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THE EFFECT OF AMBIENT TEMPERATURE ON THE VOLTAGE GENERATION OF THE PHOTOVOLTAIC PANEL AND COOLING SYSTEMS

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May 2023

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science

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Halloyta DJILANI MOHAMED

ABSTRACT

THE EFFECT OF AMBIENT TEMPERATURE ON THE VOLTAGE GENERATION OF THE PHOTOVOLTAIC PANEL AND COOLING SYSTEMS

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May 2023

The electric solar panel produces electricity throughout the day. In fact, it transforms part of the solar radiations into electricity. Indeed, the photons which come with the solar radiations collide with the electrons which are in the photovoltaic cell and consequently electricity is produced. But this production of electricity by the photovoltaic solar panel depends on the operational temperature, in other words it is influenced by the ambient temperature *T* of the location. To illustrate this influence, a PV system is concepted in Matlab-Simulink. In some regions of Africa where temperature can reach up to 50 °C, some customers complain about its influence, hence the objective of this article: the solar panel cooling systems which will make it possible to compensate the effect of temperature *T* on the production of electricity. Different cooling techniques is analyzed and described regarding the equipment and the working fluids used. In the last part of this work, to simplify users the cheapest and most efficient cooling methods is provided and commented.

2023, 78 pages

Keywords: Photovoltaic solar panel, Photons, Effect of temperature, Cooling systems

ÖZET

ORTAM SICAKLIĞININ FOTOVOLTAİK PANELİN GERİLİM ÜRETİMİNE ETKİSİ VE SOĞUTMA SİSTEMLERİ

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Elektrikli güneş panelleri gün boyunca elektrik üretir. Aslında güneşten aldığı solar radyasyonun bir kısmını elektriğe dönüştürür. Ayrıca güneş ışınlarından gelen fotonlar fotovoltaik hücredeki elektronlarla çarpışarak, sonuçta elektrik üretimine yol açar. Ancak fotovoltaik güneş panelinden elde edilen üretilen bu elektriğin üretimi çalışma sıcaklığına da bağlıdır. Başka bir deyişle, alanın ortam sıcaklığı *T'*den etkilenir. Bu etkiyi gösterebilmek için Matlab-Simulink yazılımı aracılığıyla merkezi bir güneş paneli sistemi tasarlamıştır. Bu sıcaklığın 50 ℃ ulaştığı Afrika'nın bazı bölgelerinde müşteriler bu sıcaklıktan şikâyetçidir. Bu çalışmanın amacı güneş panellerinin sıcaklığını *T* sıcaklığının elektrik üretimi üzerindeki etkisini mümkün kılacak biçimde güneş paneli soğutma sistemleri ile telafi etmektir. Çalışmada kullanılan ekipman ve akışkanlara göre farklı soğutma sistemleri analiz edilerek açıklanmıştır. Çalışmanın son bölümünde kullanıcılara en ucuz ve verimli soğutma yöntemleri basitleştirilerek anlatılmış ve yorumlanmıştır.

2023, 78 sayfa

Anahtar Kelimeler: Fotovoltaik güneş paneli, Fotonlar, Sıcaklık etkisi, Soğutma sistemleri

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CONTENTS

LIST OF SYMBOLS

A_F	Curve fitting factor
A	Area of PV module
A_c	Area of the collector
C_i	Photourrent coefficient
C_P	Heat capacity of the working fluid
C_{SI}	Solar irradiation coefficient for cell photocurrent
C_{SV}	Solar irradiation coefficient for cell output voltage
C_{TI}	Temperature coefficient for cell photocurrent
C_{TV}	Temperature coefficient for cell output voltage
C_v	Voltage coefficient
E	Electron charge
I_a	Incident angle
I	Current
I_c	Output current of the cell
I_L	Light generated current
I_m	Current at maximum power point
I_S	Dark saturation current
I_o	Reverse saturation current of the diode
I_{ph}	Photocurrent, function of irradiation level and temperature
I_{PV}	Current of photovoltaic module
I_{sc}	Short-circuit current
K	Boltzmann constant
M	Mass flow rate
N	Refrective index
N_f	Ideality factor
N_p	Number of cells in parallel
N_s	Number of cells in series
P	Power
P_{in}	Incident light power
P_m	Maximum power point
P_o	Output power
R	Refracted angle
R_s	Series resistance of the cell
S	Solar irradiation level
S_x	Ambient solar irradiation level during the test
S_C	Benchmark reference solar irradiation level of the cell
T	Operational temperature
T_a	Variable ambient temperature during the cell testing
T_x	Operational temperature during the cell testing

T_c	Operating reference temperature of the cell
T_{co}	Temperature of Zn-H_2O in the collector
T_i	Temperature of the working fluid in the inlet of collector
T_o	Temperature of standard condition
V	Voltage
V_c	Output voltage of the cell
V_m	Voltage at maximum power point
V_o	Output voltage
V_{oc}	Open-circuit voltage
V_{PV}	Voltage of photovoltaic module
A_T	Temperature coefficient provided by the manufacturer
α_S	Slope of the change in the operational temperature of the cell
β	Silicon cell coefficient
β_T	Temperature constant
γ_T	Temperature constant
$\Delta T°$	Temperature variation
η	Efficiency of a solar cell
η_{elec}	Electrical efficiency
η_o	Nominal electrical efficiency at standard condition
η_{th}	Thermal efficiency

LIST OF ABBREVIATIONS

ADC	Analog to digital converter
BLDC	Brushless DC motor
CO_2	Carbon dioxide
D	Diode
EAHE	Earth to air heat exchanger
EGS	Electronic guidance system
FF	Fill factor
FTCC	Floating tracking cooling concentrating system
GC-CPCS	Ground coupled central panel cooling system
MAT	Maximum allowable temperature
N	Negative layer of silicon
P	Positive layer of silicon
PIC	Peripheral interface controller
PN	Junction
PV	Photovoltaic
PV/T	Photovoltaic and thermal system
PVC	Polyvinlyl chloride
PVSP-THS	PV solar panel interconnected with thermoelectric heat sink
RPM	Revoltions per minute
STC	Standard test condition
Zn-H_2O	Zinc nanoparticles and water

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1. INTRODUCTION

Since ancient times, Human has used fossil fuels such as oil (also called black gold), coal and natural gas to meet their needs. The term "fossil" refers to the decomposition of the rest of living things over several thousand years. This form of energy which is rich in carbon C is found underground and is harmful to our environment because it emits greenhouse gases during its use. For a long time, humans have been using fossil fuels in several areas, including the production of electricity, to protect themselves from the cold and cars to get around, etc. In order to use them, they are brought out of the ground and then burned. When burned, they produce a lot of carbon dioxide “CO_2”. This greenhouse gas is one of the major causes of the phenomenon of “global warming”. Aware of the situation, some countries recognize the dangerousness and pollution of the atmosphere that the use of fossil fuels can cause. And this indirectly affects our health. To save our planet, some countries plan to use renewable energy (Jenkins 2019).

The Paris COP21 agreement in 2015 set targets such as lowering the temperature increase to below 1.5 °C until 2050 and encouraging all countries to phase out fossil fuels. The emission of CO_2 into the atmosphere and the increase in the average temperature of the globe can lead to serious unpredictable and irreversible consequences such as climate change, melting of the ice at the North Pole, the increase in sea level, multiplication of earthquakes, unexplained plate tectonics, floods, lack of rain, droughts, forest fires, erosions and the appearance of the hole in the ozone layer allowing infrared light to penetrate the atmosphere and thus causing serious illnesses such as skin cancer. The United Nations Organization has claimed that the past 7 years have been the hottest in all centuries. The destruction of the planet is accomplished by Man himself. At this stage, the decarbonization of the global economy and the energy transition towards clean and sustainable energies are crucial to save our planet.

According to the report written by the World Bank, more than 35 countries and more than 20 cities estimated that about 12% of greenhouse gas emissions would be carbon dioxide, which damages the environment. To increase the use of renewable energies, the price of oil is lowered. The International Energy Agency states that renewable sources will be the most important in the future. She also adds that the production of renewable energies must increase from 22% to 26% in 2020 (Charles Cormier 2015).

Industrialized countries such as European countries, some Asian countries and the United States have found it difficult to abandon fossil fuels because it essentially affects their economy. The degradation of our planet has become aware and the world is turning towards “renewable energies”. Also called green energy, it is used to fight against global warming. The term “renewable energy” refers to clean, inexhaustible energy that is present in unlimited quantities in nature. The term "clean" means non-polluting, that is to say no emission of greenhouse gases into the atmosphere (Jelley 2020). What are the sources of renewable energy? There are mainly 5 sources: hydraulic energy which comes from water, wind energy which comes from the wind, biomass energy which comes from biomass, geothermal energy which comes from the earth and solar energy which comes from the sun that the work will be focused on. The world must use these 5 energies to promote the sustainable development of the earth and thus leave a livable planet for our future children (Crane *et al.* 2010, Jenkins 2019). Each citizen can participate in the reduction of greenhouse gas emissions by lowering the heating of his house, by planting trees in front of his home, not throwing waste everywhere in the city and by using public transport and the bicycle instead of the car.

Solar energy is a branch of intermittent renewable energy, it means that it depends on solar radiation that comes from the sun and is divided in 2 parts: photovoltaic solar energy and solar thermal energy. Photovoltaic solar energy refers to the production of electricity using photovoltaic solar panels. It can be applied on small installations such as on the roofs of houses in isolated areas or on large installations such as in the power grid. While solar thermal energy refers to producing heat through thermal sensors. These 2 forms of energy are well-spread over the 4 corners of the globe (Mackay 2015).

In certain regions of the continent of Africa (for example in Djibouti) where the ambient temperature T can reach 50 °C in the summer, the electricity production of the photovoltaic solar panel can be influenced. To avoid this temperature influence, electricians have developed panel cooling systems. These different methods are mentioned in this work and the client can choose the method that suits him.

Switching from fossil fuels to renewable energies is a good thing, but it is also important to know how to better use energy without waste. The user must consume an energy source in an intelligent and rational way: this is energy efficiency. It refers to the use of energy in a judicious, clever, appropriate and logical way. It is broken down into 3 parts: energy saving, consumption management and the judicious use of energy (Crane *et al.* 2010).

2. LITERATURE REVIEW

Tripanagnostopoulos *et al.* investigated on this topic. The authors developed a concept of PV cooling technique that has less use of materials. Their PV cooling method are PV/T solar collector. The possible fluids used in this case are water and air. They preferred to use air because of the minimal use of material concept. Basically, they constructed a thermal unit at the rear side of PV module. The concept of minimal use of material is achieved using two configurations : using suspended thin flat metal sheet at the middle of the air channel and finned back wall of an air channel. At the end of the experiment, the authors were able to identify the efficiency improvement of the two low cost operating configurations (Tonui and Tripanagnostopoulos 2007).

Duell *et al.* studied the light transmission and module temperature on structured glasses on the PV module. The authors developed 4 different types of structured glasses : grooves, pyramids, inverted pyramids and lightly textured glasses. The pyramid structured glass seemed to increase short-current Isc with normal incident light. To study the effect of these structured glasses on PV module temperature wind tunnel testing was used. After the test, the authors came up to the conclusion that the glass structure plays a fundamental role in the cooling effect. The velocity of the wind also plays a fundamental role in the cooling effect because higher wind speed leads to the decrease of the PV module temperature (Duell *et al.* 2010).

Cazzaniga *et al.* highlighted one the issues large PV systems could encounter which is the lake of the available lands or spaces suitable for installing PV systems. The authors proposed the use of small lakes or artificial basins for installing floating PV system. That system is called " floating tracking cooling concentrating system. It is equipped of, as its name indicated, with the tracking system of the sun, water sprinklers installed in the PV module that achieves the cooling process and reflectors which by concentrating the solar radiations participate to the increase of ouput energy. 3 different configurations of the FTCC system is discussed along with experimental results (Cazzaniga *et al.* 2012).

Moharram *et al.* made also a research related to this PV module cooling techniques. They came up with the water spray cooling system on the solar panel. The aim of their research was to use less amount of water to cool down the PV module. MAT is the maximum allowable temperature which the PV module should not overcome. In order to achieve this goal, a matematical model is used to settle when to begin to cool down the PV module. The authors developed a cooling system to see how long period of time the cooling process takes to decrease the rising temperature in to acceptable level (Moharram *et al.* 2013).

Sahay *et al.* worked on this topic. The efficiency of PV cells decreases when the module temperature increases. They noticed that for every 1°C raise in panel temperature the panel efficiency decreases down to 0.4%. To keep efficiency of PV module at acceptable level, they developed a cheap PV cooling technique which is called " ground coupled central panel cooling system". The main advangtages of this PV cooling system are that it is a low cost operating technique and can be applied for huge central system as its name indicates. The working fluid used in this system is air. The air moves either naturally or forced by the blower to start the cooling process (Sahay *et al.* 2013) .

Mehrotra *et al.* as well affirmed that the electrical efficiency of the photovoltaic panel decreases when the surface temperature of the PV increases. To protect the PV module from this impact of surface temperature, water immersion cooling technique is proposed. Basically, PV cell is submerged in water to maintain the surface temperature to an acceptable level. Experimental study was made to see if there is enhancement of electrical efficiency and the results are shown and discussed (Mehrotra *et al.* 2014) .

Irwan *et al.* conducted an experiment to made a comparison between DC brushless fan and DC water pump cooling effect on solar panel. In the hot spaces, the temperature of PV modules is increasing and thus the efficiency is also increased. To compensate this temperature influence on the electric production of solar panel, the authors proposed these cooling methods : using a DC brushless fan to create a constant air movement at the rear side of the PV module and using DC water pump for a constant water flow movement at front side of the PV module. Sensors of temperature were used to identify the PV temperature on the surface. PIC microcontroller was used as a brain to command automatically and switch ON or OFF the DC brushless fan and DC water pump for the cooling process. In the two proposed cooling techniques the efficiency of the solar panel are increased. At the end of the experiment, the authors were able to identify the difference in the efficiency between DC brushless fan and DC water pump cooling methods (Irwan *et al.* 2015).

Nizetic *et al.* made a research related to this topic. They elaborated and proposed a cooling technique for photovoltaic panels which is a water spray cooling technique on a PV panel. They prepared an experimental set up under the mediterranean climate. The experimental set up is composed of : PV monocrystalline module of 50 W nominal power tilted with an angle of 17° and oriented south, ammeter and voltmeter are used to measure current and voltage at every point during the experimental set up, rheostat is used to set the values of resistance in the circuit, water flow valve is used to regulate the flow of water, water flow meter is used to evaluate water consumption in this circuit, pyranometer is also used to measure the solar irradiance on the surface of PV panels. The authors affirmed that the particularity of this cooling technique is that both of the front and rear sides are cooled in the same time. So, the authors used temperature sensors located in the front and at the back side of the PV panels to determine whether the temperature is raised or not. To achieve a better spray distribution, the authors used nozzles in the front and in the rear side of PV panels. At the end, the authors concluded that this experimental study showed them a positive results and this water spray cooling technique showed a favorable cooling response because the output electric power and electrical efficiency are increased by 16.3 % and 14.1 % respectively (Nizetic *et al.* 2016).

Hussein *et al.* talked about the trapped heat problem in the PV cells when operating under hot climate. That causes the conversion efficiency to decrease. To avoid this and improve the performance of the PV panels, they set up an experiment to test 2 different techniques : the effect of an active water cooling and nanofluids (Zn-H_2O) cooling effect on the PV module. Heat exchanger and pipes are used to let working fluids pass.

5 nanofluids (Zn-H_2O) concentration ratios are tested and experimental results are showed and discussed (Hussein *et al.* 2017).

