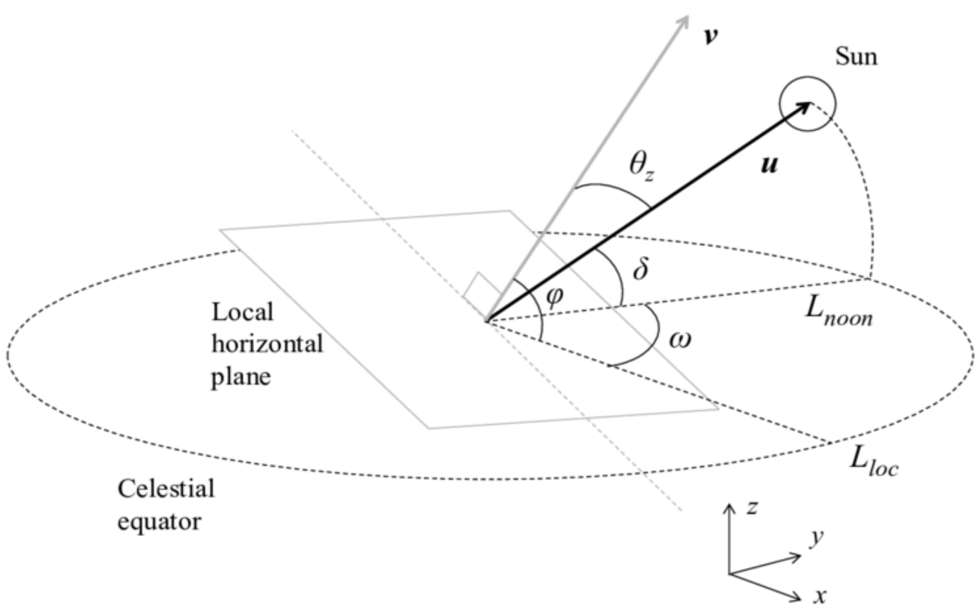


Figure 3.12 : Outline of the geometric relations between the Sun, the celestial equator, and the horizontal plane of Earth at a given location.

3.3.2 Declination angle

As shown in Figure, the earth axis of rotation (the polar axis) is inclined at an angle of 23.45° from the ecliptic axis, which is normal to the ecliptic plane. The ecliptic plane is the plane of orbit of earth around the sun. The solar declination angle is the angular distance of the sun's rays north (or south) of the equator, north declination designated as positive, it is the angle between the sun–earth center line and the projection of this line on the equatorial plane. Declinations north of the equator (summer in the Northern hemisphere) is positive and those souths are negative.

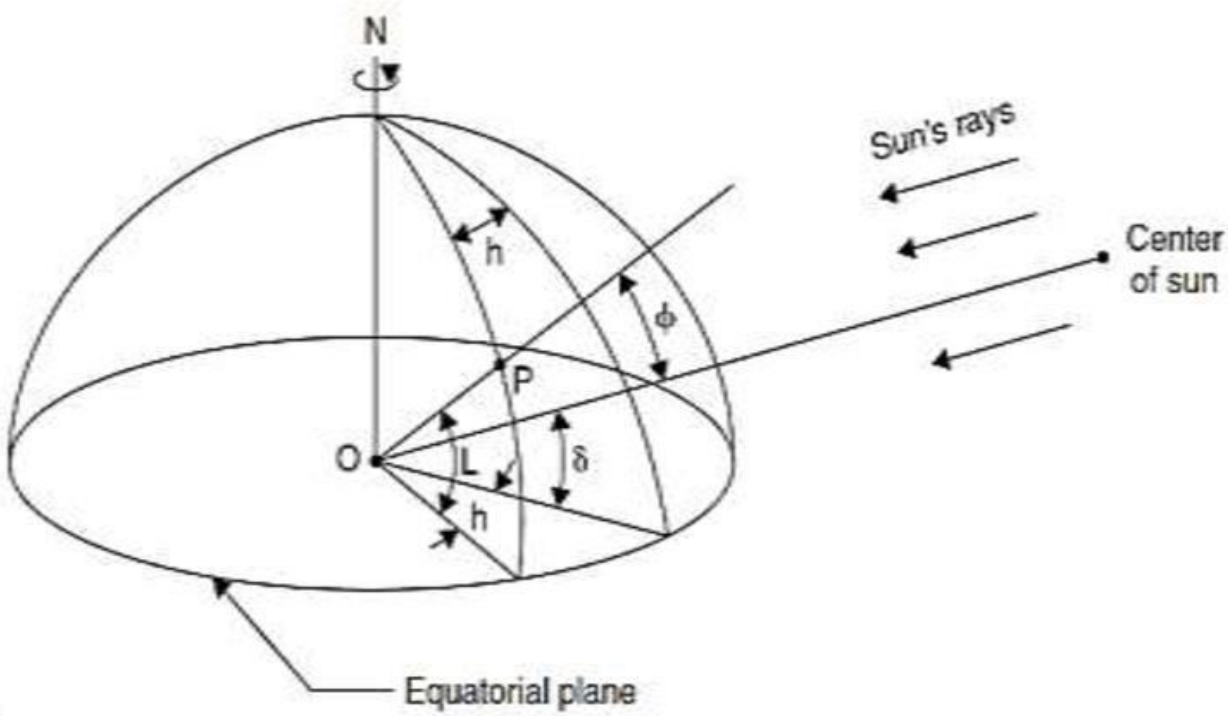


Figure 3.13 : Definition of latitude, hour angle, and solar declination.

3.3.3 The tilt angle

The tilt angle of a solar energy system is one of the important parameters for capturing maximum solar radiation falling on the solar panels. This angle is site specific as it depends on the daily, monthly and yearly path of the sun. The accurate determination of the optimum tilt angle for the location of interest is essential for maximum energy production by the system. A number of methods have been used for determining the tilt angle at different locations worldwide. Keeping in view the relevance of the optimum tilt angle in energy production and reducing the cost of solar energy systems, the study shows that for maximum energy gain, the optimum tilt angle for solar systems must be determined accurately for each location. The review will be useful for designers and researchers to select suitable methodology for determining optimal tilt angle for solar systems at any site. The optimum tilt angle determination of a solar panel is fundamental to its efficient operation because incorrect positioning leads to loss of potential solar power.

3.4 Thermal Modeling

Thermal effects on the surface of the PV panel significantly affect its performance. The increment in cell temperature causes the module efficiency to decrease due to reduction in fill factor and open circuit voltage. Also, if there is non-uniformity of heat transfer and temperature across the panel, PV cell also experiences loss in conversion efficiency because of the effect of current mismatch problem. The temperature distribution in PV panels depends on the PV cell material, PV cell type, the panel configuration, the existing ambient state and for the purpose cooling, the characteristics of the heat dissipation technique. For PV panels operating in hot climate, the need for cooling system becomes larger. For the case of PV panel under extreme conditions, the problems with PV panel becomes two-fold; first the drop in cell efficiency because of increasing temperature and secondly structural defects may occur due to long term thermal stresses.

3.5 Mathematical Module Formulation

Model based on energy balance approach PV modules that are currently available on the market have an efficiency ranging between 14% and 21%. It means that between 14% and 21% of the incident irradiance is converted into electricity, and the remainder is converted into thermal energy that heats the cells. These heat losses cannot be estimated as they depend on the material's band gap and on the weather, i.e. the solar irradiance. However, a fraction of the sunlight is reflected on the front cover of the cell: it doesn't contribute to either the electrical power generation or the heating of the cells. Consequently, when trying to estimate the heat losses, one can consider that the incoming irradiance which is not converted into electricity is $(1-\eta)$ G, knowing that G is the solar irradiance.

one assumes the following expression to calculate the heat losses:

$G_h = (1-\eta)G - (\rho_r+\alpha)G$

where ρ and α are respectively the reflectance and the absorbance of the front cover of the cell.

For common glass, $\rho_r = 0.04$ and $\alpha = 0.05$.

The heat transfer processes involved are convection and radiation. To simplify the calculations, we are going to neglect heat transfers by radiation.

It is known that the cell temperature increases as the solar irradiance gets higher. But the incoming sunlight is not the only parameter that influences the cell temperature. The ambient air and the wind speed are to be considered as well as the solar irradiance. In order to determine a PV module operating temperature, there is an approximate expression given:

$$T_{cell}(°C) = T_{air} + \frac{NOCT - 20}{800} * G$$

Where T_{air} is in °C, G in W/m² and NOCT stands for nominal operating cell temperature. It is defined as the temperature of a cell at standard reference environment (SRE) .

In general, the best PV module operates at NOCT = 33°C and the worst at 58°C and a typical module at 48°C.

In the module we are using the NOCT = 45±2°C.

To evaluate the cell temperature as a function of the wind speed, then we can use the following expression for typical modules:

$$T_{cell}(°C) = T_{air} + \frac{0.32}{8.91 + 2 * v_{wind}} * G$$

Depending on the previous expression we found that the theoretical temperature is equal to 59 ^oC and we can see that the experimental temperature is 55 ^oC at 1 o'clock, 44 ^oC NOCT and 950 W/m^2 irradiation and that means that there is an agreement between the theoretical and experimental values.

Temperature characteristics on the PV surface are affected by cooling technique, solar intensity, radiation absorbed, convection losses by wind, radiation losses, wind speed, type of material and length of the layer of material.

Where,

$Q_C + Q_E$ = Total heat loss.

Where Q_C is the heat loss by convection and Q_E is the heat loss by evaporation.

Convection heat transfer from a surface (Qc):

$Q_C = \dot{m}\, Cp\, (T_{out} - T_{in})$

Total heat loss by evaporation depends significantly on the applied water spray flow temperature (i.e. the water temperature in the boundary layer of the PV panel) and also from the relative humidity and surrounding air temperature, air velocities respectively,

$Q_E = e\, A_p\, (P_s - P_d)\, r$

where *e* represents evaporation factor, p_s , p_d partial pressures and *r* latent heat of evaporation. The evaporation coefficient will have significant influence on evaporation heat loss which in general depends on the water spray temperature, temperature and relative humidity of the surrounding air.

The reason why we chose this water spray cooling technique is to additionally increase overall heat rejection by knowing that the amount of latent heat released much greater than the amount of sensible heat.

Showing that the Convection heat transfer represents sensible heat and Evaporation heat transfer represents latent heat.

Sample of Calculation at 12:00 o'clock:

$Q_{\text{from sun}} = A_{\text{panel}} * G$

Where A the area of the panel and G is the irradiance of the sun.

$Q_{\text{from sun}} = 1.96*981$

So, $\mathbf{Q_{\text{from sun}} = 1922.76}$ **watt**

$\text{Power}_{\text{output}} = I*V$

Where I is the current and V is the voltage

$\text{Power}_{\text{output}} = 6.4*44.73$

So, $\mathbf{Power_{\text{output}} = 412.08}$ **watt**

$Q_{\text{loss}} = G_h = (1-\eta)\, G - (\rho_r + \alpha)G$

$Q_{\text{loss}} = G_h = Q_{\text{from sun}} - P_{\text{output}} - (\rho_r + \alpha)\, Q_{\text{from sun}}$

$Q_{\text{loss}} = 1922.76$ watt - 412.08 watt - (0.04+0.05)1922.76 watt

$\mathbf{Q_{\text{loss}} = 1337.6}$ **watt**

Sensible heat at 12:00 o'clock :

$Q_C = \dot{m}\, Cp\, (T_{\text{out}} - T_{\text{in}})$

Where $\dot{m}$ is mass flow rate, Cp is specific heat of the water which is equal to (4184J/kg.K).

$Q_C = 0.0175(kg/s) *4184(J/kg.\ K) *(25.85 - 19.3)$

So, $\mathbf{Q_C = 478.85}$ **watt**

Showing that the PV panel reached a steady state mode.

In **steady-state conduction**, the amount of **heat** entering any region of an object is equal to the amount of **heat** coming out.

$Q_{in} = Q_{out}$

Q_{loss} =1337.6 watt

Q_C = 478.85 watt

$Q_E = Q_{loss} - Q_c = 1337.6 - 478.85$ watt

Q_E = 858.7 watt

3.6 Feasibility aspect

P_{pump} = voltage of the pump * current

P_{pump} = 24 V * 0.8 A = 19.2 watt.

Maximum power for cooled PV = 414.79 watt

$P_{max} – P_{pump}$ = 414.79 – 19.2 = 395.59 watt

Maximum power for uncooled clean PV = 387.585 watt

The relative increase in panel power output = 395.59 – 387.585 = 8.005 watt

Effective increase in panel power output = (8.005 / 387.585)*100% = 2.06 %

To compare our increase in panel power output we take **S. Nizˇetic et al. [16]** research as an example and the results were as follows:

The effective increase in panel power output was found out to be around 5.7% according to his research.

Finally, we notice that the net power output increase is not a great one, however feasibility is proven.

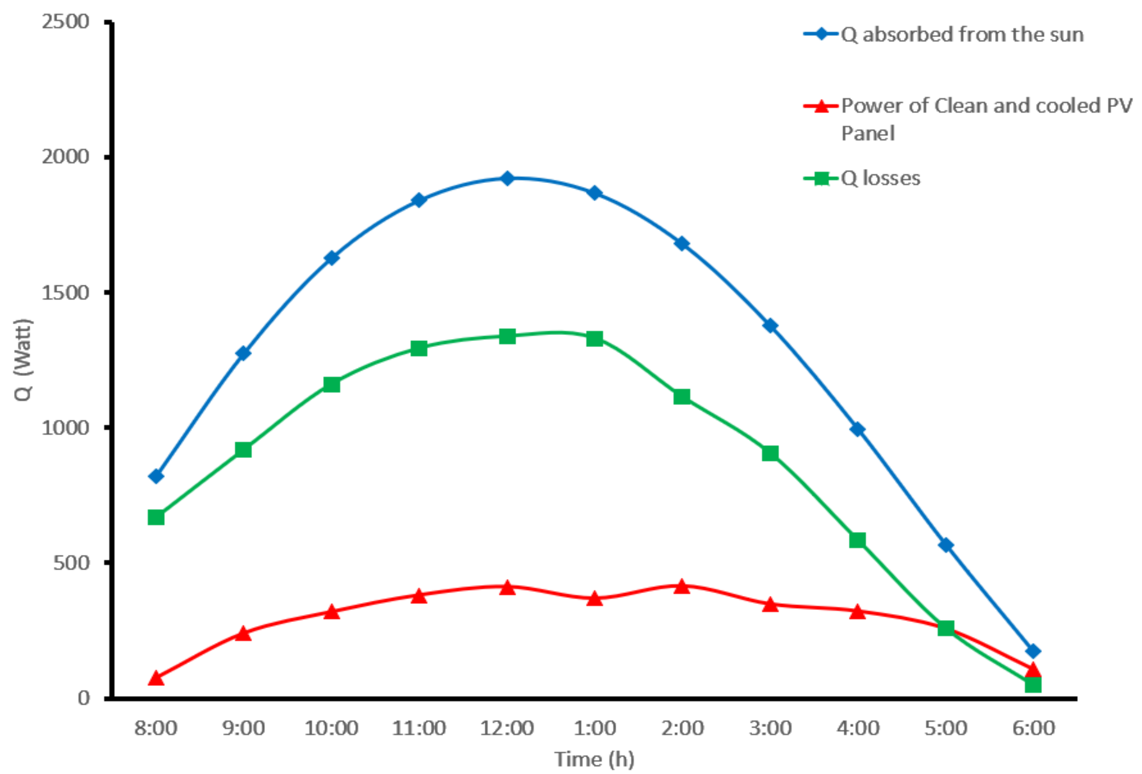


Figure 3.14 : Heat comparison with time.