Another alternative cooling technique is conducted by Elminshawy *et al*. Indeed, the objective of this cooling system is to reduce the operational temperature of the PV panel. To do that, the authors employed an experimental set up which took place in Port-Said, Egypt with the latitude of 31°16 N 32°18 E. This research took place in 2019. This cooling technique is mainly consisted of : Polycrystalline PV modules of 250 W nominal power oriented south and tilted with an angle of 30°, connected with the buried earth to air heat exchanger (EAHE). The air blower takes the atmospheric ambient air and passes to the buried earth to air heat exchanger. The air flow can be set manually by the control valve. The atmospheric ambient air is then heated by the air heater. There is a temperature controller to set the temperature value in the air heater. The heated air passes now to the buried earth to air heat exchanger which is consisted of a vertical and 12 horizontal tubes made of cooper. In this stage, previously heated air is cooled. The pre-cooled air now goes to the lower side of the air cooling channels located at the back side of PV modules. The heat transfer is happening in the air cooling channels. Indeed, as the pre-cooled air passes at rear side of PV modules, the temperature is decreased. Finally, the pre-cooled air which absorbed heat now goes out of upper side of the air cooling channels. To prevent heat exchange from atmospheric ambient air, the authors employed a glass wool for insulation at the back side of air cooling channels. Various equipments are used such as thermocouples and multi-meter to measure and collect data. This cooling technique showed the authors a favorable and positive response to decrease the operational temperature because at 0.0288 m3 /s of air flow rate the electrical efficiency and PV output power is improved by 22.98% and 18.90% respectively (Elminshawy *et al.* 2019).

Arefin *et al.* put in light the waste of energy in the form of heat when the photovoltaic panel is operating under hot climate. Useful energy is wasted for no reason. An integrated photovoltaic-thermal (PV/T) is suggested and analysed. One of the purpose of the system is to use this wasted heat into other domestic appliances. The cooling process starts when the water flows over the top surface of the PV module and then forced by a pump to passe through the collector which is apart of the system. The effect of different mass flow rate of the water and the impact on the efficiency of the system are studied and the results are shown (Arefin *et al.* 2020).

Hamzah *et al.* again talked about the decrease of performance of photovoltaic solar panel because of the increase of working temperature. The thermoelectric heat sink cooling process of the PV module is suggested and presented. Furthermore, 4 different geometrical shapes of the pin-fin heat sink is tested for the cooling impact on the photovoltaic solar panel. Air is used as a working fluid in this case. The numerical analysis was made to examine how long the cooling mechanism of the pin-fin heat sink of the PV panel takes to drop the increasing temperature to an acceptable level. The effectiveness and reliability and results of this cooling technique is discussed and presented (Hamzah *et al.* 2021).

3. SIMULATION IN MATLAB / SIMULINK

To demonstrate the impact of temperature on the PV module electric efficiency a photovoltaic system is concepted using Matlab/Simulink software

3.1 Production of Electricity

There are 365 days in one year and every day the sun provides an abundance of solar radiations to us. The sun is known as a source of light energy and it shines without interruption. Photovoltaic solar cells convert some of these solar radiations into electricity. In fact, photons from sunlight collide with the electrons in the photovoltaic cell and thereby the production of electricity. However, certain external factors can influence this electricity production, especially the local operating temperature. The electric production by the PV cell is shown in Figure 3.1.

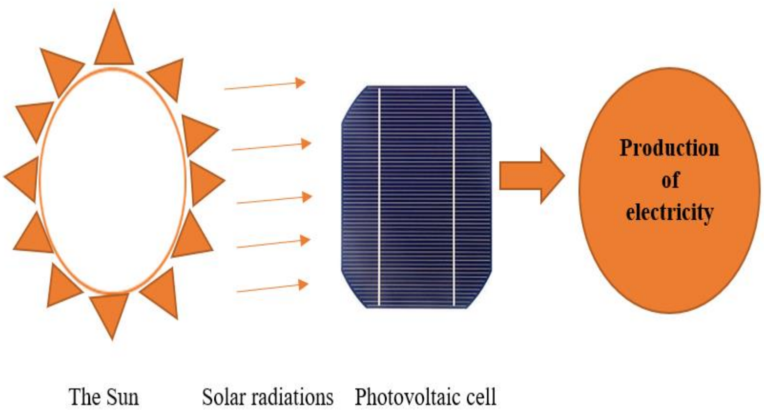

Figure 3.1 General overview of production of electricity

3.2 Theorical Knowledges

A photovoltaic cell is an electronic component that makes up a photovoltaic module. Here are the characteristics of a photovoltaic cell :

3.2.1 Characteristics of photovoltaic cell

A mathematical equations of the PV cell parameters which depend on the operational temperature *T* are listed below.

a) The short-circuit current (I_{sc}) is the current that flows through the photovoltaic cell when the voltage at the edge of the cell is zero, that is, when the cell is short-circuited. I_{sc} is the largest current that a photovoltaic cell can deliver.
b) The open-circuit voltage (V_{oc}) is the maximum voltage that can be obtained from a solar cell and this happens when the current is zero, V_{oc} is calculated using the following equation :

$$V_{oc} = \frac{n_f \times k \times T}{e} \times ln(\frac{I_L}{I_S} + 1) \quad (3.1)$$

Where, V_{oc} is the open-circuit voltage, n_f is the ideality factor, *k* is the Boltzmann constant, *T* is for operational temperature, *q* is the electronic charge, I_L is light generated current and I_S is the dark saturation current. Equation (3.1) explicitly indicates that V_{oc} depends of the operational temperature *T*.

c) V_c is the PV cell output voltage. V_c is calculated using the equation below :

$$V_c = \frac{A_F \times k \times T_c}{e} ln(\frac{I_{ph} + I_0 - I_c}{I_0}) - R_s \times I_c \quad (3.2)$$

Where, V_c is the output voltage of a single cell, A_F is the curve fitting factor, T_c is the reference operating temperature of the PV cell, *e* is the electron charge, I_{ph} is the photocurrent, I_0 is the reverse saturation current of the diode, I_c is the cell output current and R_s is for the series resistance of cell.

d) PV cell output current I_c is found by using the equation below :

$$I_c = I_{ph} - I_0 \left\{ exp\left[\frac{e}{k \times T_c}(V_c + R_s \times I_c)\right] - 1 \right\} \quad (3.3)$$

Equations (3.2) and (3.3) indicate that the output voltage of the cell V_c and output current of the cell I_c depend on the reference cell operating temperature T_c which depends on the operational temperature T.

e) Fill factor FF provides the maximum power using the following formula :

$$FF = \frac{P_m}{I_{sc} \times V_{oc}} = \frac{I_m \times V_m}{I_{sc} \times V_{oc}} \tag{3.4}$$

Where, FF is the fill factor, P_m is the power at maximum point, I_m is the current at maximum point and V_m is the voltage at maximum point. Equation (3.4) explicitly indicates that fill factor depends on V_{oc} which depends on the operational temperature T. Fill factor is a white coloured area in Figure 3.2.

f) From equation (3.4) an expression for maximum power point P_m can be derived :

$$P_m = FF \times I_{sc} \times V_{oc} \tag{3.5}$$

Equation (3.5) explicitly indicates that maximum power depends on V_{oc} which depends on the operational temperature T.

g) Current at maximum power point (I_m)

h) Voltage at maximum power point (V_m)

i) The efficiency of a solar cell, often abbreviated η, is calculated using the following formula :

$$\eta = \frac{P_m}{P_{in}} = \frac{I_{sc} \times V_{oc} \times FF}{P_{in}} \tag{3.6}$$

Where, η is electrical efficiency of PV cell and P_{in} represents the power of the incident light. η is the ratio of the output electrical power P_m at the maximum power point divided by the incident light power P_{in}. Equation (3.6) explicitly indicates that electrical efficiency depends on V_{oc} which depends on the operational temperature T. The equations above showed that theorically all the characteristics of photovoltaic cell depend on the operational temperature T. For a given solar irradiation level S and operational temperature T, the V-I and V-P respective curves are illustrated in a same axis in Figure 3.2. Parameters above are also indicated in the Figure 3.2.

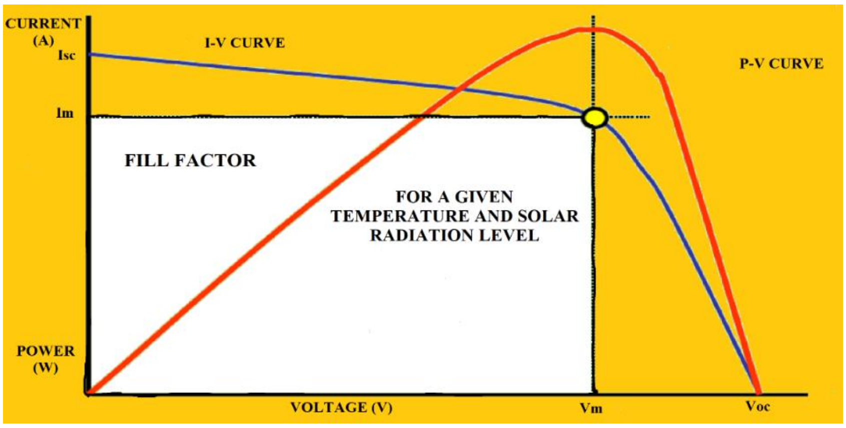

Figure 3.2 Characteristics of photovoltaic cell

3.2.2 Equivalent electrical circuit of photovoltaic cell

Figure 3.3 illustrates the equivalent circuit of an ideal photovoltaic cell :

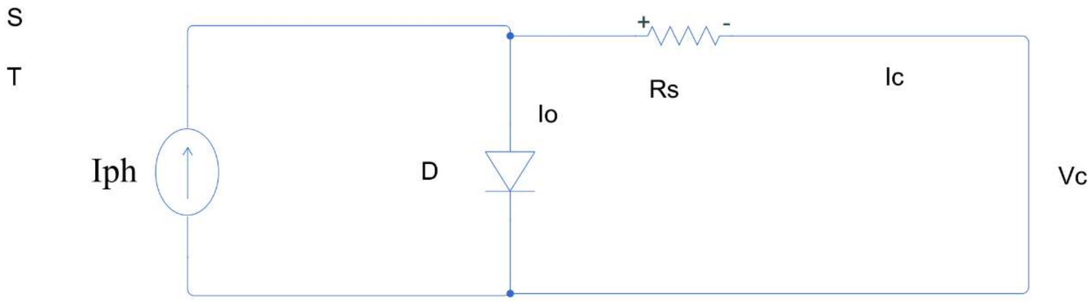

Figure 3.3 Equivalent electrical circuit of photovoltaic cell

Where S represents the solar irradiation level, I_o equals 0.0002 A and R_s is about 0.001 Ω. The role of diode is to protect the cell and to facilitate the current flow.

3.3 Photovoltaic Module

Photovoltaic solar panel, also called photovoltaic module, is used to convert some of the solar irradiations into electricity. One photovoltaic module consists of several photovoltaic cells connected in series and parallel. The combination of several photovoltaic modules is called central solar photovoltaic. The PV cell is shown in Figure 3.4.

Figure 3.4 Photovoltaic cell

Figure 3.5 shows an example of PV module.

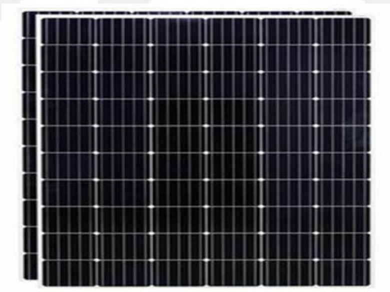

Figure 3.5 Photovoltaic module

There are different types of photovoltaic modules : Polycrystalline silicon which has about 55% of the world market, monocrystalline silicon which has approximately 36% of the world market and amorphous silicon which has about 3% of the world market (Pickerel 2015).

3.4 Photovoltaic Effect

The photovoltaic effect is implemented in photovoltaic cells to produce electricity from solar irradiations. To manufacture photovoltaic cells, semiconductors are used because they easily absorb light and allow the generation of an electric field and an electric voltage. This electric field will be obtained by the superposition of 2 layers of silicon, one of the layers of silicon is thus doped with phosphorus atom, one of these electrons does not participate in the bonds and therefore free to move, we speak of a layer N because the moving charge is negative. The other layer of silicon is doped with boron atoms, the boron will therefore capture electrons in the rest of the materials which will leave behind an electron holes which are mobile and have a positive charge. We speak of layer P because the mobile charge is positive. 2 silicon layers are shown in the Figure 3.6.

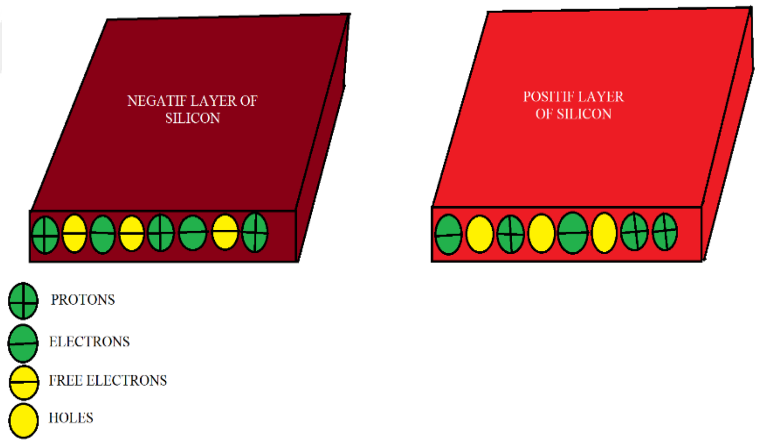

Figure 3.6 Silicon layers

In the vicinity of their interface, displacement by diffusion leads to recombination between electrons and holes. An electric field is thus obtained within the semiconductor and this region is called the pn junction. When the rays of the sun strike a PV cell, the photons of light transmit their energies to the electrons which are torn from the atoms in which they leave holes. The electrons and the holes thus formed will tend to recombine but when the phenomenon takes place in or near the pn junction, the electric field causes the electrons to repel towards the N layer and the holes towards the P layer (Zeman 2003).

The electrons seeking to combine with the holes are then forced to go through an external circuit to join the holes thus creating a direct electric current called the photoncurrent, the electrons are delivered under the voltage created in the pn junction called the photonvoltage. Photoncurrent and photonvoltage are illustrated in Figure 3.7.

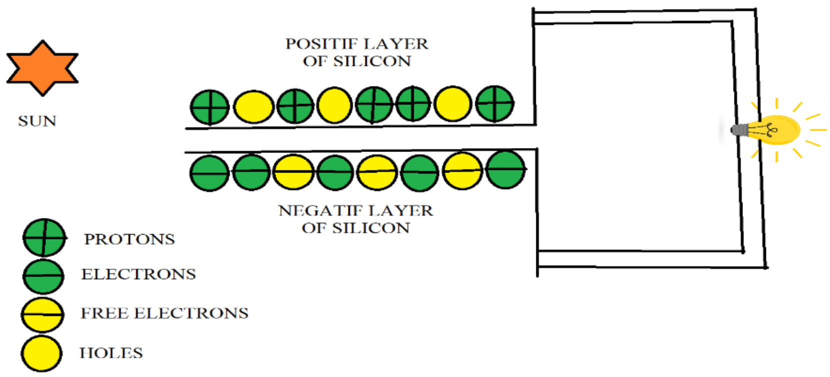

Figure 3.7 Photoncurrent and photonvoltage

3.5 Sistem Conception in Matlab/Simulink

A PV system is concepted using Matlab/simulink to analyze the effect of temperature T on the outpout voltage, and all the blocks and subblocks of the concepted PV system are illustrated below. Figure 3.8 shows V_c subblock. Equation in (3.2) is followed to concept the below V_c subblock in Matlab (Altas and Sharaf 2007).

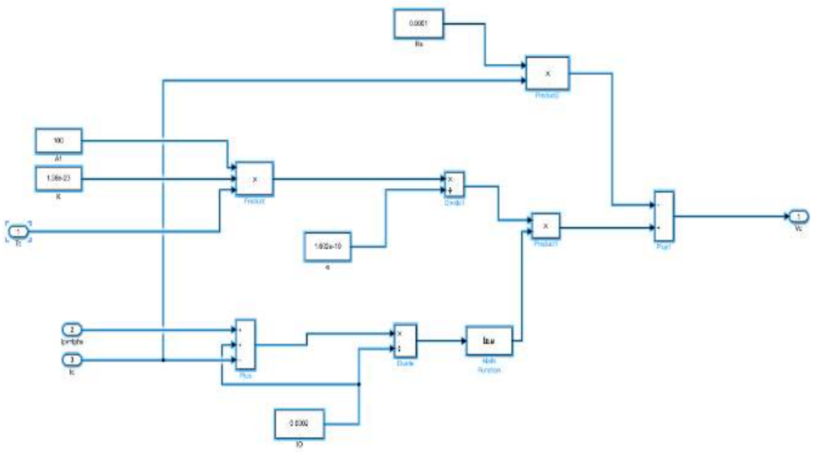

Figure 3.8 V_c subblock (Altas and Sharaf 2007)

Table 3.1 explains the parameters which are used to create V_c subblock above (Altas and Sharaf 2007).

Table 3.1 Parameters of V_c formulla (Altas and Sharaf 2007)

SIGNIFICATIONS	PARAMETERS	VALUES
Curve fitting factor	A_F	100
Boltzmann constant	k	$1.38e^{-23}$ J/K
Temperature of the PV cell	T_c	20 °C
Photocurrent	I_{ph}	5 A
Series resistance of the cell	R_s	0.001 Ω
Electron charge	e	$1.60e^{-19}$ C
Reverse saturation current of the diode	I_o	0.0002 A
Output current of the cell	I_c	

C_I and C_v are respectively the photocurrent and the voltage coefficients.

$$C_{TV} = 1 + \beta_T \times (T_a - T_x) \tag{3.7}$$

$$C_{TI} = 1 + \frac{\gamma_T}{S_C} \times (T_x - T_a) \tag{3.8}$$

$$C_{SV} = 1 + \beta_T \times \alpha_S \times (S_x - S_C) \tag{3.9}$$

$$C_{SI} = 1 + \frac{1}{S_C} \times (S_x - S_C) \tag{3.10}$$

Equations (3.7) to (3.10) are followed to concept the solar irradiation and temperature subblock in Figure 3.9 (Altas and Sharaf 2007).

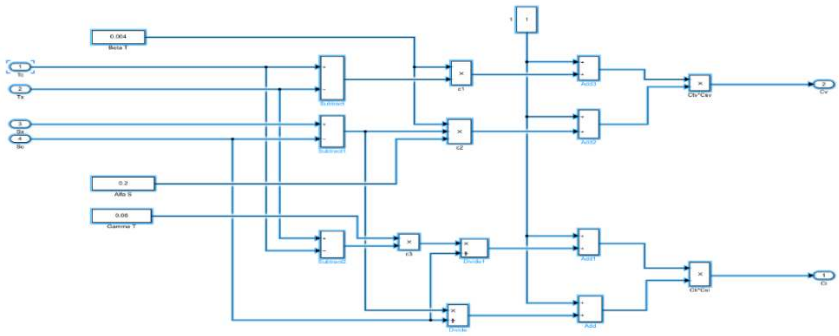

Figure 3.9 Temperature and irradiation subblock (Altas and Sharaf 2007)

Table 3.2 shows the parameters which are used to create temperature and solar irradiation subblock (Altas and Sharaf 2007).

Table 3.2 Parameters of C_I and C_V formullas (Altas and Sharaf 2007)

SIGNIFICATIONS	PARAMETERS	VALUES
Operating temperature during the cell testing	T_x	T_1=28 °C, T_2=80 °C and T_3=100 °C
Variable ambient temperature during the cell testing	T_a	20 °C
Ambient solar irradiation level during the test	S_x	75.34 W/m^2
Benchmark reference solar irradiation level of the cell during the test	S_C	100 W/m^2
Slope of the change in the operational temperature of the cell	α_S	0.2
Temperature constant of the cell	β_T	0.004
Temperature constant of the cell	γ_T	0.06
Temperature coefficient for cell output voltage	C_{TV}	

Table 3.2 Parameters of C_I and C_V formullas (Altas and Sharaf 2007) (Continued)

Temperature coefficient for cell photocurrent	C_{TI}	
Solar irradiation coefficient for cell output voltage	C_{SV}	
Solar irradiation coefficient for cell photocurrent	C_{SI}	

Figure 3.10 illustrates the subblock created to obtain the parameters V_c and I_c. So far, Matlab is utilized to concept PV cell parameters (Altas and Sharaf 2007).

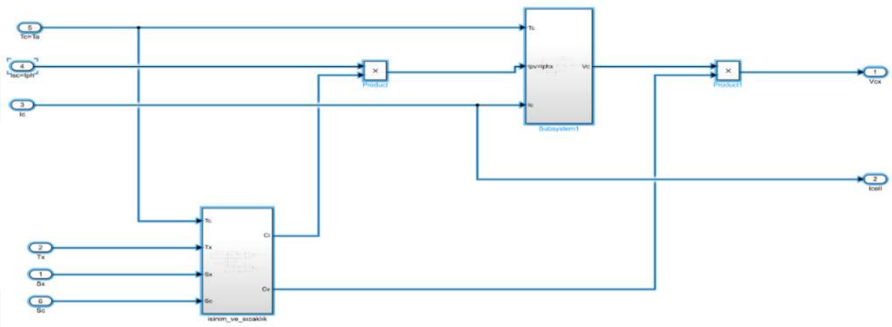

Figure 3.10 Third subblock (Altas and Sharaf 2007)

The module voltage V_{pv} and module current I_{pv} are created in this subblock. We are gradually moving from conception of PV cell to PV module. Figure 3.11 shows a single PV module conception subblock (Altas and Sharaf 2007).

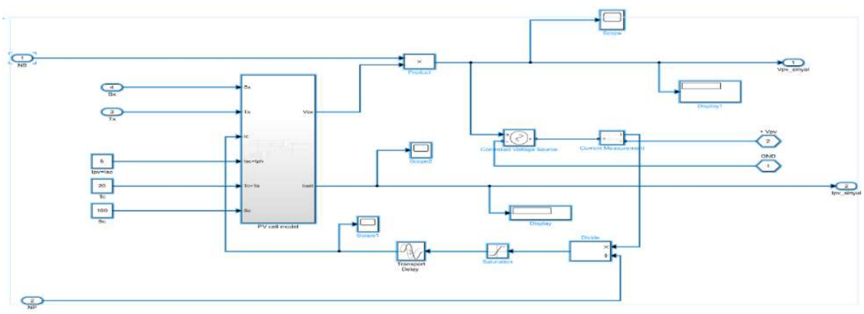

Figure 3.11 Photovoltaic panel subblock (Altas and Sharaf 2007)

The parameters which are used to create the first subblock are explained in this below Table 3.3.

Table 3.3 Parameters of the first subblock.

SIGNIFICATIONS	PARAMETERS	VALUES
Number of cells connected in series	N_s	100
Number of cells connected in parallel	N_p	90

In this subblock voltage, current and power are measured to see the effect of temperature. This is shown in Figure 3.12.

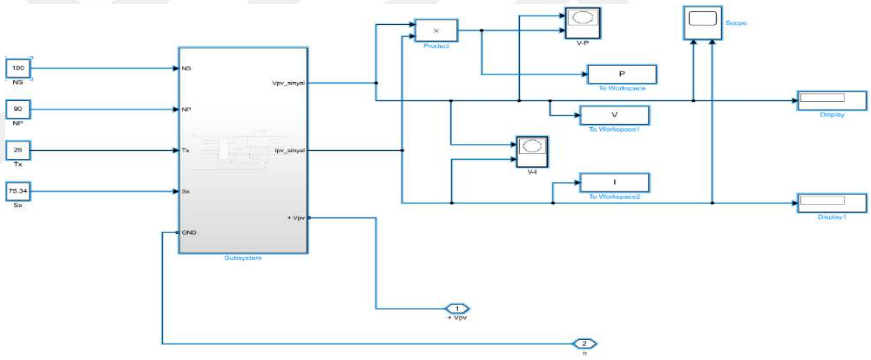

Figure 3.12 First subblock

The main block of a series circuit of the PV module system concepted in Matlab is shown in Figure 3.13.

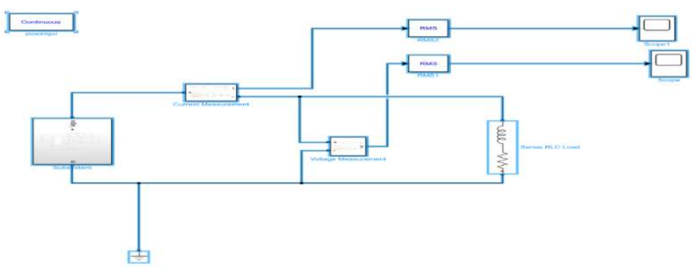

Figure 3.13 Photovoltaic module circuit

3.6 Theorical Voltaj Loss Equation

The voltage loss caused by the rise of operational temperature T can be calculated using this equation below :

$$\boldsymbol{V}(\boldsymbol{T}°) = \boldsymbol{V}(\boldsymbol{25}\ ℃) + \Delta\boldsymbol{T}° \times \boldsymbol{A_T} \tag{3.11}$$

Where, V is the voltage corresponding for a particular temperature, $\Delta T°$ is temperature variation between particular temperature and STC temperature and A_T represents temperature coefficient provided by the manufacturer in [mV / K]. Equation (3.11) helps us to determine theorically the loss of voltage.

3.7 Simulation Results

In this section, results of the simulated PV module system in Matlab-simulink are presented. The performance and response of the system is showed below. Only the T_x values are changed to make an efficient comparison, but the other parameters are remained the same : $N_s = 100$, $N_p = 90$ and $S = 75.34$ W/m^2. Figure 3.14 – 3.19 show the results.

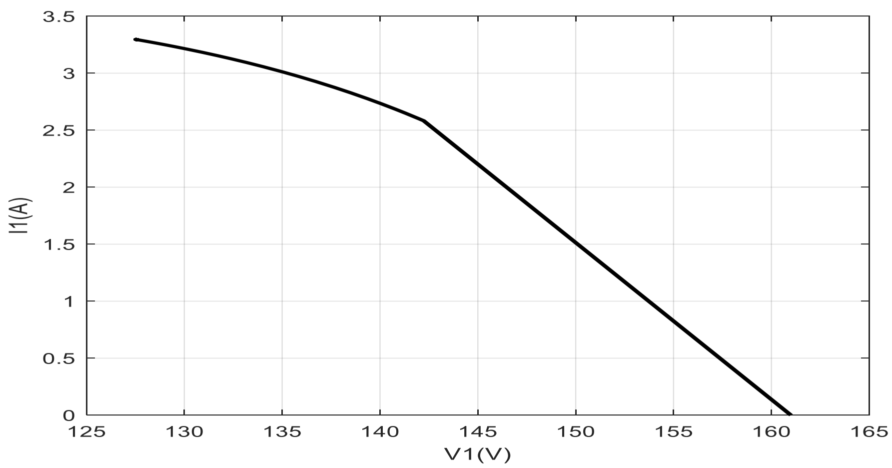

Figure 3.14 V_1-I_1 curve at $T_1 = 28$ ℃

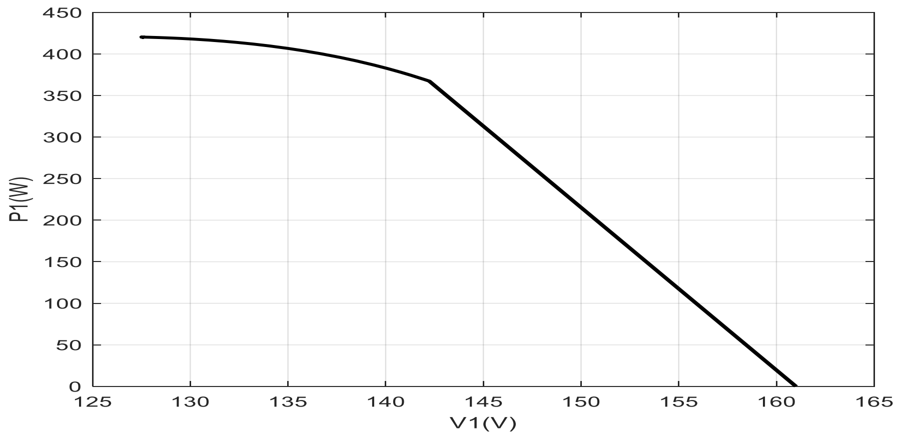

Figure 3.15 V_1-P_1 curve at T_1 = 28 ℃

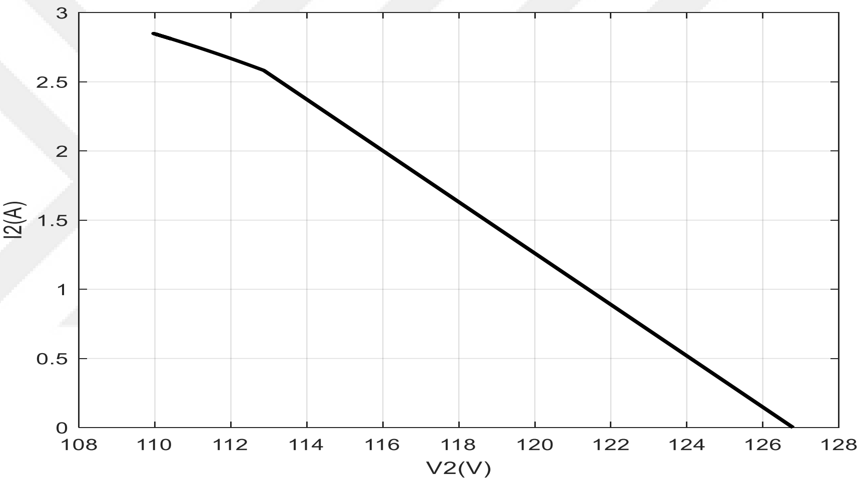

Figure 3.16 V_2-I_2 curve at T_2 = 80 ℃

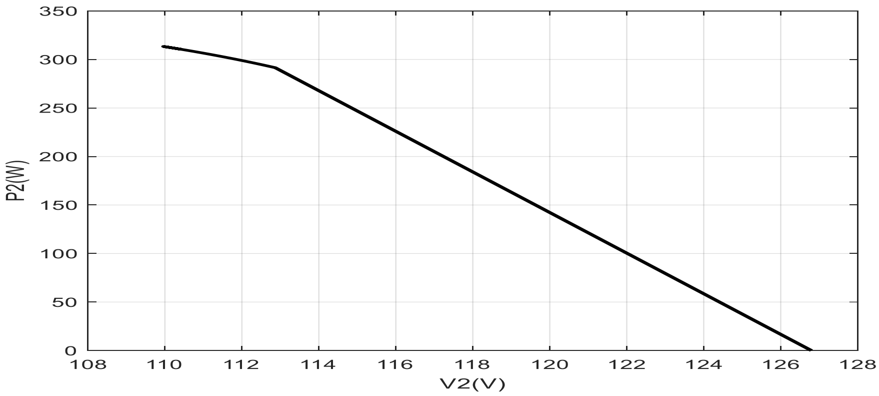

Figure 3.17 V_2-P_2 curve at T_2 = 80 ℃

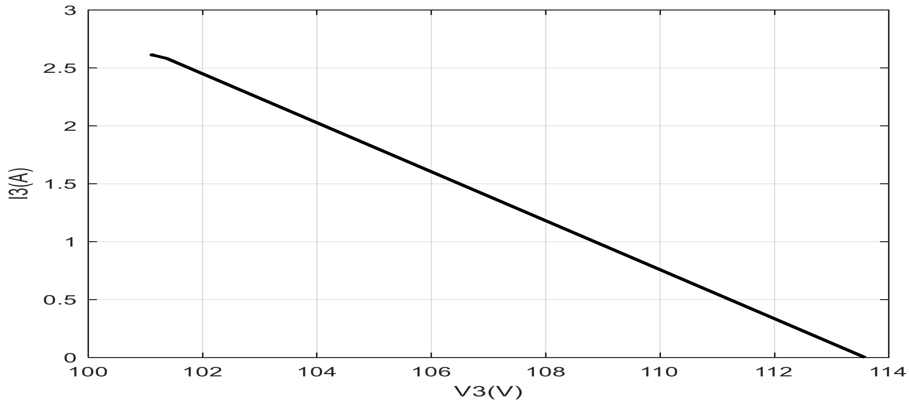

Figure 3.18 V_3-I_3 curve at T_3 = 100 °C

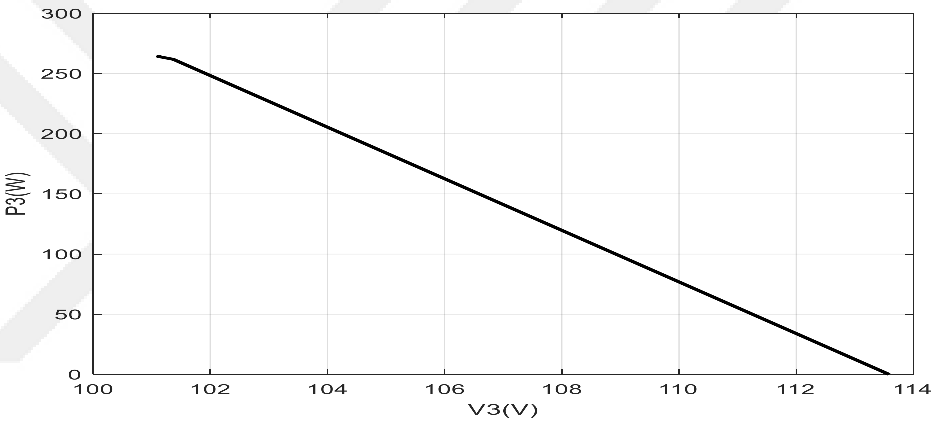

Figure 3.19 V_3-P_3 curve T_3 = 100 °C

In the Figure 3.20, all the *V-I* curves are gathered in a same axis to draw an explicit conclusion.