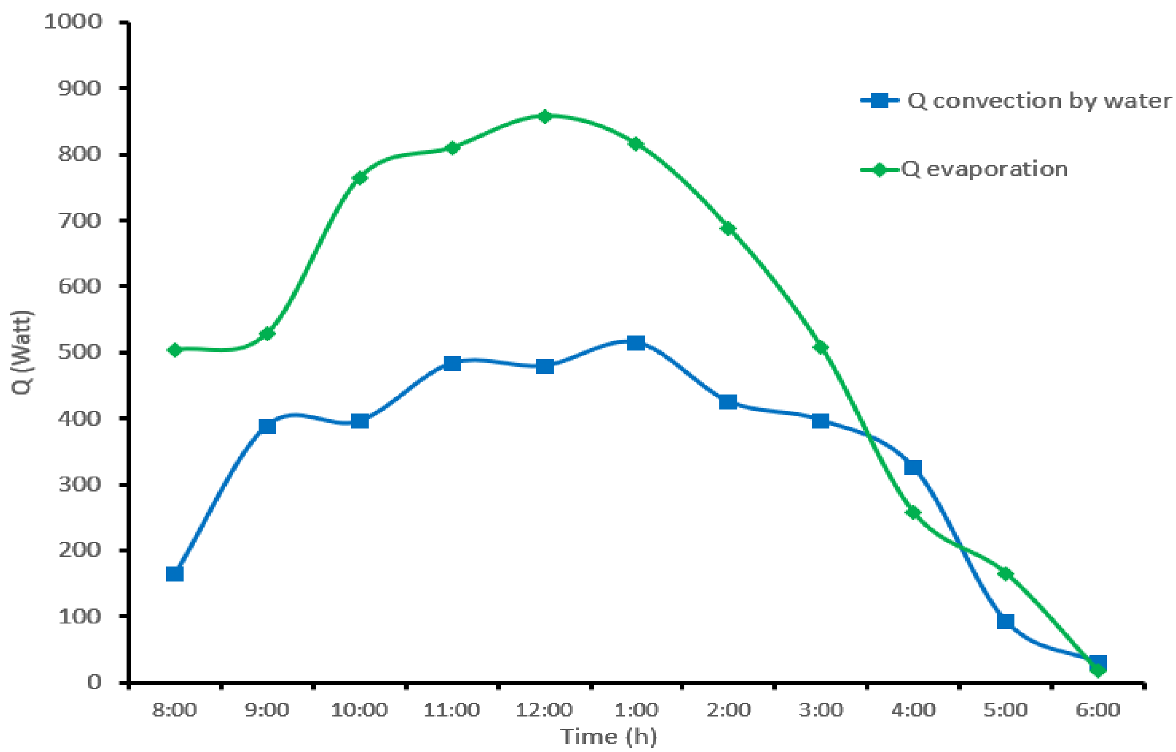


Figure 3.15 : Comparison between convection heat transfer and evaporation.

Time and Date

2/5/2021 , Sunday

Temperature (Celsius)	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00
T1 (Temperature in the tip of the uncooled and cleaned panel)	25.62	42.75	46.25	50.56	53.25	55.63	52.88	51.44	44.5	38.31	31.44
T2 (Temperature reading for clean uncooled PV panel)	25.94	43.19	46.63	49.88	52.44	54.63	52.25	51	44	37.88	31.25
T3 (Temperature of water in tank)	19.31	19.37	19.81	21.12	21.25	21.25	21.81	22.62	23.56	23.37	22.31
T4 (Temperature l in the tip of dirty panel)	26.37	40.56	44	49.31	51.81	54.94	51.56	49.94	43.69	37.75	30.94
T5 (Temperature reading for dirty PV panel)	26.25	39.56	42.94	47.81	49.94	53.13	49.88	48.81	43.06	37.13	31
T6 (Ambient temperature under the sunshine)	23.06	30.31	32.25	35.63	38.63	41.88	40.75	40.75	39.5	37.5	33.56
T7 (Temperature at the tip of the cooled panel)	16.87	20.5	21.81	25.31	25.75	26.37	26	25.75	24.19	22.06	18.87
T8 (Temperature reading for cooled PV panel)	17	21.25	22.31	24.5	25.12	26.44	25.37	24.94	23.87	21.94	18.69
T9 (Temperature of the spray)	15.25	16.56	17.56	18.62	19.31	20.19	20.31	20.25	20.12	21.31	17.31
T10 (Ambient temperature under the shade)	24.81	27.69	28	29.37	33.38	36.81	33.63	32.63	32.31	32.19	30.69
T11 (Temperature out from the panel)	17.4998	21.87475	22.965914	25.2203	25.858528	27.217336	26.115878	25.673236	24.571778	22.585036	19.239486
Voltage(volt)											
Voltage for dirty PV Panel	42.56	42.31	42.21	42.36	42.26	42.21	42.31	42.12	42.86	42.21	41.18
Voltage clean uncooled PV Panel	43.69	43.45	43.35	43.5	43.4	43.35	43.5	43.25	43.99	43.35	42.21
Voltage clean and cooled PV Panel	43.96875	44.49625	44.5386	44.59125	44.5975	44.6619	44.6972	44.52985	44.87015	44.05625	42.88705
Power (watt)											
Power of Clean and Uncooled PV Panel	68.1564	214.2085	287.844	357.135	387.562	386.682	387.585	338.215	292.0936	232.7895	107.2134
Power of Dirty Uncooled PV Panel	60.435	200.55	278.59	343.54	372.31	371.45	374.44	329.38	282.88	218.65	104.5972
Power of Clean and Cooled PV Panel	77.385	241.17	319.79	381.26	412.08	413.44	414.79	368.48	322.17	258.17	108.93
Performance											
Increase in performance between uncooled clean and cooled clean PV panel	13.54%	12.586%	11.097%	6.7538%	6.3264%	6.9187%	7.0191%	8.9481%	10.296%	10.903%	1.604%
Increase in performance between uncooled clean and uncooled dirty PV panel	12.776%	6.8108%	3.3232%	3.9574%	4.0964%	4.1012%	3.5096%	2.6828%	3.2585%	6.4678%	2.5012%
Increase in performance between cooled clean and uncooled dirty PV panel	28.046%	20.255%	14.789%	10.979%	10.682%	11.304%	10.775%	11.871%	13.89%	18.076%	4.1453%
Q loss by water	164.7304	389.146	395.821	483.274	479.4832	514.5415	425.1064	397.0893	325.9592	93.35814	141.277
irradiation	418	650	830	939	981	953	857	703	508	290	88
Q absorbed from the sun	819.28	1274	1626.8	1840.44	1922.76	1867.88	1679.72	1377.88	995.68	568.4	172.48
Power of Clean and cooled PV Panel	77.385	241.1697	319.7871	381.2552	412.0809	369.3539	414.79	348.2234	322.1677	258.1696	108.9331
Q losses	668.1598	918.1703	1160.601	1293.545	1337.631	1330.417	1113.755	905.6474	583.9011	259.0744	48.02369
Q convection by water	164.7304	389.146	395.821	483.274	479.4832	514.5415	425.1064	397.0893	325.9592	93.35814	30.5456
Q evaporation	503.4294	529.0243	764.7798	810.2712	858.1475	815.8753	688.6488	508.558	257.9419	165.7162	17.47809

3.6 Project Components

- Polycrystalline Solar Module

- Concrete Blocks

- Steel Structure

- Household Reverse Osmosis Water Filter System 24v dc RO Booster Pump

- Water Reservoir

- Water Mist Sprinklers

- DS18B20 Temperature Sensor

The pull-up resistor is used to keep the line in high state when the bus is not in use. The temperature value measured by the sensor will be stored in a 2-byte register inside the sensor. This data can be read by the using the 1- wire method by sending in a sequence of data.

Voltage Range on Any Pin Relative to Ground: -0.5V to +6.0V

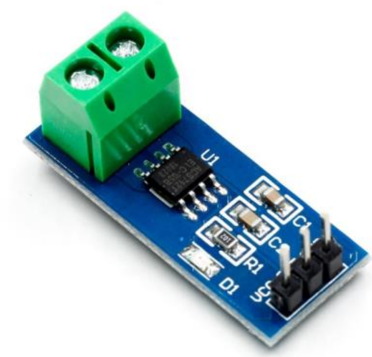
Operating Temperature Range: -55°C to +125°C

- Relay Arduino 2 Channels

A relay is a programmable electrical switch, which can be controlled by Arduino or any micro-controller. It is used to programmatically control on/off the devices, which use the high voltage.

- ACS712 Current Sensor

ACS712 Current Sensor uses Indirect Sensing method to calculate the current. To sense current a liner, low-offset Hall sensor circuit is used in this IC. This sensor is located at the surface of the IC on a copper conduction path. When current flows through this copper conduction path it generates a magnetic field which is sensed by the Hall effect sensor. A voltage proportional to the sensed magnetic field is generated by the Hall sensor, which is used to measure current.



- Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 14 can be used as PWM outputs),16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, aUSB connection, a power jack, an ICSP header, and a reset button.