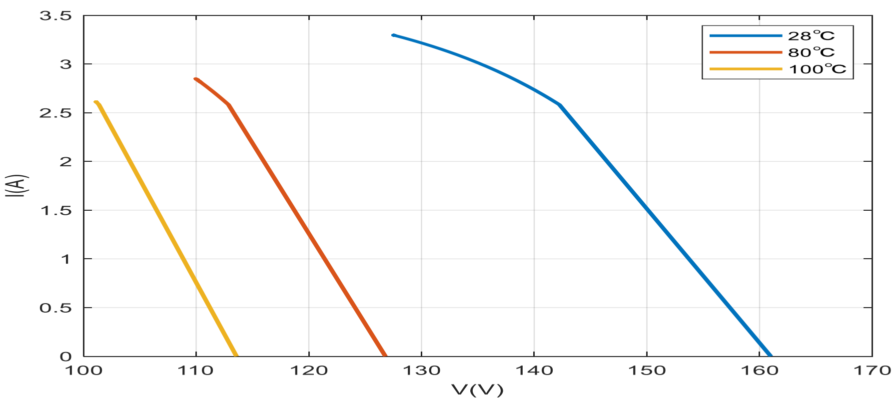

Figure 3.20 *V-I* curves at T_1 = 28 °C, T_2 = 80 °C and T_3 = 100 °C

In the Figure 3.21, all *V-P* curves are gathered in a same axis to draw an explicit conclusion.

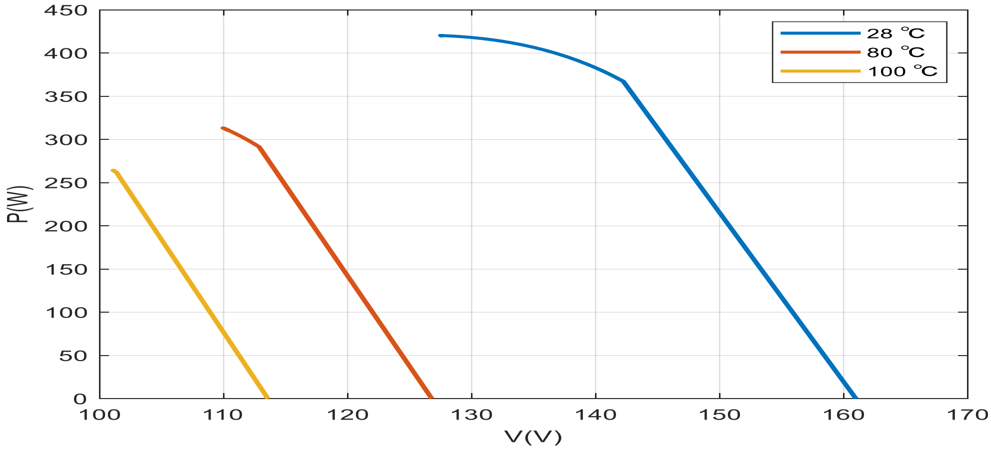

Figure 3.21 *V-P* curves at T_1 = 28 °C, T_2 = 80 °C and T_3 = 100 °C

From *V-I* and *V-P* curves above at different temperatures, it is noticed that when the values of operational temperature T_x are increasing the values of voltage *V* and power *P* are decreasing, but the values of current *I* are increasing slightly. Indeed, it is concluded that the ambient temperature T_x has an impact on the electric production of the PV module. Clearly, any change in atmospheric ambient temperature affects the behaviour of PV panel. The aim of this paper is to show the influence of temperature on the electric production of the PV module. In this section, with the commentary of the results, the objectif of this work is achieved.

4. SOLAR PANEL COOLING METHODS

To prevent the rise of temperature to affect the efficiency of the PV module several cooling methods are presented in this paper.

4.1 Direct Current Brushless Fan Cooling System

In this section, the process of DC fan cooling technique of the PV module is presented and analyzed.

4.1.1 DC brushless fan diagram

To protect PV module from efficiency drop a cooling technique driven by a brushless fan is presented in Figure 4.1.

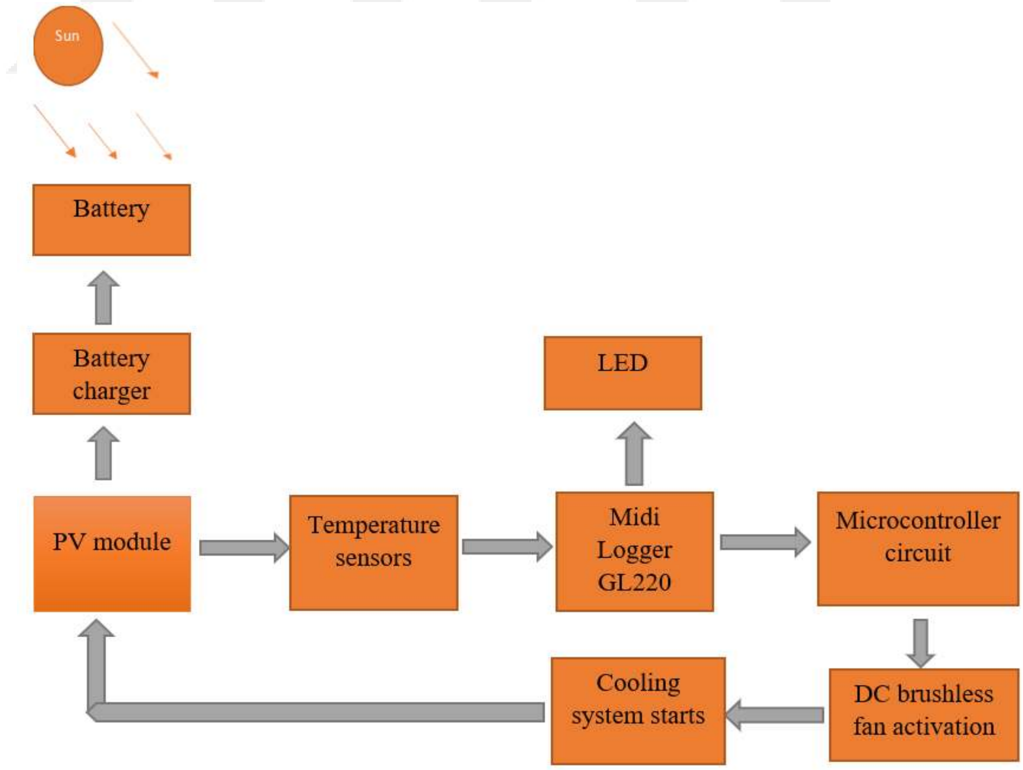

Figure 4.1 DC brushless fan diagram

The diagram above in Figure 4.1 illustrates the DC cooling system driven by the DC brushless fan. It begins with the PV module. The PV module absorbs solar irradiation coming from the sun and that way produces 24 V DC. Firstly, the charging process begins ; the 24 V DC output voltage of PV module charges the battery. The role of a battery charger is to charge and protect the battery. After the charging process is completed, the DC current goes to AC loads via the inverter. During the supply, if the operational temperature T reaches up to 35 °C or above, the thermocouple temperature sensors detect the problem and send immediatly the analogic data to the circuit of commands. The role of Midi Logger GL220 is to record the data send by the temperature sensors. In the next step, the microcontroller commands the DC brushless fan to ventilate the PV module and begins to cool the system in order to eliminate the effect of rising temperature. One LED can turn to green when the cooling system is activated and has no color when the cooling system is absent.

4.1.2 Equipments of DC brushless fan cooling system

One of the objective of this paper is to clarify which equipments are used of every cooling methods. Therefore, the equipments used in DC brushless fan cooling method are :

PV module plays an important role in the DC brushless fan cooling system because if there is no PV module, there is no cooling system. It is the crucial element and the behaviour of DC brushless fan will depend on it. PV module plays a role of DC source delivering DC current to the DC brushless fan.

The temperature sensors are also necessary equipments and they are the first step in the mecanism of cooling process. Basically, they are various type of temperature sensors but the most common, most cheaper and with great accuracy are LM 35 shown in Figure 4.2.

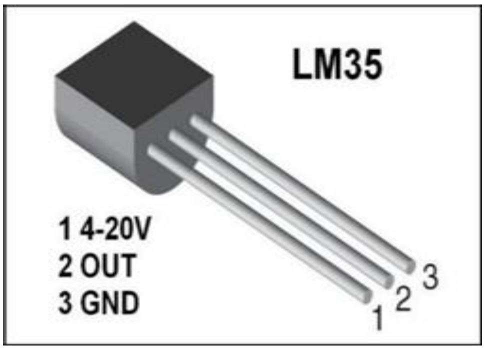

Figure 4.2 LM 35

LM 35 has 3 pins : pin 1 is for voltage supply from 4-20 V from photovoltaic module, pin 2 is for output voltage directly connected to the Midi Logger GL220 and pin 3 is for connection to the ground. In this simple circuit configuration illustrated in Figure 4.3, LM 35 can measure only positive values of temperature. Linear scale factor equals +10 mV/ °C.

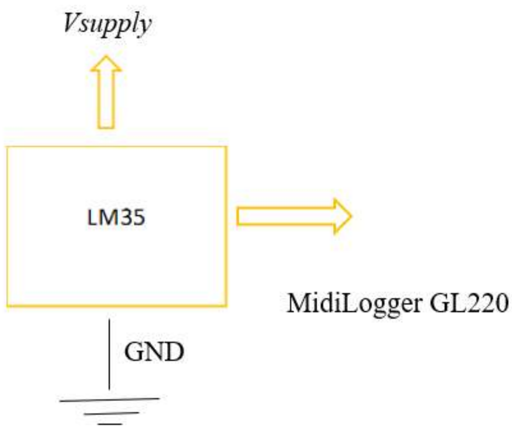

Figure 4.3 Circuit configuration of LM35

Before to jump to measuring the temperature, it is important to clarify what is linear scale factor. It is a formula given with LM 35 characteristics. It is different from one sensor to another along with its capacity. For example, LM 35 has linear scale factor of +10 mV/ °C. It means for a given output increasing 10 mV voltage the corresponding temperature is +1.

The LM 35 provides an analogic signal of output voltage in pin 2 which is proportional to the operational temperature. This analogic signal is connected directly to the analog terminal inputs of the Midi Logger GL220. The first thing to do with LM 35 is to set the level of temperature which should not be overpass. For example 35 °C. As soon as LM 35 dectects the settled temperature, it sends the analogic data to the circuit of command. This analogic data says that the PV module is heating and its efficiency is decreasing, so DC brushless fan should start to blow the PV module. The LM 35 are put in couples in the top and bottom part of the PV module as shown in Figure 4.4.

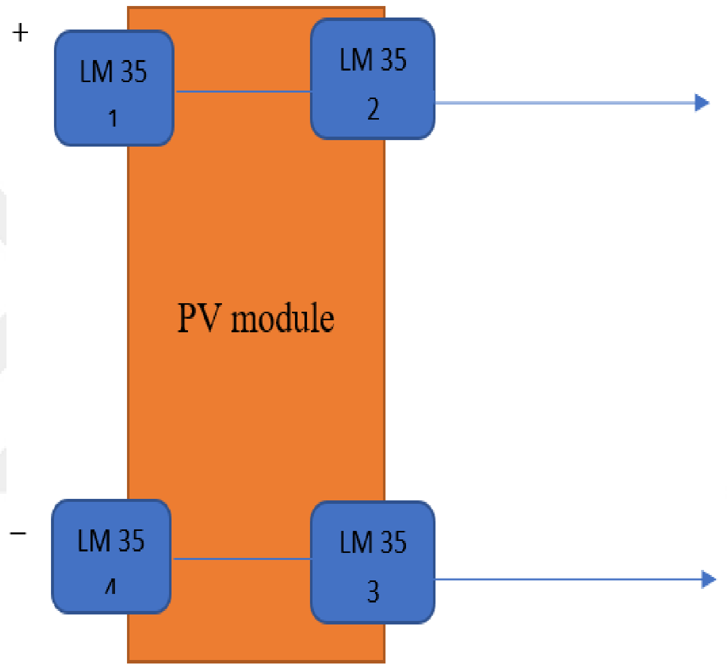

Figure 4.4 Temperature sensors in PV module

The description of the Midi Logger GL220 is presented in Table 4.1.

Table 4.1 Description of the Midi Logger GL220

FEATURES	DESCRIPTIONS
Name	Midi Logger GL220
Weight	520 g
Dimension	194 × 117 × 42
Sampling interval	From 10 ms to 1 hour ; but for the temperature input sampling interval should be more than 50 ms
Monitor	- To display temperature values while running - If necessary to display other inputs - To set up settings
Control panel keys	Control and command circuit
Power switch	To switch ON / OFF
Operation status LED	For POWER, START and CHARGE
AC adapter	To supply power to AC loads
External terminals	- A connection to transfer data temperature to microcontroller circuit - Output to LED
USB memory feature	2 GB internal memory to save the data temperature
Number of analog input terminals	10
Analog input terminals	Temperature sensors send the data temperature to channel 1
Battery	B517, 2200 mAh

The analogic data of temperature is transfered to the Midi Logger GL220. It is an essential equipment because it permits to save the data. One of the advantages of the Midi Logger GL220 is to capture, visualize and read the data in real-time on the screen for every ten minutes. It has 10 channels for analogic inputs for instance terminal 1 is used for temperature input and terminal 2 is used for the voltage input. It has a control and command circuit to press next to the monitor to start, stop or change manually the cooling conditions for the DC brushless fan. It is equipped of the internal memory of 2 GB so that the captured data can be recorded. The users can save the data temperature in Midi Logger GL220, and import it and put it in new file on his computer. This material can supply both DC and AC power to the loads. The circuit of control and command is composed of the Midi Logger GL220 and microcontroller. Thus, the output of Midi Logger GL220 is connected to the microcontroller. Figure 4.5 shows all the features of this equipment.

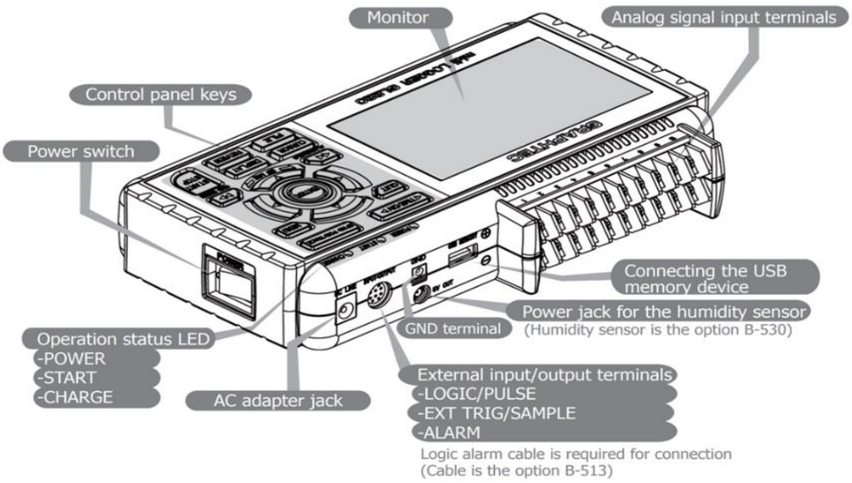

Figure 4.5 Description of Midi Logger GL220

Connection to the analog terminal input is represented in Figure 4.6 below :

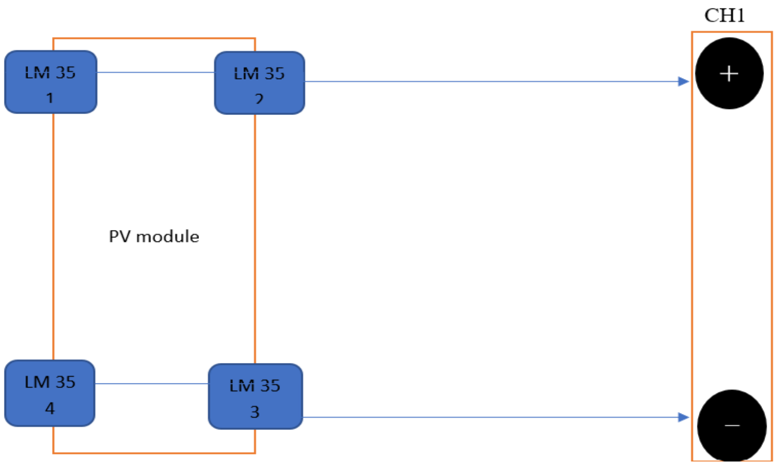

Figure 4.6 Connection to the Midi Logger GL220

Peripheral Interface Controller (PIC) microcontroller is an electronic device that is used for many purposes and applications. In this system, its role is only to turn ON or OFF the DC brushless fan automatically. PIC18 microcontroller plays a control and command circuit in this PV module cooling process. Table 4.2 introduces a large family of PIC18 microcontroller such as :

Table 4.2 Family of PIC18 microcontroller

TYPES OF PIC18 FAMILY	MODEL 1	MODEL 2	MODEL 3	MODEL 4
PIC18 F F for flah memory	PIC18F2455	PIC18F2550	PIC18F4455	PIC18F4550
PIC18 C C for Electrically erasable programmable read-only memory	PIC18C2455	PIC18C2550	PIC18C4455	PIC18C4550
PIC18 LF L indicates low voltage operation and F stands for flash	PIC18LF2455	PIC18LF2550	PIC18LF4455	PIC18LF4550

The users have a large choice to use one of these microcontrollers listed above in their system. In this paper, not only for its 13 channels analog digital converter and also come along with brand new features PIC18F4550 is used. Fabricated by Microchip with nano-watt technology, PIC18F4550 microcontroller has 35 programmable pins . it is widely used in control domain. To illustrate that, an example of PIC18F4550 microcontroller is shown in Figure 4.7.

Figure 4.7 PIC18F4550 microcontroller with 40 pins

If the user does not find the PIC18F4550 microcontroller to run his cooling technique a PIC18F4455 is suggested as a solution to cool down the PV module. The Plastic dual in-line package of PIC18F4550 microcontroller is shown in Figure 4.8.

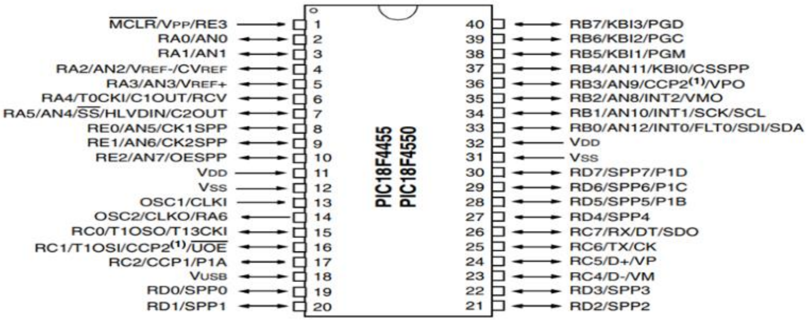

Figure 4.8 PIC18F4455 the replacement of the PIC18F4550

The description of PIC18F4550 microcontroller is presented in Table 4.3.

Table 4.3 Features of PIC18F4550 microcontroller

FEATURES	FUNCTIONS	PINS
PIC18F4550 microcontroller	To turn ON or OFF the DC brushless fan	
Central processing unit	8-bit internal operations	
Flash memory	32 K (bytes)	

Table 4.3 Features of PIC18F4550 microcontroller (Continued)

Static random access memory	2048 bytes	
Number of pins	40	
Capture input/Compare output/Pulse-width modulation	1	Pin 16, pin 17, pin 30 and pin 33
Enhanced universal synchronous asynchronous receiver transmitter	1	Pin 25 and pin 26
Streaming parallel port data	Yes	Pin 19, pin 20, pin 21 and pin 22
Analog to digital converters (ADC)	13 channels	
ADC comparators	2	Pin 4 and pin 7
Timers	4	Pin 6, pin 15 and pin 16
External oscillator	Yes	Pin 13 and pin 14
USB interface	Yes	Pin 6, pin 16, pin 24, pin 35 and pin 36

Before talking about the brushless DC fan, it is essential to talk about the DC brushless motor. The brushless DC motor (BLDC) are powerful, reliable device, very efficient and operate with less energy loss. Also called synchronous motor, they are commonly used in the cooling system. Like any other motor, the BLDC motor are consisted of two parts : the rotor which rotates and the winding stator which is fixed and do not move. The input voltage value or the current provided to these windings control the speed and the torque of the synchronous motor. Figure 4.9 shows brushless DC motor.

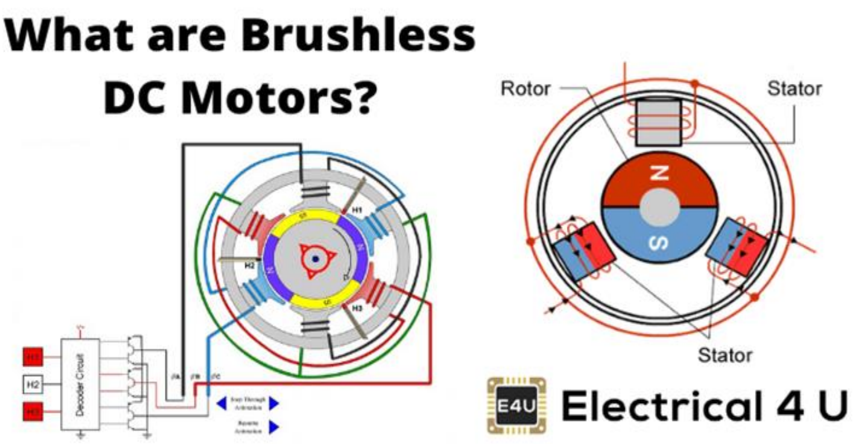

Figure 4.9 DC brushless motor

Before we talk about the working function of the brushless DC motor, it is important to mention other components such as : the permanents magnets on the rotor, armature, shaft and electromagnets. To start with, when the power is turned ON, the electromagnetic in the stator creates the magnetic fields which start to rotate the armature and then the rotor. This is the working principle for both DC brushed and DC brushless motor. The difference is that in the DC brushless motor, there are no brushes. To replace the function of those commutators, it is necessary to use transistor with great power to activate the electromagnets in the stator to maintain and keep the rotation of the armature, and thus the rotation of the shaft. Components of the DC brushless motor is shown in Figure 4.10.

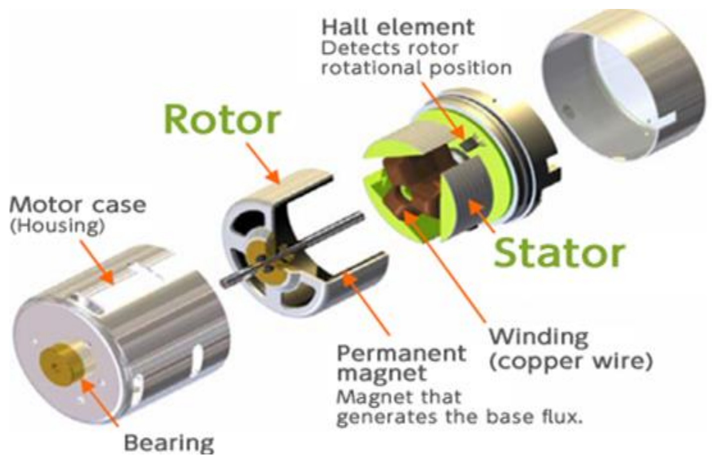

Figure 4.10 Components of the BLDC motor

There are mainly two differents types of technology of the DC brushless motor :

- Inrunner design : in this design the rotor is placed in the core of the motor, which means the rotor is inside the stator. This inrunner design of the motor produces a big amount of torque because the heat is dissiped very easily.
- Outrunner design : in this design the rotor is placed outside the winding of the stator, which means the rotor surround the stator. This outrunner design does not let the heat to be dissiped easily from the motor. So, the produced amount of torque is low.

Some DC brushless fan are equipped of the sensor motor known as half effect sensor which helps to detect the position of the magnets. It is a matter of individual financial support. Figure 4.11 shows a DC brushless fan.

Figure 4.11 DC brushless fan

DC brushless fan is located at the back of PV module to ventilate and hence to cool down the solar panel. When the LM 35 sensors detect the rising temperature, it sends analogic signal to PIC18F4550 microcontroller that will turn ON the DC brushless fan to start the cooling process of the PV module. This fan can work at 12 V, 24 V and 48 V. But when the voltage is dropped the revolutions per minute is also dropped. Thus, the cooling behaviour of the fan decrease considerably. So, the user must choose an efficient and stable fan that cool down the solar panel even the power fluctuation occurs. After PIC18F4550 microcontroller turned ON the DC brushless fan, the temperature begin to decrease until it became under the settled temperature. At that point, LM 35 sensors sends an analogic signal to PIC18F4550 microcontroller to turn OFF the DC brushless fan, and hence to stop the cooling process. This is happening evey ten minutes. This system is an intelligent cooling method because it runs automatically.

4.2 DC Water Pump Cooling System

In this section, a process of a pump cooling technique of the PV module is presented.

4.2.1 DC water pump diagram

To protect PV module from efficiency drop a cooling technique driven by a DC water pump is presented in Figure 4.12.

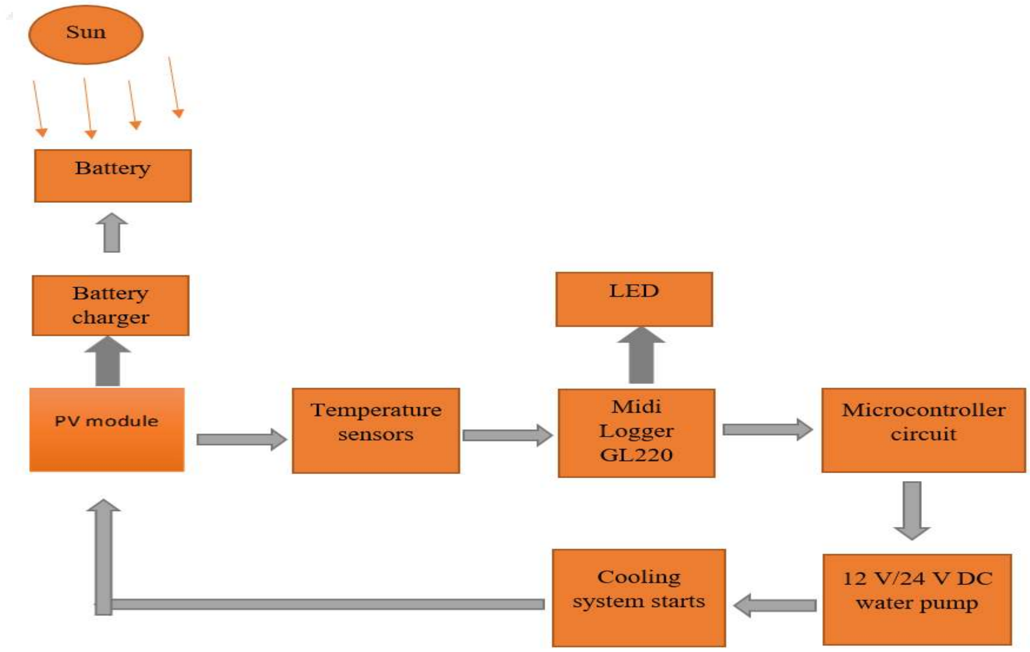

Figure 4.12 DC water pump diagram

The basic function of the DC water pump diagram is as same as the DC brushless fan. From the electricity production by the PV module to the microcontroller step, the mecanism does not change at all. As you can see the diagram above, the users can use the same materials of the DC brushless fan cooling system. The only difference is that DC brushless fan is changed by the DC water pump. The 12 V DC output voltage of PV module supplied directly the DC water pump and thus the cooling system to cool down the temperature of the PV module starts.

4.2.2 Equipments of the DC water pump cooling system

One of the objective of this paper is to clarify which equipments are used in the any cooling methods. So, the equipments used in DC water pump cooling system are :

The users can utilize the same equipments of the DC brushless fan listed above from page 24. The only difference in this system is that DC water pump is used to spray water in front side of the PV module to drop the arised temperature. DC water pump receives water to the inlet and pump it from the outlet to the surface of the PV module. A layer of glass should be built on the surface of the PV module to allow water to run off. DC water pump will pump water until the temperature is dropped under the desired temperature. The DC water pump works without making noise. Working function of the DC water pump is illustrated in Figure 4.13.

Figure 4.13 12 V DC water pump

The DC water pump is located in front of the PV module to spray water. One layer of glass must be contructed in the top side of PV module. Overview of DC water pump working system is shown in Figure 4.14.

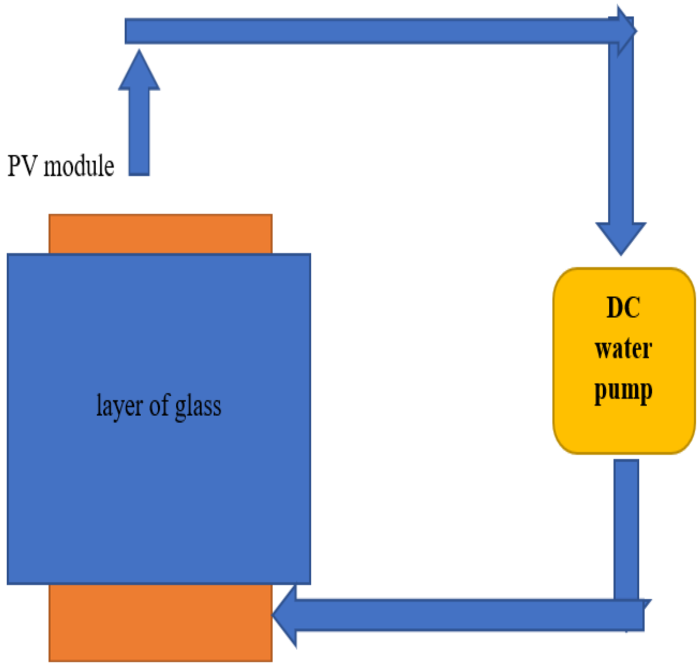

Figure 4.14 Layer of glass

Table 4.4 describes the main features of the DC water pump (Irwan *et al.* 2015).

Table 4.4 Features of the DC water pump (Irwan *et al.* 2015)

FEATURES	**FUNCTIONS**
DC water pump	To spray water on the surface of the PV module
Voltage input	12 V DC / 24 V DC
Pumping quantity	500 litres per hour
Pump cable	Sleeving and heatshrink
Price	34.95 $

4.2.3 Comparison of the DC brushless fan and DC water pump

The average ambient temperature during the test was 27 °C and average solar irradiation level was 3800 Wh/m^2. The authors constructed 2 systems : 1 DC brushless fan cooling system and 1 DC water pump cooling system. They used 130 W peak power polycristalline Sharp Solar Module ND-130T1J of V_{oc} = 22 V and I_{sc} = 8,09 A connected with 84 W DC lamp (Irwan *et al.* 2015). Table 4.5 shows the results observed in terms of efficiency.

Table 4.5 Comparison of efficiency between the DC brushless fan and DC water pump (Irwan *et al.* 2015)

PARAMETERS	DC BRUSLESS FAN	DC WATER PUMP
Temperature drop	6.1 °C	6.36 °C
Outpout voltage	3.47 %	3.52 %
Output current	29.55 %	36.27 %
Output power	32.23 %	38.98 %

From the results above, it is concluded that DC water pump cooling technique is more efficient than the DC brushless fan.

4.3 Ground Coupled Central Panel Cooling System

To prevent the rise of temperature to affect the efficiency of the PV module ground coupled central cooling method is presented in this part.

4.3.1 Ground coupled central panel

Several methods of solar panel cooling systems have been developed in the past, the aim of the cooling system is to reduce the temperature in order to increase the efficiency of the PV module. It is noticed that for every 1 °C increasing temperature, the efficiency is decreased by 0.5% (Sahay *et al.* 2015). DC brushless fan and DC water pump performance provide great cooling system but they are expensive for huge central of hundreds of solar panels. Indeed, the researchers have developed a new cooling system called " ground coupled central panel cooling system (GCCP-CS)" which is a low-cost approach for such a grid. It is a financialy suitable for central panel and it is already operational at the Energy Park of Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, India.