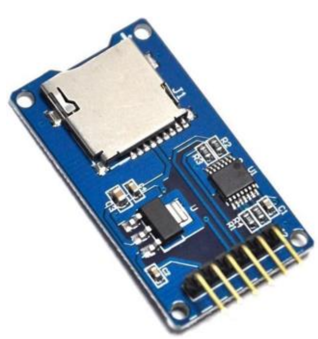
It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.

- Solid-State Relay SSR-40DD

Essentially the solid-state relay is a switch where the input or control voltage lights up a light emitting diode. This acts as the transmitter of an optocoupler which then controls a switching device: thyristor, triac, bipolar transistor of MOSFET.

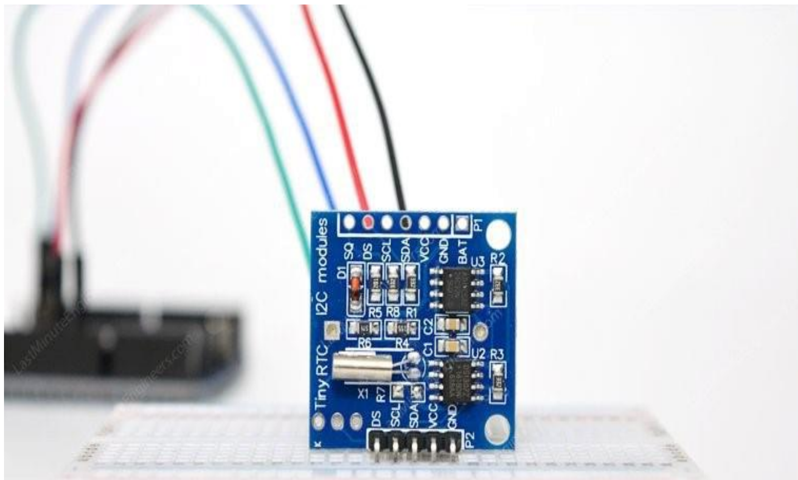
- Micro Sd Card Micro SDHC Mini TF Card Adapter Reader Module for Arduino.

The module (MicroSD Card Adapter) is a Micro SD card reader module, and the SPI interface via the file system driver, microcontroller system to complete the MicroSD card read and write files. Arduino users can directly use the Arduino IDE comes with an SD card to complete the library card initialization and read-write.



- Interface DS1307 RTC Module with Arduino

Real Time Clock (RTC) is used for monitoring time and maintaining a calendar. In order to use an RTC, we need to first program it with the current date and time. Once this is done, the RTC registers can be read any time to know the time and date. DS1307 is an RTC which works on I2C protocol.



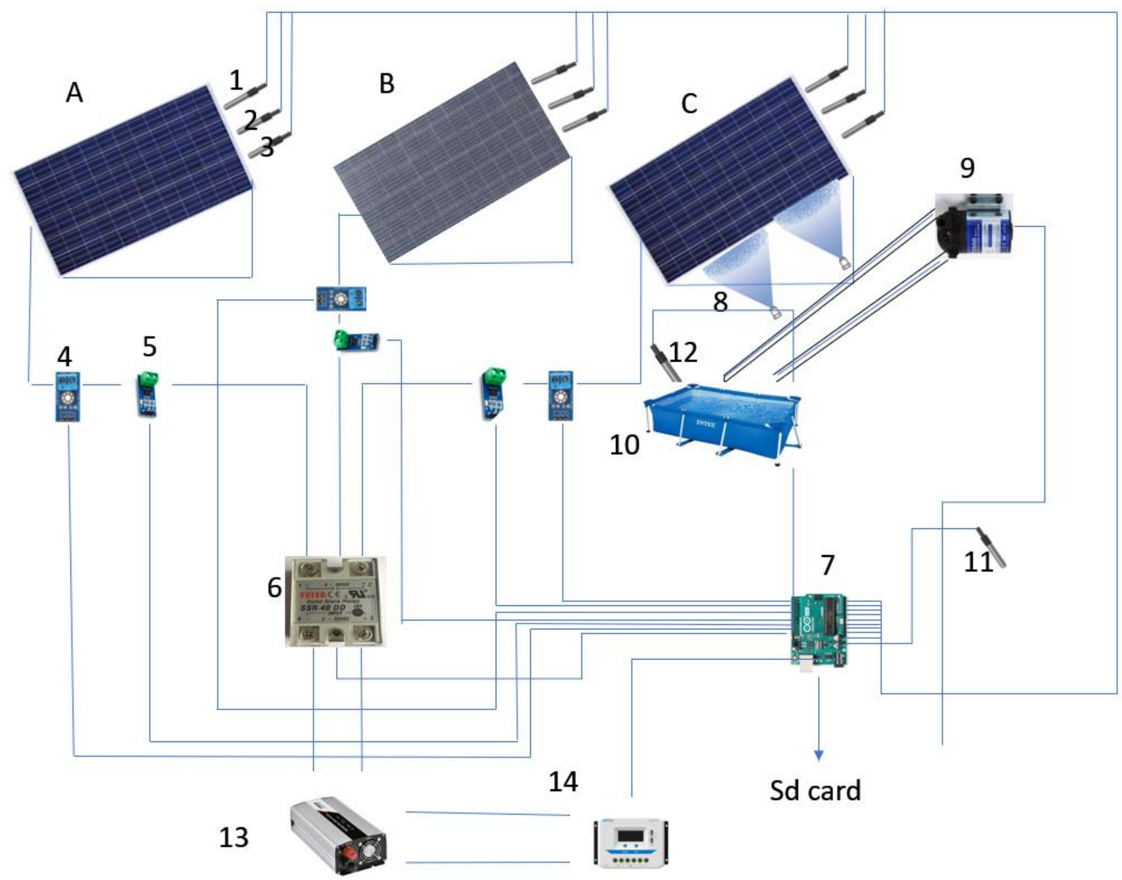


Figure 3.16 : A Schematic diagram for components used.

1	Sensor at left side of panel
2	Sensor at center of panel
3	Sensor at right side of panel
4	Voltage sensor
5	Current sensor
6	Solid state relay
7	Arduino mega
8	Water spray
9	Water pump
10	Water collector
11	Ambient temperature sensor
12	Water temperature sensor
13	inverter
14	Charge controller
A	Clean panel without cooling
B	Dirty panel
C	Clean panel with cooling

Figure 3.17 (a) : Photographic view of panels and the cooling system.

In the following link we added an illustrating video to show the components and how the cooling system works:

https://drive.google.com/file/d/16Eh3-yNzYS-qKtPXlyETOlRnDdcReVEQ/view?usp=drivesdk

Or by using QR code:

Figure 3.17 (b) : Photographic view of Arduino and sensors connected on panels.

Chapter 4: Results and Discussion

In this project, we used real photovoltaic panels which are used in (residential building, industrial building and mainly in Power plants). Our study is based on comparing panels that uses water spray cooling system and panels that are not cooled but cleaned frequently and panels that are not cleaned nor cooled.

The panel was tested on a geographical location located at Marka-Amman on a typical clear summer day where average temperatures of the surrounding air ranged from 24 ^{o}C and up to 37 ^{o}C. Measurements were provided from 8 AM to 6 PM, during irradiation ranged from 88 W/m^2 to 981 W/m^2.

During a typical summer day, during the measurement series, air velocities were less than 1 m/s (The impact of the surrounding wind was neglected during the measurements), and the inlet water temperature was approximately found out to be constant at around 21^{o}C.

4.1 Mechanical Characteristics

We used “SUNTECH STP330-24/VFW” which has:

- High module conversion efficiency.
- High PID resistant (Potential-induced degradation).
- High durability during snow and windy days.
- High system voltage compatibility.