4.3.2 Operation of ground coupled central panel cooling system

To protect PV module from efficiency drop a cooling technique driven by a heat exchanger is presented in this part. Convection is a form of heat transfer that occurs everywhere and at any time. The basic function of the convection is related about density of the air ; the warm air is less dense than the cool air so naturally the warm air is transferred above and the cool air goes down. Figure 4.15 shows the convection.

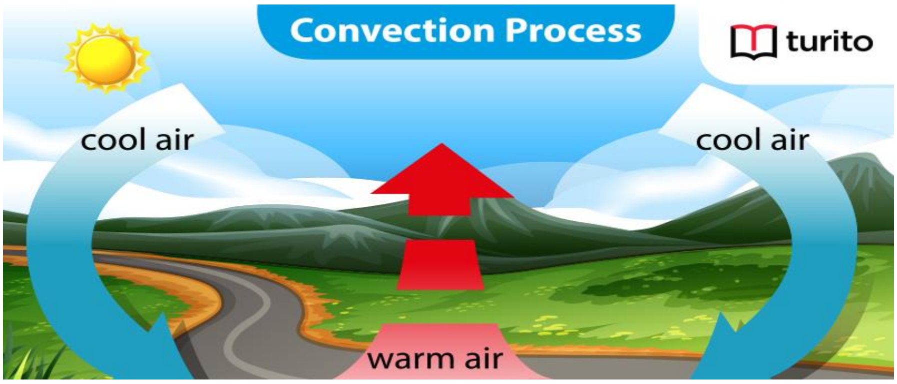

Figure 4.15 Convection

Figure 4.16 shows the overview of the GC-CPCS system (Sahay *et al.* 2015).

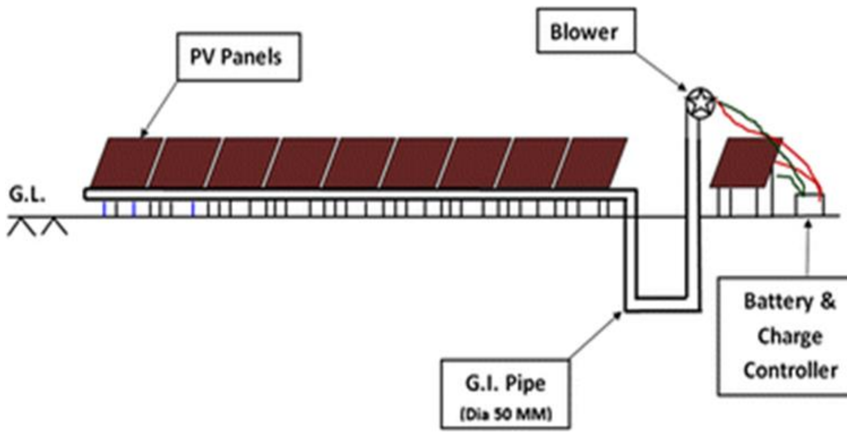

Figure 4.16 Ground coupled central panel cooling system (Sahay *et al.* 2015)

One of the objective of this paper is to clarify which equipments are used in any cooling methods. Therefore, the equipments used in the GC-CPCS are :

The blower that forces the ambient air to enter the pipe. It creates a forced convection of the air. The blower moves the air into the entrance pipe of the underground heat exchanger. This blower is designed and supplied by a separate PV modules. For example 9 solar panels of 100 W can supply one blower.

To cool down the PV module, the blower forces the dry warm ambient air to enter the pipe. It is an entry of a ground-coupled heat exchanger. The pipe takes the warm air down under the ground where its temperature and pressure are dropped. That is the reason why this system is called ground coupled. The pipes of the ground-coupled heat exchanger should be in parallel layers in order not to make any disruption or intermixing of the pipes. The parallel and horizontale form of the pipes are chosen so that the velocity of the fluids should be constant. To cool the warm air, it uses the Earth’s relatively constant temperature to dissipate the heat from the warm air. Therefore, the warm air becomes cooler.

Nozzles are placed at the rear surface of the PV module between the pipe and fiber sheet. Approximately, there are 20 nozzles in each solar panel. The objectif of the nozzles are to let the air comes out of the pipe. That way the pre-cooled air in the ground-coupled heat exchanger is distributed to every PV panels. The second objectif of the nozzles are to establish the streamlines of the air in the desired directions. Nozzles are shown in Figure 4.17 (Sahay *et al.* 2015).

Fiber sheet is placed at the rear surface of the PV module. It is constructed below the nozzles. The main objectifs of the fiber sheet are firstly to establish the streamlines of the pre-cooled air and secondly not to let the pre-cooled air get dissipated once it gets outside of the nozzles. Fiber sheet are shown in Figure 4.17 (Sahay *et al.* 2015).

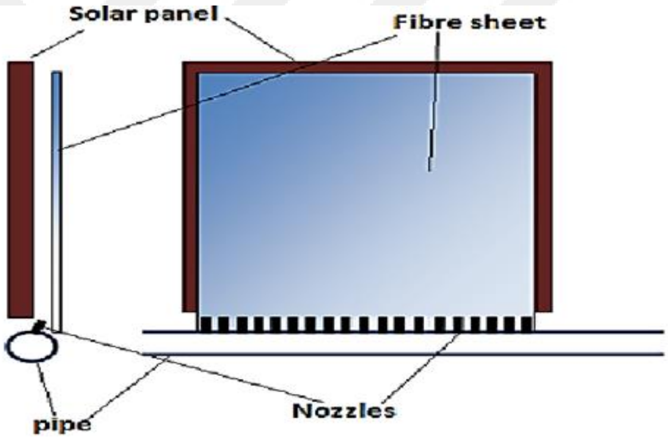

Figure 4.17 Fibre sheet, nozzles and pipes (Sahay *et al.* 2015)

4.3.3 Efficiency of ground coupled central panel cooling system

The role of the blower is to switch START or STOP the GC-CPCS. In other words, when the blower is ON the cooling system is started. The authors installed the GC-CPCS on a 9 PV modules of 100 W each, and for every 10 minutes during the running of the test they follow this procedure : time - on/off of the blower – temperature of air out of nozzles – current and voltage – efficiency (Sahay *et al.* 2015).

During the test, they concluded that : the efficiency depends on the temperature on the surface of the PV module. When the blower is on and the GC-CPCS is started, the efficiency of the PV module is increasing (Sahay *et al.* 2015).

4.4 Floating Tracking Cooling Concentrating System

To prevent the rise of temperature to affect the efficiency of the PV module floating tracking cooling concentrating FTCC method is presented in this section.

4.4.1 FTCC

The FTCC system is one of the course of action to produce electricity from PV panels. It is equipped with some features such as : a tracking system, a cooling system of the panels by water sprinklers and also a concentrating system composed by reflectors which concentrate the solar radiations to increase the production. The FTCC technology is a floating PV modules which are built on a platform (circular form or rectangular form) that is supported by a polyethylenes tubes.

In general, PV plants encounters limitations such as thermal drift (temperature influence), the availability of lands that is not occupied by buildings and the expensive price of the tracking system. The FTCC technology brings solutions for these problems with :

- Water veil generated by water sprinklers decreases temperature on the surface of the PV modules. Water veil and reflectors both contribute to increase annual efficiency more than 15% (Cazzaniga *et al.* 2012).
- The unavailability of lands can be solved by planting FTCC technology in artificial basins and small lake (Cazzaniga *et al.* 2012).
- The platform provides a perfect one-axis tracking system for the reflectors to concentrate more solar radiations on the panels (Cazzaniga *et al.* 2012).

The FTCC system has an impressive and competent sensing and tracking system which takes into consideration the location of the sun and reflectors. However, this type of system encounters shadows problems and lack of homogeneity of solar irradiation on the surface of PV module.

4.4.2 The platform system

The platform which supports the PV modules is made from rectangular or circular form. The platform is constructed on rafts which float on the surface of lake or artificial basins. There is a mooring system fixed at the center of the system which allows the platform to rotate. Two electric outboard motors facilitate the rotation of the platform. Figure 4.18 illustrates the platform system (Cazzaniga *et al.* 2012).

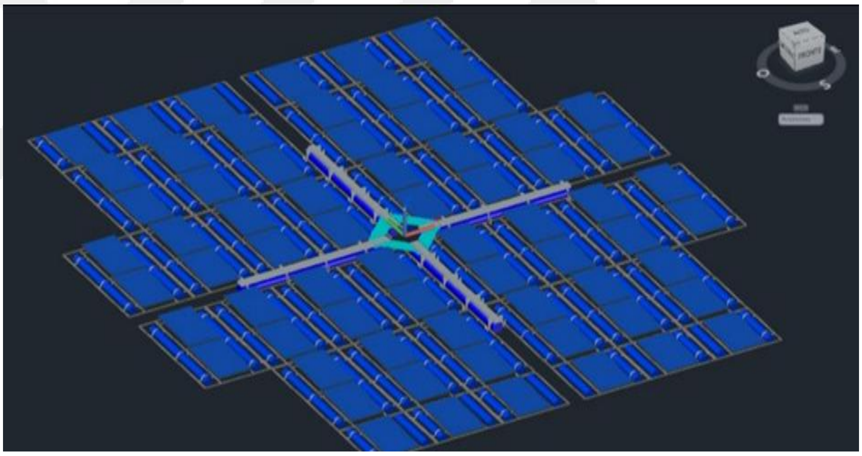

Figure 4.18 Platform of the FTCC system (Cazzaniga *et al.* 2012)

An example of the electric outboard motor used to facilitate the rotation of the platform is shown in Figure 4.19.

Figure 4.19 Electric outboard motor

4.4.3 Configuration of the floating tracking cooling concentrating system

There are various ways of organization of the FTCC system :

This is a first solution. As mention above, the FTCC system encounters the unevenness of solar irradiation on the solar cells and shadow issues. Therefore, to overcome this irradiation issue PV panels should be equipped of reflectors in a particular way : this is the first solution. The settings of the FTCC system in the first solution are :

- PV modules should be tilted of an optimal angle of 38° (Cazzaniga *et al.* 2012).
- The platform in which PV modules are inclined of 38° should be oriented in such a way to concentrate more solar radiations on the PV modules (Cazzaniga *et al.* 2012).
- A large space of catwalk should be left between PV modules and reflectors (Cazzaniga *et al.* 2012).

First solution is shown in Figure 4.20 (Cazzaniga *et al.* 2012).

Figure 4.20 First solution system which is built in Suvereto, Italy (Cazzaniga *et al.* 2012)

A second solution is proposed to overcome the shadows problem and a lack of homogeneity of solar irradiation issue on solar cells. The settings of the FTCC system in the second system solution are :

- PV modules are tilted by a small angle of 2° just enough to be in alignment with the sun radiations and also to produce water veil (Cazzaniga *et al.* 2012).
- Reflectors are placed by side of PV modules of 2° in an inverted V configuration. Angle of reflectors is important for the geometrical concentration. For example, 2° of reflector angle is suitable for an efficient concentration of solar irradiation on the solar cells (Cazzaniga *et al.* 2012).

The gain in efficiency of the concentration system taking into consideration panels cooling can reach between 60% and 70% depending on the location site and weather conditions (Cazzaniga *et al.* 2012). Seconde solution is shown in Figure 4.21 (Cazzaniga *et al.* 2012).

Figure 4.21 Second solution system which is built in Colignola-Pisa, Italy (Cazzaniga *et al.* 2012)

In the third solution, instead of reflectors, a parabolic mirror is used to concentrate the solar radiations. A parabolic mirror is very efficient to collect solar flux. In this case cooling system by water is proceed on the rear of the PV cells. This third solution is still in progress.

4.4.4 Refrective index

In physics, refrective index is the changing of angle when the sunlight travel one material to another. This concept explains how fast the sunlight can travel from one medium to another. It is calculated through this formula (4.1) below ;

$$n = \frac{\sin i_a}{\sin r} \tag{4.1}$$

Equation (4.1) helps us to define the refrective index n, incident angle i_a and r represents refracted angle. In the presence of reflectors, there is a better solar radiations capture through a better refraction index.

4.4.5 FTCC tracking system

The tracking system of FTCC technology is composed of :

a) Electronic guidance system (EGS). The purpose of the EGS is to find maximum radiations zone. To achieve that, the EGS is consisted of 3 sections as shown in Figure 4.22:

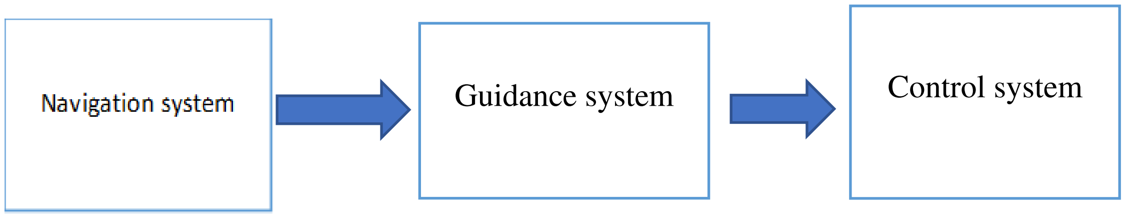

Figure 4.22 Tracking system of FTCC

b) Two electric outboard motors located both at the edge of the platform are used to power and to steer the platform.
c) A fixed mooring post located at the center which facilitates the rotation of the platform through the chains.
d) Another mooring post that protects the cables from twisting. It also permits the platform to turn to a certain angle.

The navigation system calculates the current solar irradiation level of the zone from the sensor data. Then, the guidance system compares the solar irradiation level with another location, and commands the instructions to the control system. The control system changes the position and orientation of the object to the zone where there is a maximum radiations surface. To achieve that, it switches on/off the two electric outboard motors.

4.4.6 Cooling effect

FTCC system provides a solution for the influence of temperature that leads to the decrease of outpout power. Water sprinklers or irrigators create water veil. This water veil helps the gain in the energy conversion thus the increase in efficiency. This water veil flows on the layer of glass located on the top surface of PV module. Indeed, the low water refraction index (n = 1.33) helps the correction of thermal drift. The correction of thermal drift is the reason of the increase of output power.

The authors have also indicated that the increase in yield of more than 5% of the panel is due to the cooling effect of water veil generated by water sprinklers. This efficiency can reach up to 14%. The best configuration of the FTCC system is : Panel angle of 35° + reflectors + cooling system. The researchers noticed that the cooling effect through the water veil is remarkably efficient in the presence of reflectors in the system (Cazzaniga *et al.* 2012).

4.4.7 Albedo effect

The Albedo effect is the capability of every surfaces to reflect light coming from the sun. Some areas in the Earth's surface are covered with snow and ice (North Pole) : these zones are qualified as high Albedo. It means that light coloured areas reflect more sunlight into the atmosphere. Other areas like the ground and oceans are darker. So, they absorb more and reflect less sunlight into the atmosphere : these zones are known as low Albedo.

The researchers conducted an experience comparing data between the FTCC system and panel tilted 35° on the ground which occured in Colignola, Italy. They found that the results in output power are approximately the same, which means that the theory of oceans absorb more sunlight so that FTCC system will gain in efficiency in comparison with panels planted on ground is false. Thus, the Albedo positive effects on the artificial basins or lake are disproved (Cazzaniga *et al.* 2012).

4.4.8 Hydroelectric system

The FTCC technology can be mounted in the hydroelectric basins equipped with pumping facilities. There are two reservoir devices : the upper reservoir can be utilised to store energy produced by FTCC technology in the form of water, and it will be used if there is more energy demand : it is like a discharge. The lower reservoir can be used to charge the upper reservoir (Cazzaniga *et al.* 2012).

4.5 Hybrid Photovoltaic/Thermal System Using Zn-H_2O Nanofluid Cooling Technique

To protect PV module from the effect of the rise of temperature hybrid photovoltaic/thermal system using Zn-H_2O nanofluid cooling method is presented in this part. Zinc nanopowder is mixed with ionized water to use as a working fluid.

4.5.1 Hybrid photovoltaic system

Especially in the summer, people are suffering from power cuts. This problem of power cuts is a result of a high demand of power compared to the production. In order to overcome this issue, a concept of " hybrid photovoltaic system" is developed. Hybrid solar photovoltaic system is simply a solar photovoltaic system connected to the collector which produces thermal energy.

4.5.2 Introduction to hybrid photovoltaic/thermal system using Zn-H_2O nanofluid cooling technique

In this type of system, cooling technique can be proceed using Zn-H_2O nanofluid. The main problem in this system is the heat accumulated in PV cells. Zn-H_2O is used to extract heat from PV cells in order to decrease the temperature and cool down the PV modules. Zn nanoparticles are used to enhance thermal conductivity, which means to improve heat transfer. The heated working fluid is replaced by fresh new one by convection and that way the cycle of cooling technique continues. The heated Zn-H_2O can be used for others applications.

4.5.3 Description of the cooling technique of the photovoltaic/thermal system

This system below in Figure 4.23 is built in order to pump water to the tank (Hussein *et al.* 2017).

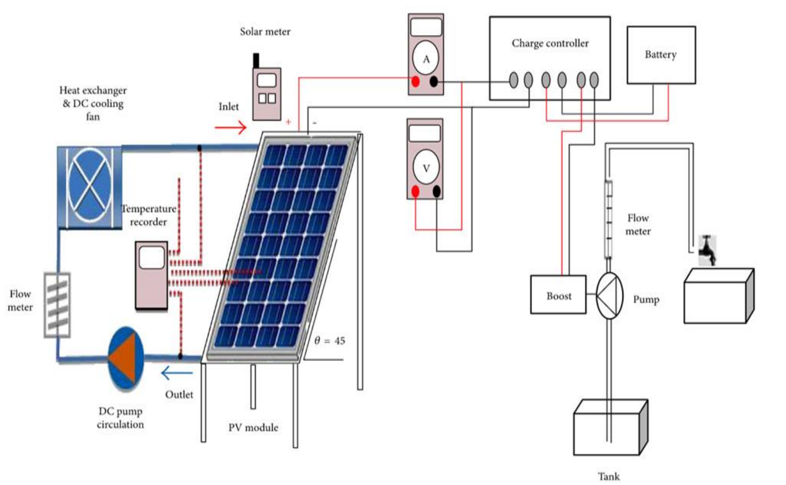

Figure 4.23 Photovoltaic/thermal system (Hussein *et al.* 2017)

In the above system, SR100S solar panel of output power of P = 100 W_p and I_{sc} = 5.8 A at standart test conditions is used to produce electricity (Hussein *et al.* 2017). Because that Iraq is a hot country and PV panel works under a hot weather, the efficiency conversion starts to decrease. PV panel needs to be cooled. A solar meter is placed at the top part of the PV module to show the variation in solar irradiation level. One of the major components in this design is the collector. The cooling technique starts in the collector which is shown in Figure 4.24 (Hussein *et al.* 2017).

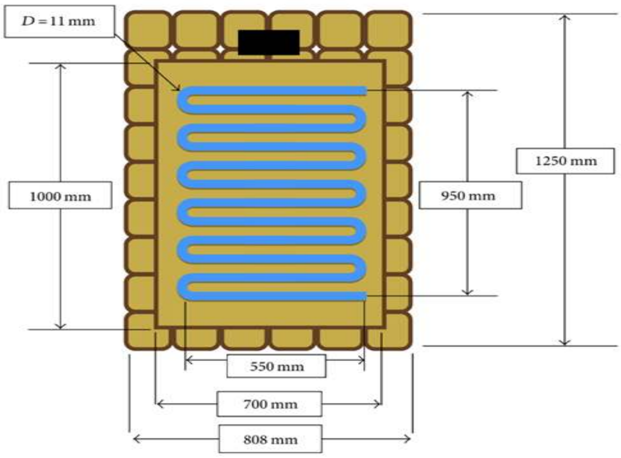

Figure 4.24 Dimensions of the collector (Hussein *et al.* 2017)

The copper pipes have 11 mm of diameter and 1 mm of thickness (Hussein *et al.* 2017). The objective of the collector is to transfer heat from the PV cells to the working fluid Zn-H_2O. The collector is built and attached at the back side of PV panel. It has a form of serpentine. The collector is contructed of copper pipes welded on the copper sheet. The collector is made of copper because it has a great heat transfer capacity. Thermal sink is used to increase this heat transfer. The inlet of the collector is the entry for cold Zn-H_2O nanofluids and the outlet is the exit for hot Zn-H_2O nanofluids. Cold working fluid enters the collector and absorb the heat from the PV surface. Thus, as a result the PV solar panel is cooled. The output hot Zn-H_2O can be used for other purposes.

The hot Zn-H_2O nanofluids enter DC pump and circulates to the radiator with a fan. Flow meter is placed at the rear surface of the PV module to measure the mass flow rate of the working fluid. Hot Zn-H_2O nanofluids enter heat exchanger and DC cooling fan where they are cooled. At that point, Zn-H_2O nanofluids are freshly cold and are ready to absorb heat from PV surface for the second time. This cooling cycle continues whenever PV solar panel decreases efficiency conversion. Multimeter is used to take manually the values of maximum current I_m, maximum voltage V_m, open-circuit voltage V_{oc} and short-circuit current I_{sc}. Thermocouples are linked to the Lutron BTM-4208 SD to indicate the temperature of solar panel, temperature of Zn-H_2O working fluid and ambient temperature.

4.5.4 Zn-H_2O nanofluids

As mentioned above, the working fluid used in this work is Zn-H_2O : Zn nanopowder is mixed with ionized water. Zn-H_2O nanofluids have a physical properties such as density, viscosity, specific heat and thermal conductivity. Zn has a thermal conductivity of 112.2 W/m. k and water has thermal conductivity of 0.596 W/m. k. The use of Zn metal increases more electrical efficiency due to that Zn has a huge thermal conductivity in comparison to the water. These physical properties depend on concentration ratio of Zn nanoparticles. High temperature has a huge impact on these physical properties. Increasing temperature of the Zn-H_2O working fluid provides the increase of thermal conductivity that leads to the increase of absorbed heat from PV surface (Hussein *et al.* 2017).

4.5.5 Advantages of Zn-H_2O nanofluid

They can pass easily through pipes and pumps because they are very small, they can directly and efficiently absorb heat from PV surface, nanofluids are selective because they absorb a certain solar irradiations, they provide heat transfer improvement and modifying the size of the nanoparticles can provide the improvement of the absorption efficiency (Hussein *et al.* 2017).

4.5.6 Electrical and thermal equations

Electrical efficiency equation is obtained by using this below formula ;

$$\eta_0 = \frac{V_m \times I_m}{S \times A} \tag{4.2}$$

$$\eta_{elec} = \eta_0 \times [1 - \beta \times (T_{co} - T_0)] \tag{4.3}$$

Where η_o is the nominal electrical efficiency at standard condition, V_m is the voltage at maximum point, I_m is the current at maximum point, A is the PV module area, β is the silicon cell coefficient (β = 0.0045 °C $^{-1}$), T_{co} is temperature of Zn-H_2O in the collector, T_o is temperature of standard condition and η_{elec} is the electrical efficiency.

Thermal efficiency equation is determined by using this below formula ;

$$\eta_{th} = \frac{m \times C_p \times (T_0 - T_i)}{A_c \times S} \tag{4.4}$$

Where η_{th} is the thermal efficiency, m is the mass flow rate, C_p is the heat capacity of the working fluid, T_i is the temperature of the working fluid in the inlet of collector and A_c is the area of the collector.

4.5.7 Concentration ratio and flow rate

Concentration ratio of 0.3% of the Zn nanoparticles and at flow rate of 2 L/min configurations provide the best heat transfer ability and cooling performance in the system. Thus, at this configurations PV module produces a maximum voltage and maximum power output which increase water pump output performance in the system, and therefore both thermal and electrical efficiency are in its optimum level. If concentration ratio is increased of 0.3%, density and viscosity property of the Zn-H_2O nanofluid are increased, so PV module temperature is increased and therefore outpout performance of the water pump is decreased. Increasing flow rate leads to a decrease of an output temperature of the collector outlet. The working fluid gets a long time to extract heat from solar panel (Hussein *et al.* 2017).

A flow rate of 2 L/min of Zn-H_2O provides the best heat transfer. At this flow rate, output temperature in outlet is decreased, and more heat is dissipated in the radiator, PV module is cooled and as a result both thermal and electrical efficiency are improved. The authors found out that at 2 L /min flow rate thermal efficiency is improved up to 60% and electrical efficiency is improved up to 7.8% (Hussein *et al.* 2017).

4.6 Pin Fin-Heat Sink Cooling Technique

To protect PV module from the effect of the rise of temperature pin fin-heat sink cooling technique is presented in this section.

4.6.1 Working principle of the pin fin-heat sink

This is an overview of a hybrid photovoltaic solar panel system interconnected with thermoelectric heat sink (PVSP-THS). This below figure shows the process of cooling of the PV solar panel using thermoelectric heat sink. When the sunlights hit the surface of the PV module, it produces electricity. The thermoelectric heat sink is the element that ensures heat is removed from PV module surface. It is built at the back side of PV module. Heat is absorbed from PV module surface and it is rejected outside by the heat sink. Ambient air is used as a cooler fluid. Air flows between the fins by natural or forced convection. Absorbed heat is dissipated in the pin fin-heat sink. In a consequence, the surface temperature of PV module is decreased. PVSP-THS system is shown in Figure 4.26 (Hamzah *et al.* 2021).

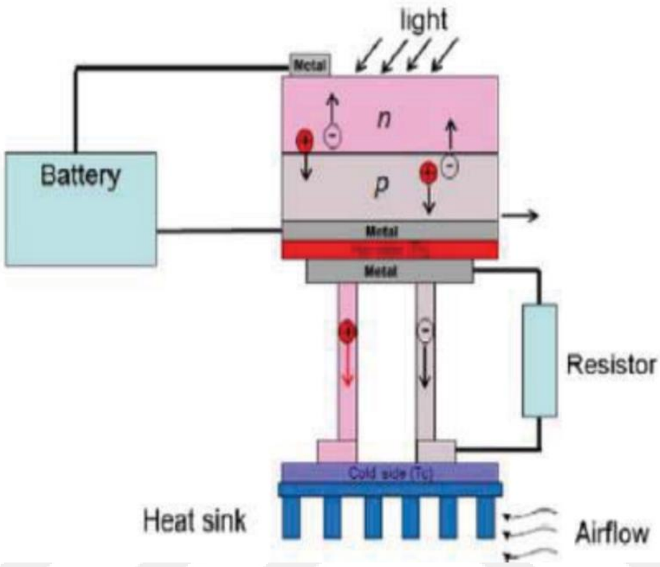

Figure 4.25 Cooling mechanism of the PVSP-THS system (Hamzah *et al.* 2021)

Because of the heat transfer, the temperature distribution increases along the heat sink. The reason for that is that heat is absorbed, transferred and rejected outside. Blue is the cool ambient air and red is the hot air rejected into the environment. Heat transfer is shown in Figure 4.27 (Hamzah *et al.* 2021).

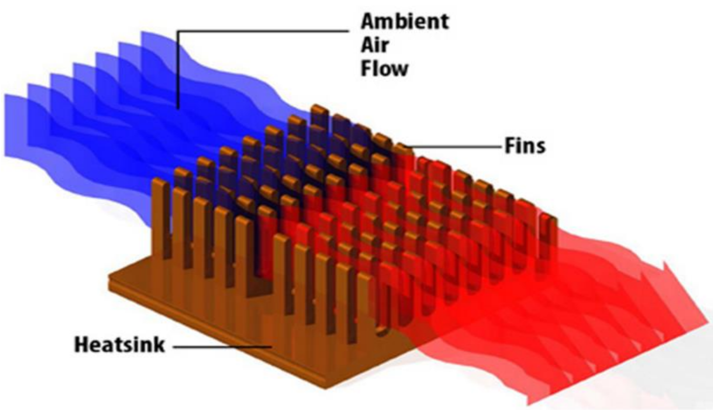

Figure 4.26 Heat transfer in pin fin-heat sink (Hamzah *et al.* 2021)

4.6.2 Geometrical configurations of fins

There are different geometrical configurations of the pins on the heat sink to see which design has the best cooling process on the hybrid PVSP-THS. The authors set an experiment under Iraq weather conditions. The solar irradiation is 500 W/m^2 and ambient temperature is 27 °C during the test. The various geometrical designs are : the original pin fin-heat sink with 128 fins, circular carved model with 257 fins, square carved model with 204 fins and triangular carved model with 262 fins (Hamzah *et al.* 2021). Geometrical configurations of fins are shown in Figure 4.28 (Hamzah *et al.* 2021).

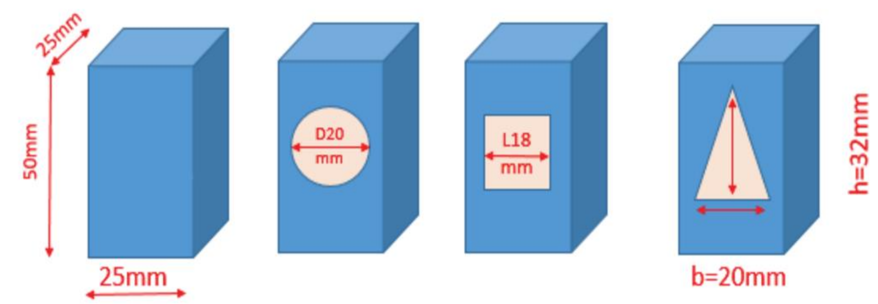

Figure 4.27 Original and different shape of holes on the pin fins (Hamzah *et al.* 2021)

The authors conducted an experimental analysis based on two criteria : the number of perforated fins in the heat sink and which geometrical design has most cooling effect. After the test, the authors concluded that : increasing the number of perforated fins leads to the decrease the gap between the pin fin-heat sink which allows the temperature of PV module to decrease (Hamzah *et al.* 2021).

Distribution of temperature in the PVSP-THS system is shown in Figure 4.29 (Hamzah *et al.* 2021).

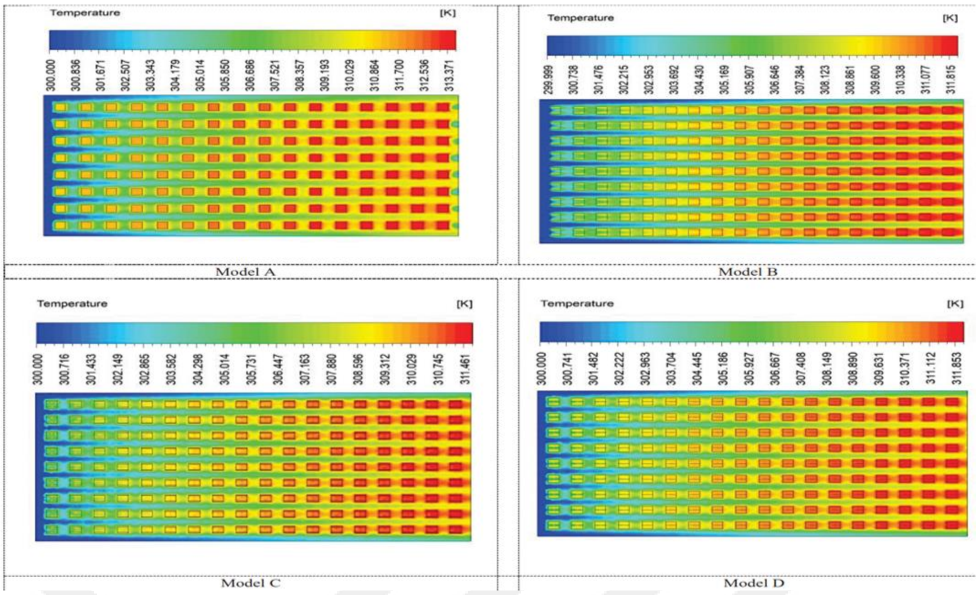

Figure 4.28 Temperature distribution during the heat transfer of the PVSP-THS system (Hamzah *et al.* 2021)

Model A is the original form of the fins, model B is a circular form, module C is a square form and model D is a triangular form. During the heat transfer, the temperature distribution along the heat sink is nearly the same but model B shows a slight better difference.

Air velocity is also discussed in the study, and they concluded that due to a various holes configurations of fins the air velocity changes. In model B, the air velocity can reach up to 0.19 m/sec. Model B has a better heat transfer with a small difference in comparison with other models. When the air velocity is increased, pressure drop follows. So, that is why model B has a higher pressure drop compared to the other fins configurations (Hamzah *et al.* 2021).