Solar Cell	Polycrystalline silicon 6 inches
No. of Cells	72 (6 × 12)
Dimensions	1960 × 992 × 40mm (77.2 × 39.1 × 1.6 inches)
Weight	25.9 kgs (57.1 lbs.)
Front Glass	4.0 mm (0.16 inches) tempered glass
Frame	Anodized aluminum alloy
Junction Box	IP68 rated (3 bypass diodes)
Output Cables	TUV (2Pfg1169:2007) 4.0 mm2 (0.006 inches2), symmetrical lengths (-) 1100mm (43.3 inches) and (+) 1100 mm (43.3 inches)

Water pump characteristics:

Input voltage	24VDC
Working pressure	70PSI
Flow rate	1050ml/min
Current	0.8 A

4.2 Thermal performance of PV panel

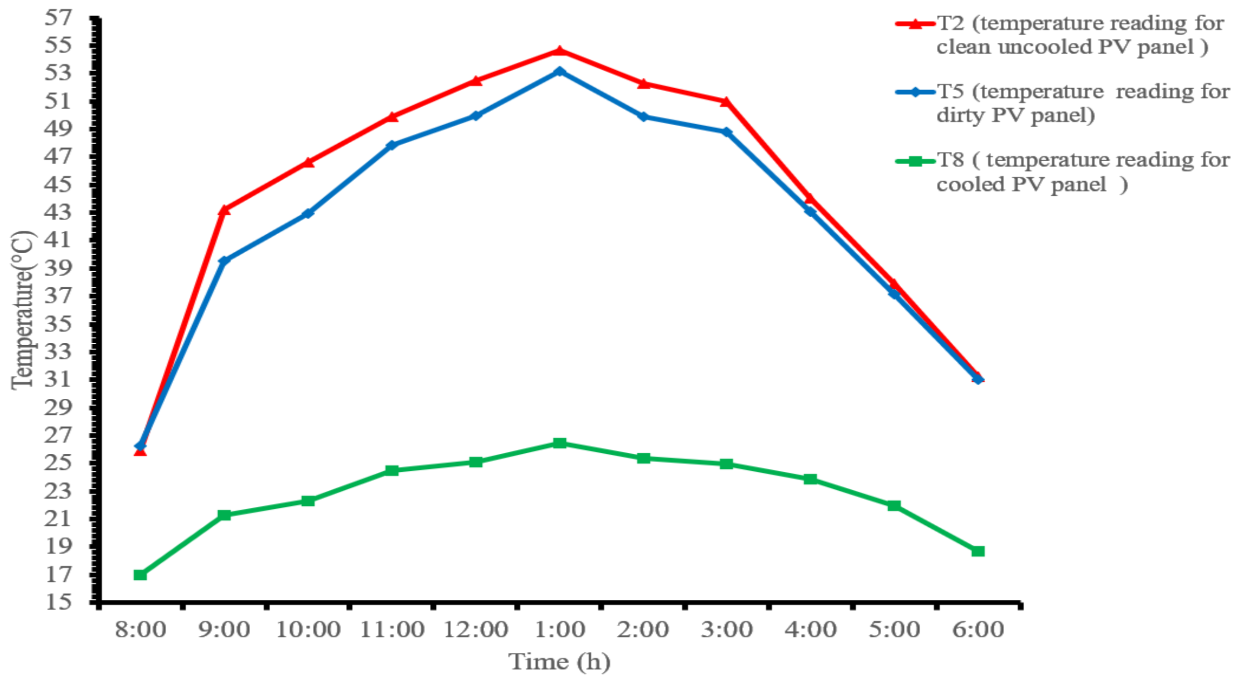


Figure 3.18 : Experimental temperature readings with time.

Sensor number	Sensor location/Job
T2	Temperature reading for clean uncooled PV panel
T5	Temperature reading for dirty PV panel
T8	Temperature reading for cooled PV panel

As the main purpose is to provide a reliable cooling system, determination of the temperature distribution of the PV panel is a crucial factor. In order to investigate the variation of the average surface temperature of the PV cell at different locations from the middle to the side the PV panel surface.

Temperatures were measured for every half an hour at different selected positions by thermocouple temperature sensor, The figure shows the average temperature at the backside of PV panel for different conditions.
A PV system is normally designed according to the average surrounding temperature at site location, which is primarily a product of the ambient temperature. The average ambient temperature through the experimental day is 35.67 °C while the maximum value was 41.88 °C.

Generally, the PV panel temperature will be higher than ambient temperature, as can be seen in this figure (3.18), PV panels without a cooling system experience high level of operating temperature. The maximum PV panel temperature found out to be about 56 °C at 42 °C of ambient temperature for PV panel with no cooling system attached. The high operating temperature normally produced during high-intensity solar radiation.

Based on the experimental readings and the figure (3.18), water cooling technique reduced the temperature of the panels by 48% at the peak temperature.

4.3 Electrical performance of PV panel

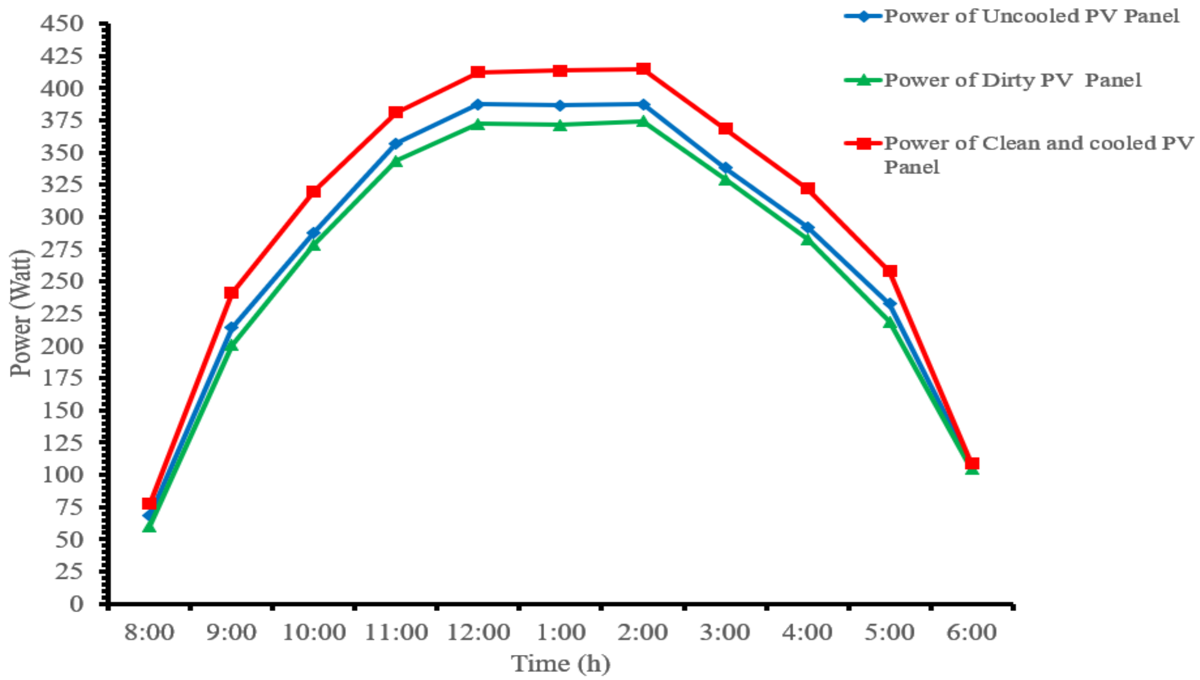


Figure 3.19 : Calculated power readings with time.

Different conditions were carried out to evaluate the impact of these methods in the sector of improving the performance of the PV panel.
The I-V characteristic of the PV panel in the experiment was measured in order to calculate the generated output power produced.

Figure (3.19) shows the output power produced by each PV panel through the experiment, the output power for each condition was observed to have an increased value from 11.00 AM to 2.00 PM, which is at the peak solar radiation and highest ambient temperature.

With the existing of cooling mechanism, the output power obtained increased to reach average of 408W However, the clean uncooled PV panel power reached 382W also the dirty uncooled PV panel power reached 368W. With the temperature reduction of the PV panel, the power output of the PV panel cooled by water spray is higher than that generated without cooling attached.

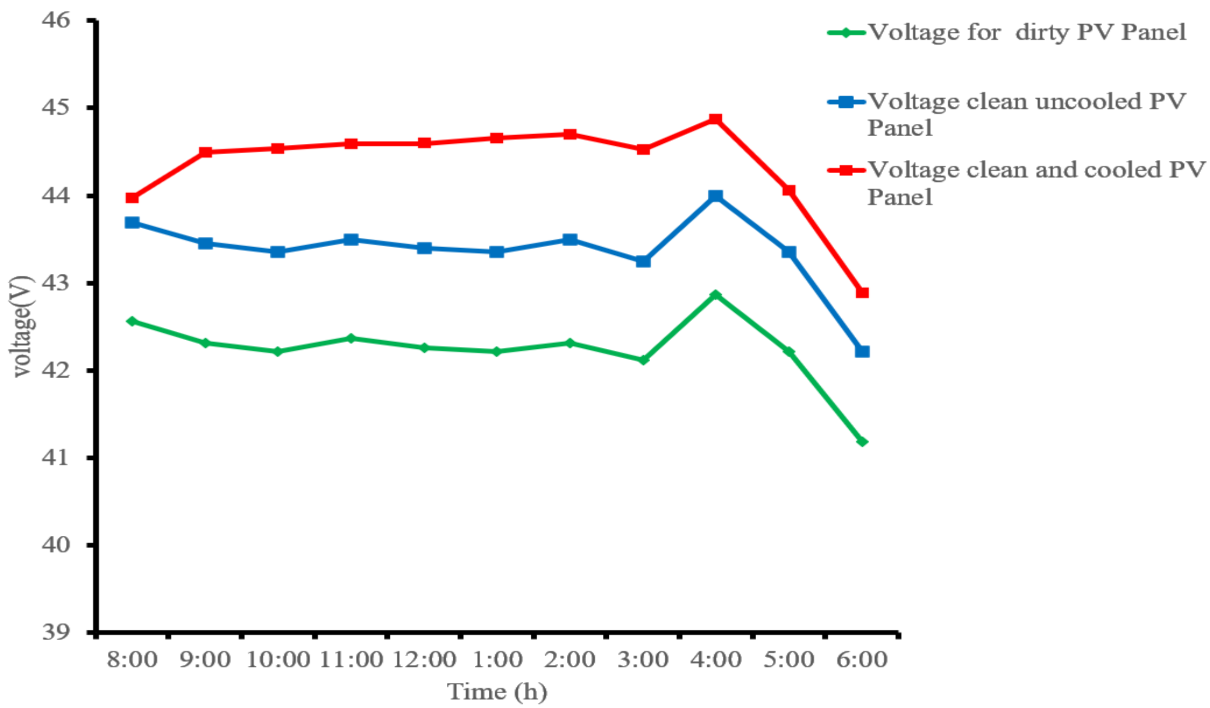


Figure 3.20 : Voltage Experimental readings with time.

It was also noticed that in the case of the clean uncooled PV panel, maximal electric power output occurs at voltages reaching 43.99 V and in the case of the PV panel that was cooled the specific point of maximal electric power output was shifted at voltages reaching 44.95 V. A cooling effect causes the point with maximal power output to shift at higher voltage values. An example of a typical voltage-current characteristic for different cooling circumstances was presented.

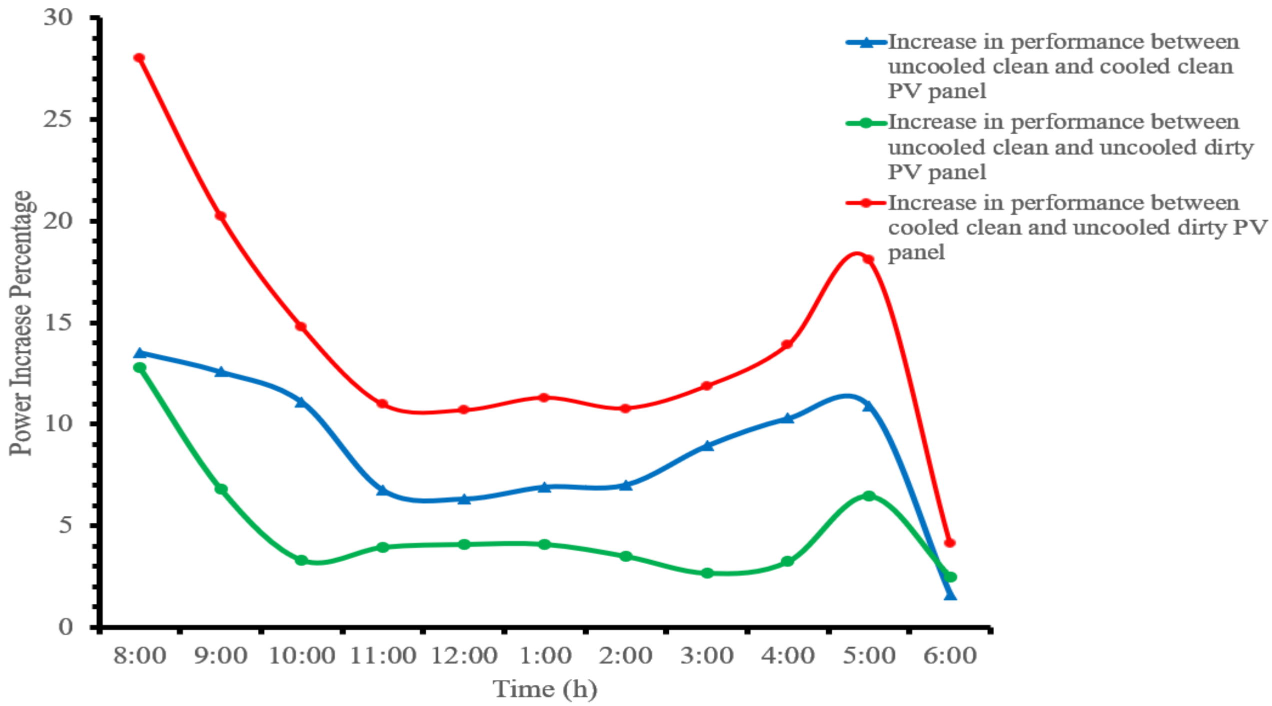


Figure 3.21 : Performance improvement with time.

The highest increase in the electrical PV panel power output was achieved in the case of water spraying cooling technique, where the total average power output between cooled and clean uncooled panel increase was in the amount of 8.22% and between the clean uncooled and dirty uncooled panel, output power increase was in the amount of 6.81% as shown in figure (3.21) , however the increase in performance between the cooled clean panel and the uncooled dirty was 15.54%.

To compare our results with another project we took **A. Khalil et al. [17]** research as an example to compare the achieved temperature reduction between the case of uncooled PV panel and cooled PV panel in different cooling regimes and the results were as follows:

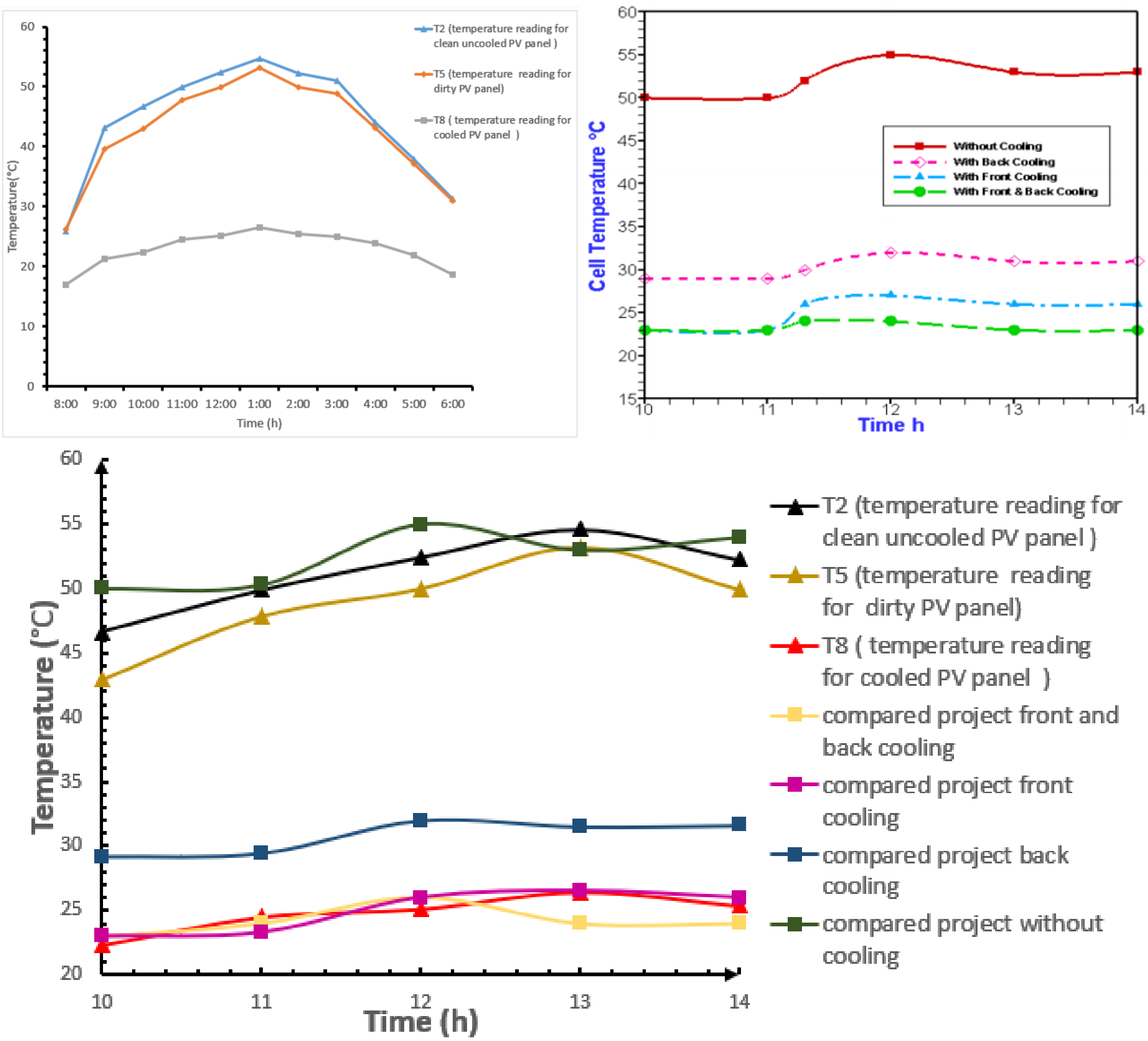


Figure 3.22 : Temperature comparison with another project.

According to his research in the case of uncooled PV panel the temperature ranged from 50°C to 55°C . However, with the implementation of water spray cooling technique it was possible to reduce the temperature down to 24°C which is a significant decrease. On the other hand, in our project in the case on uncooled PV panel the temperature ranged from 42.75°C to 55.63°C for the period from 10:00 AM to 14:00 PM, and after installing the water spray cooling technique the temperature went down to reach 22.31°C in the same period.

Chapter 5: Conclusion and Recommendations

Conclusion

One of the largest issues with photovoltaics is the significant reduction in output voltage as operating cell temperature increases and this increase will result in an overall large reduction in a modules power output.

In this project, a water spray cooling technique was proposed and experimentally tested on panel for different situations. And looking at the results obtained in this project we figured out that the best cooling option turned out to be cooling of backside PV panel surface compared to other cooling techniques.

Maximal achieved relative increase in the panel power output performance was for the cooled and clean PV panel when compared to the uncooled dirty, in the amount of average 15.54% of relative increase in panel's performance. Average panel temperature was reduced from 56.67 ^{o}C to an average of 21.44 ^{o}C, and the lowest possible panel temperature was limited due to constant pipeline water temperature that was around 17^{o}C. Water spray flow influence showed approximate linear dependence with panel's performance, however, a feasibility aspect is crucial in decision of applied water spray flow magnitude.

This table below summarize the increment in power and voltage :

	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	average
1)percentage increment of voltage for clean pv panel	2.66%	2.69%	2.70%	2.69%	2.70%	2.70%	2.81%	2.68%	2.64%	2.70%	2.50%	2.68%
2)percentage increment of voltage for cooled pv panel	0.64%	2.41%	2.74%	2.51%	2.76%	3.03%	2.75%	2.96%	2.00%	1.63%	1.60%	2.28%
3)percentage increment of voltage for cooled and clean pv panel	3.31%	5.17%	5.52%	5.27%	5.53%	5.81%	5.64%	5.72%	4.69%	4.37%	4.15%	5.02%
	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	average
1)percentage increment of power for clean pv panel	12.78%	6.81%	3.32%	3.96%	4.10%	4.10%	3.51%	2.68%	3.26%	6.47%	23.98%	6.81%
2)percentage increment of power for cooled pv panel	13.54%	12.59%	11.10%	6.75%	6.33%	7.39%	7.02%	2.96%	10.30%	10.90%	1.60%	8.22%
3)percentage increment of power for cooled and clean pv panel	28.05%	20.25%	14.79%	10.98%	10.68%	11.79%	10.78%	5.72%	13.89%	18.08%	25.97%	15.54%

1) Difference between uncooled clean and uncooled dirty panel .

2) Difference between cooled clean and uncooled clean .

3) Difference between cooled clean and uncooled dirty panel .

Finally, according to the gained experimental results, it can be concluded that the proposed water spray cooling technique has got a favorable effect on panel performance, and it is also a feasible one. However, cooling technique optimization should certainly be provided to get more realistic performance data as well as data for the cooling process energy consumption and this is one of the future research tasks that need to be done. (Which is also an important advantage of the herein proposed cooling technique).

However, to get more precise data, a small-scale prototype plant of this kind should be assembled to check all aspects (operation, initial investment, and maintenance issues, etc.), and to see if PV panel water spray cooling is most efficient just in the period of highest solar irradiation levels for specific geographical locations.

Finally, this study is cross bonding larger PV arrays (with a higher demand for cooling system power and with certain issues that had previously been addressed in this paper and that will influence panel performance in the scale of large-scale PV arrays).

Recommendations for Future Work

Further research can be carried out in the following areas:

- A study may be carried out to investigate the Economic feasibility of the system and whether it is good for small systems or not.
- An experimental study using air cooling technique and to compare with the results obtained from this project.
- Developing the system used in the project by adding heat exchanger to cool the water used by the sprinklers.
- An experimental study using nano-fluid as a cooling factor.

Appendix

The code below represents the Arduino code that we used during the project.

The language used is C++ using Arduino Program .

```
#include <Wire.h>
#include "RTClib.h"
#include <OneWire.h>
#include <DallasTemperature.h>
#define ONE_WIRE_BUS 2
OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);
uint8_t sensor1[8] = { 0x28, 0x3D, 0xB2, 0x75, 0xD0, 0x01, 0x3C, 0x9C
};
uint8_t sensor2[8] = { 0x28, 0x7A, 0x73, 0x75, 0xD0, 0x01, 0x3C,
0x83};
uint8_t sensor3[8] = { 0x28, 0xDE, 0xFE, 0x75, 0xD0, 0x01, 0x3C,
0x24};
uint8_t sensor4[8] = { 0x28, 0xF1, 0x5E, 0x75, 0xD0, 0x01, 0x3C,
0x85};
uint8_t sensor5[8] = { 0x28, 0xA9, 0x54, 0x75, 0xD0, 0x01, 0x3C,
0xB7};
uint8_t sensor6[8] = { 0x28, 0xA4, 0x1E, 0x75, 0xD0, 0x01, 0x3C,
0xA9};
uint8_t sensor7[8] = { 0x28, 0xC6, 0x0C, 0x75, 0xD0, 0x01, 0x3C,
0xFB};
uint8_t sensor8[8] = { 0x28, 0x26, 0xC4, 0x75, 0xD0, 0x01, 0x3C,
0xCE};
uint8_t sensor9[8] = { 0x28, 0x81, 0xDC, 0x75, 0xD0, 0x01, 0x3C,
0x55};
uint8_t sensor10[8] = { 0x28, 0x25, 0xAF, 0x75, 0xD0, 0x01, 0x3C,
0xF6};
uint8_t sensor11[8] = { 0x28, 0xEE, 0x20, 0x08, 0x14, 0x15, 0x01,
0x59};

RTC_DS3231 rtc;

char daysOfTheWeek[7][12] = {"Sunday", "Monday", "Tuesday",
"Wednesday", "Thursday", "Friday", "Saturday"};
#include <SPI.h>
#include <SD.h>

File myFile;

// change this to match your SD shield or module;
const int chipSelect = 53;
```

```
#define VIN1 A0 // define the Arduino pin A0 as voltage input (V in)
#define VIN2 A1
#define VIN3 A2
const float VCC   = 5.0;// supply voltage is from 4.5 to 5.5V.
Normally 5V.
const int model = 1;   // enter the model number (see below)

float cutOffLimit = 1.01;// set the current which below that value,
doesn't matter. Or set 0.5


float sensitivity[] ={
          0.185,// for ACS712ELCTR-05B-T
          0.100,// for ACS712ELCTR-20A-T
          0.066// for ACS712ELCTR-30A-T

         };


const float QOV1 =   0.5 * VCC;// set quiescent Output voltage of 0.5V
const float QOV2 =   0.5 * VCC;
const float QOV3 =   0.5 * VCC;
float voltage1;// internal variable for voltage
float voltage2;
float voltage3;



void setup ()
{
  Serial.begin(9600);
    sensors.begin();
  while (!Serial) {
    ; // wait for serial port to connect. Needed for Leonardo only
  }
  delay(3000); // wait for console opening

  if (! rtc.begin()) {
    Serial.println("Couldn't find RTC");
  }

  if (rtc.lostPower()) {
    Serial.println("RTC lost power, lets set the time!");

  // Comment out below lines once you set the date & time.
    // Following line sets the RTC to the date & time this sketch was
compiled
    rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));
```

```
    // Following line sets the RTC with an explicit date & time
    // for example to set January 27 2017 at 12:56 you would call:
    // rtc.adjust(DateTime(2017, 1, 27, 12, 56, 0));
  }
    Serial.print("Initializing SD card...");

  if (!SD.begin()) {
    Serial.println("initialization failed!");
    return;
  }
  Serial.println("initialization done.");

  // open the file. note that only one file can be open at a time,
  // so you have to close this one before opening another.
  myFile = SD.open("test.txt", FILE_WRITE);


  // if the file opened okay, write to it:
  if (myFile) {
    Serial.print("Writing to test.txt...");
    // close the file:
    myFile.close();
    Serial.println("done.");
  } else {
    // if the file didn't open, print an error:
    Serial.println("error opening test.txt");
  }

  // re-open the file for reading:
  myFile = SD.open("test.txt");
  if (myFile) {
    Serial.println("test.txt:");
    pinMode(5,OUTPUT);
}
}

void loop ()
{
    DateTime now = rtc.now();

    Serial.println(" Date & Time: NOW ");
    Serial.print(now.year(), DEC);
    Serial.print('/');
    Serial.print(now.month(), DEC);
    Serial.print('/');
    Serial.print(now.day(), DEC);
    Serial.print(" (");
    Serial.print(daysOfTheWeek[now.dayOfTheWeek()]);
    Serial.print(") ");
    Serial.print(now.hour(), DEC);
    Serial.print(':');
```

```
  Serial.print(now.minute(), DEC);
  Serial.print(':');
  Serial.print(now.second(), DEC);
  Serial.println();
  sensors.requestTemperatures();
 Serial.print("Sensor 1: ");
printTemperature(sensor1);
     delay(3000);

 Serial.print("Sensor 2: ");
printTemperature(sensor2);
     delay(3000);

 Serial.print("Sensor 3: ");
printTemperature(sensor3);
     delay(3000);

 Serial.print("Sensor 4: ");
printTemperature(sensor4);
     delay(3000);

 Serial.print("Sensor 5: ");
printTemperature(sensor5);
     delay(3000);

 Serial.print("Sensor 6: ");
printTemperature(sensor6);
     delay(3000);

 Serial.print("Sensor 7: ");
printTemperature(sensor7);
     delay(3000);

 Serial.print("Sensor 8: ");
printTemperature(sensor8);
     delay(3000);

Serial.print("Sensor 9: ");
printTemperature(sensor9);
     delay(3000);

Serial.print("Sensor 10: ");
printTemperature(sensor10);
     delay(2000);

Serial.print("Sensor 11: ");
printTemperature(sensor11);
     delay(3000);

Serial.println();
 // read the input on analog pin 0.1.2:
```

```
  int V1R = analogRead(A3);
  int V2R = analogRead(A4);
  int V3R = analogRead(A5);

  // Convert the analog reading (which goes from 0 - 1023) to a
voltage (0 - 50V):

    float voltage11 = V1R * (5.0 / 1024.0) * 10.1;
    float voltage22 = V2R * (5.0 / 1024.0) * 10.1;
    float voltage33 = V3R * (5.0 / 1024.0) * 10.1;


  Serial.print("V1: ");
  Serial.print(voltage11);
  Serial.println(" V");

  Serial.print("V2: ");
  Serial.print(voltage22);
  Serial.println(" V");

  Serial.print("V3: ");
  Serial.print(voltage33);
  Serial.println(" V");


      myFile = SD.open("test.txt", FILE_WRITE);



  // if the file opened okay, write to it:
  if (myFile) {
    Serial.print("Writing to test.txt...");
    myFile.println("testing 1, 2, 3.");
    myFile.println("Current Date & Time: ");
    myFile.print(now.year(), DEC);
    myFile.print('/');
    myFile.print(now.month(), DEC);
    myFile.print('/');
    myFile.print(now.day(), DEC);
    myFile.print(" (");
    myFile.print(daysOfTheWeek[now.dayOfTheWeek()]);
    myFile.print(") ");
    myFile.print(now.hour(), DEC);
    myFile.print(':');
    myFile.print(now.minute(), DEC);
    myFile.print(':');
    myFile.print(now.second(), DEC);
    myFile.println();
    myFile.print("Sensor 1: ");
  printTemperature(sensor1);
```

```
    myFile.println();

  myFile.print("Sensor 2: ");
  printTemperature(sensor2);
    myFile.println();

   myFile.print("Sensor 3: ");
  printTemperature(sensor3);
    myFile.println();

   myFile.print("Sensor 4: ");
  printTemperature(sensor4);
    myFile.println();

   myFile.print("Sensor 5: ");
  printTemperature(sensor5);
    myFile.println();

   myFile.print("Sensor 6: ");
  printTemperature(sensor6);
    myFile.println();

   myFile.print("Sensor 7: ");
  printTemperature(sensor7);
    myFile.println();

   myFile.print("Sensor 8: ");
  printTemperature(sensor8);
    myFile.println();

  myFile.print("Sensor 9: ");
  printTemperature(sensor9);
    myFile.println();

  myFile.print("Sensor 10: ");
  printTemperature(sensor10);
    myFile.println();

  myFile.print("Sensor 11: ");
  printTemperature(sensor11);
    myFile.println();

   myFile.println();
   myFile.print("V1: ");
   myFile.print(voltage11);
   myFile.print(" V");
   myFile.println();
   myFile.print("V2: ");
   myFile.print(voltage22);
   myFile.print(" V");
   myFile.println();
```

```
    myFile.print("V3: ");
    myFile.print(voltage33);
    myFile.print(" V");
    myFile.println();


   digitalWrite(5,LOW);
     delay(4000);
   float voltage1_raw =   (5.0 / 1023.0)* analogRead(VIN1);// Read the
voltage from sensor
   voltage1 =  voltage1_raw - QOV1 + 0.012 ;// 0.000 is a value to make
voltage zero when there is no current
   float current1 = voltage1 / sensitivity[model];

   float voltage2_raw =   (5.0 / 1023.0)* analogRead(VIN2);// Read the
voltage from sensor
   voltage2 =  voltage2_raw - QOV2 + 0.012 ;// 0.000 is a value to make
voltage zero when there is no current
   float current2 = voltage2 / sensitivity[model];

   float voltage3_raw =   (5.0 / 1023.0)* analogRead(VIN3);// Read the
voltage from sensor
   voltage3 =  voltage3_raw - QOV3 + 0.012 ;// 0.000 is a value to make
voltage zero when there is no current
   float current3 = voltage3 / sensitivity[model];


   Serial.print(current1,2);
     Serial.println("A");
     Serial.print(current2,2);
     Serial.println("A");
     Serial.print(current3,2);
     Serial.println("A");
        myFile.println();

     myFile.print("current1");
     myFile.print(current1,2);
     myFile.println("A");
     myFile.print("current2");
     myFile.print(current2,2);
     myFile.println("A");
     myFile.print("current3");
     myFile.print(current3,2);
     myFile.println("A");
      myFile.println();
    myFile.println();
    myFile.println();
    myFile.println();


      delay(1000);
```

```
    digitalWrite(5,HIGH);
    // close the file:
    myFile.close();
    Serial.println("done.");
  } else {
    // if the file didn't open, print an error:
    Serial.println("error opening test.txt");

  }

    delay(000);
}
void printTemperature(DeviceAddress deviceAddress)
{
  float tempC = sensors.getTempC(deviceAddress);
  Serial.print(tempC);
  Serial.print("C  |  ");
  Serial.print(DallasTemperature::toFahrenheit(tempC));
  Serial.println("F");
    myFile.print(tempC);
    myFile.print("C  |  ");
    myFile.print(DallasTemperature::toFahrenheit(tempC));
    myFile.print("F");

}
```

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