4.6.3 Conclusion

In conclusion, in order to decrease the temperature of photovoltaic solar panel, the number of perforated fins should be increased. Thermal resistance interconnects photovoltaic solar panel and thermoelectric heat sink. Decreasing the thermal resistance leads to the increasing of the efficiency of PVSP-THS system. The efficiency of a hybrid PVSP-THS system is more than 14% (Hamzah *et al.* 2021). The perforated fins increase the heat transfer, as a result pin fin-heat sink dissipates and eliminates heat, and in a consequence THS remove heat from PV surface.

4.7 Forced Water Circulation Cooling Technique

To prevent the rise of temperature to affect PV module efficiency forced water circulation cooling technique is presented in this section

4.7.1 Description of the system

The cooling process begins when water flows in the upper surface of solar panel and ends out of the collector. The collector is located not at the rear side of solar panel but outside and apart of the solar panel. To get to the collector, water is pushed by a DC pump. That is why this system is called " forced circulation water". All the cooling mecanism which use thermal collector to decrease the panel temperature is located at the rear surface of solar panel. In this work, the collector is located outside the panel. As a result, the solar radiations can hit in a straight line the collector. Thus, the efficiency of the collector and overall efficiency are improved.

The collector is the device that transforms solar radiations into thermal energy. That is the reason this study is also thermal system. Water is used as a working fluid. Figure 4.30 illustrates the collector (Arefin *et al.* 2020).

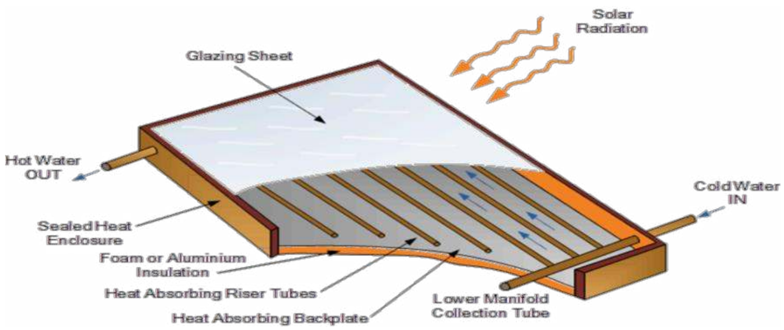

Figure 4.29 Flat-plate collector (Arefin *et al.* 2020)

4.7.2 Balance of energy of water

The first objectif of water is to drop the temperature of PV module. The second objectif is to produce thermal energy in the output of the system. That is the reason this system is hybrid. Heat is transferred to the water. In order to do that, water absorbs heat from both upper surface of PV module and direct solar radiations. At the end of the system, hot water is produced. Balance of energy of water is shown in Figure 4.31 (Arefin *et al.* 2020). As solar radiations hit solar panel and water flows in the upper surface of PV module, the possible energy losses and gains occured in the PV module are :

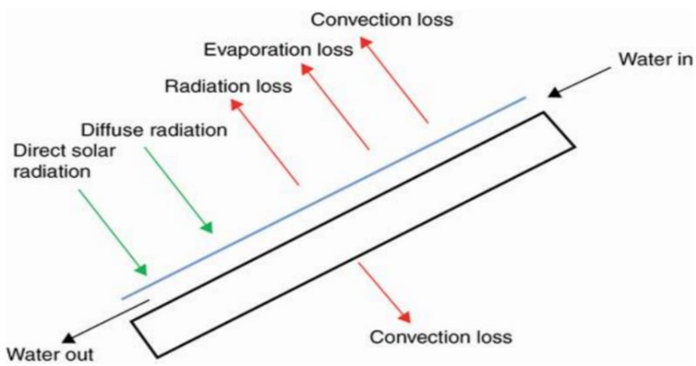

Figure 4.30 Balance of energy of flowing water in the front side of PV module (Arefin *et al.* 2020)

- When sunlights hit PV module, the temperature starts slowly to increase. One part of solar radiations are converted to electrical energy and other part are wasted and dissipated in the air and that causes solar panel to warm. In a result, difference of temperature is created between the upper surface of PV module and ambient air. So, heat transfer is happening when the fresh cool ambient air moves over hot surface of PV module : that is convection loss.
- Water is used to cool down the temperature of PV module. Because of solar radiation energy, PV module is heated and hot. As water flows in the upper surface of PV module, heat causes a little amount of water to be evaporated : that is evaporation loss.

- Sun provides freely solar energy to the PV module. One part of this solar radiations are converted into electrical energy and other part disappear in the environment : that is radiation loss.
- When sun supplies solar radiations, sometimes they encounter new medium, materials or environment, for example clouds ; this solar radiations change direction and then get absorbed by PV module : that is diffuse radiation.
- Direct solar radiations are the one that comes directly from the sun without changing any directions.

4.7.3 Working principle of the system

Everything starts with the water tank that is located next to the PV module. There is water in the tank. Water goes from water tank to the PV panel through the pipes. When the valve is opened, a pump facilitates water circulation from the tank to PV module. The flow meter is used to determine mass flow rate of water entering the PV module. Polyvinlyl chloride (PVC) pipe is located at the top part of the PV module to let water flows from above. As water flows down, it extracts heat from PV module and decrease its temperature. A tray is placed under PV module to collect output water. Once water is collected, it is forced to go to the flat-plate collector where it is heated. The forced circulation of water is achieved by a DC pump. The flat-plate collector is an instrument that produces thermal energy from solar radiations.

Inside the collector, solar radiations are collected in the sealed enclosure and thus heat is produced and trapped inside. Foam or aluminium insulation do not let heat dissipated. Riser tubes and backplate are used to absorb heat. As water flows in the riser tubes, heat is absorbed and transferred to it.

As a result, hot water is obtained and collected at the output of the flat-plate collector. This hot water goes to the storage tank and also can be used for other applications. The whole system is shown in Figure 4.32 (Arefin *et al.* 2020).

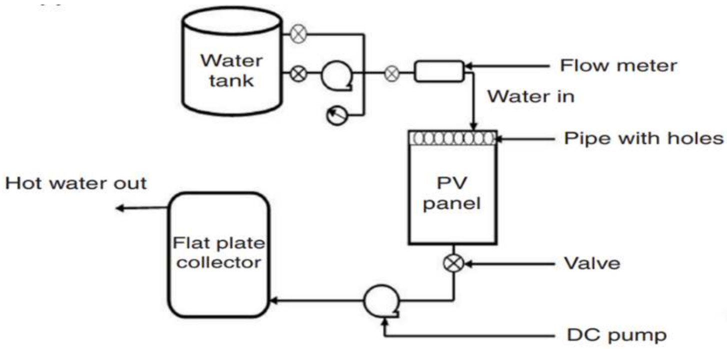

Figure 4.31 Forced water circulation cooling system (Arefin *et al.* 2020)

An example of PVC tube is illustrated in Figure 4.33.

Figure 4.32 Perforated PVC pipe

Water is used in this cooling system because it has the highest specific heat so it can absorbs more heat compared to other liquids with a lower specific heat. When the mass flow rate of water increases, more water falls down from PVC perforated pipe, so more heat is extracted from PV surface and as a result temperature is dropped, PV module is cooled down and efficiency is increased. The authors affirmed that for every 1 °C temperature drop, the efficiency is increased by 0.3% (Arefin *et al.* 2020). The authors also declared that there is a relation between the tilt angle of PV module and efficiency of the panel, and they concluded that in the forced water circulation system PV module should be tilted by an angle of 45° to let the efficiency increased by 0.9% (Arefin *et. al.* 2020). The authors moreover affirmed that, after the experiment, efficiency of the panel is increased between 14.9% and 16.4% respectively for the water mass flow rate of 2 L/min and 3 L/min (Arefin *et al.* 2020). When mass flow rate of water increases the evaporation rate of water decreases. So, more heat is absorbed and panel temperature is decreased and efficiency is increased.

4.7.4 System efficiency

The system efficiency depends both on solar panel efficiency and collector efficiency. The efficiency of the collector depends mainly on the tilt angle of the collector. This factor should be taken into consideration to increase the system efficiency. The authors affirmed that, after the test, an optimum efficiency of the collector is obtained for the tilt angle of the collector of 30° and the mass flow rate of water of 2 L/min (Arefin *et al.* 2020). In this situation, collector efficiency is raised up to 65%. Under all these conditions, the overall efficiency of the system can reach up to 80% (Arefin *et al.* 2020).

4.8 Solar Panel With Water Immersion Cooling Technique

To protect PV module from the effect of the rise of temperature solar panel with water immersion cooling technique is presented in this part.

4.8.1 Description

When the surface of PV cell starts to heat more and hence the cell efficiency begins to decrease, the cooling mecanism should starts. This type of cooling technique is called " immersion cooling technique". Basically, the PV cell is submerged in the water to decrease its temperature. Usually, water is used as an immersed fluid.

4.8.2 Equipments of water immersion cooling technique

The users can use these equipments listed below to achieve the immersion cooling technique (Mehrotra *et al.* 2014) :

- PV panel (for example 2 W polycrystalline solar panel)

- Plastic box filled with water
- Solar module analyser to measure parameters of PV panel
- Solar power meter to measure solar irradiation
- Infrared thermometer to measure the temperature of the surface of the PV panel submerged in the water.
- Mercury thermometer to measure the temperature of water
- Digital thermo hygrometer to measure humidity and ambient temperature of the area.

4.8.3 Results

The authors conducted an experiment to see the performance of a PV panel with water immersion cooling technique. This experiment occured in India under the meteorological conditions of (Mehrotra *et al.* 2014):

- Latitude : 23.16 N
- Longitude : 77.24 E
- Time : from 10 :00 am to 5 :00 pm
- Day : from 18.04.2014 to 23.04.2014.

During the experiment, the authors were taking the electrical parameters and they concluded that (Mehrotra *et al.* 2014):

- The temperature of the surface of the PV panel decreases when the depth of water increases.
- The output voltage V_o depends on solar radiation. So, the output voltage V_o decreases with time. The output voltage does not depend on the depth of water.
- The output power P_o also decreases with time and depth.
- The electrical efficiency also decreases with time. The panel efficiency depends on immersion depth of the panel in water. The maximum electrical efficiency of 17.8 % is obtained for a panel submerged at a depth of 1 cm. After this depth,

the electrical efficiency tends to decrease. This cooling technique can also be applied in the lake or sea.

5. RESULTS AND DISCUSSION

All the PV module cooling techniques developed above demonstrate that a drop of temperature leads automatically of an increase in the output electrical efficiency. From those cooling techniques, the DC water pump and fan cooling techniques are the most commonly used, the ground coupled central panel cooling system is the most suitable for huge plant because of the use of Earth tubes, the floating tracking cooling concentrating system is the best solution for the unavailability of lands for the PV plant by using lakes and basins, the Zn-H_2O nanofluids are the best working fluid to extract heat from PV cells, the pin fin-heat sink is the cost-effective cooling technique and the top-surface forced circulation of water has the highest electrical efficiency improvement in comparison of all the PV panel cooling systems explained above.

Many external factors can influence the electrical performance of the PV module such as solar radiation, tilt angle of the PV module, wiring losses, dust and shading (Karafıl *et al.* 2016). Among these factors humidity, moisture, atmosphere salt, rain, mechanical stress, rain and frost also affect the PV cell efficiency (Kumar and Sarkar 2013).

Temperature is not the only external factor that can impact the efficiency of PV cell, solar radiation also affects the electric production of the PV module. Figure 5.1 and Figure 5.2 shows the influence of solar radiation on the solar cell at different level such as S_1=100 W/m^2, S_2=200 W/m^2, S_3=300 W/m^2. The other parameters remain the same during the whole process for example T=28°C, N_s=100 and N_p=90.

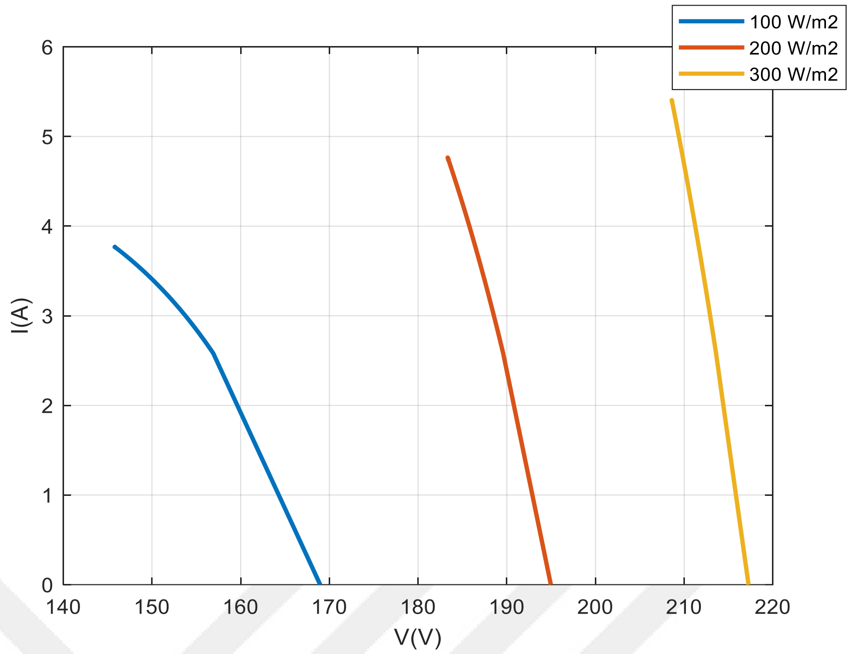

Figure 5.1 *V-I* curves at different solar irradiation level

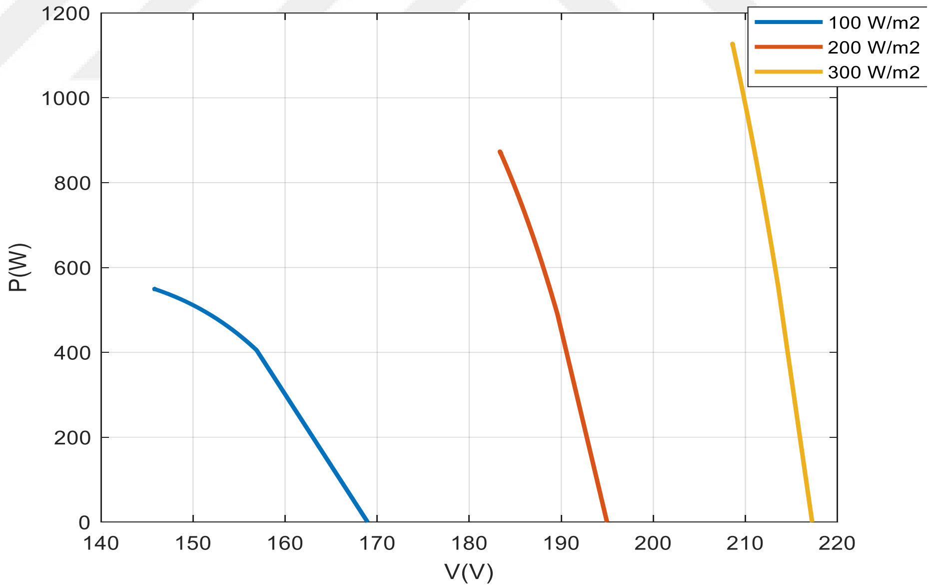

Figure 5.2 *V-P* curves at different solar irradiation level

As illustrated from above figures, when the solar irradiation level increases current and power increase in a straight way, however the voltage increases but slightly. Therefore, it is concluded that solar irradiation level has also a direct and linear impact on the current I and power P, in other words current I and power P change proportionally with the change of solar irradiation level. In other hand, the voltage V changes marginally with the change of solar irradiation level.

6. CONCLUSION

Since homosapiens until recently, Human has always preferred to use fossil fuels to get their needs. Oil, coat or natural gas occupied an important role to meet our needs. This form of energy is formed underground from the decomposition of the perished living creatures. This form of energy takes naturally a very long period of time to be ready to use. After that, humans take it out of the ground and burned it. The burning process releases a large amount of carbon dioxide CO_2 into the atmosphere. This greenhouse gas is very dangerous to our environment because it causes holes in the ozone layer which let penetrate ultraviolet and infrared rays into our atmosphere. The use of fossil fuels facilitated people in the various fields but unfortunately well aware of their negative impact on our mother nature some countries and organisations took actions to eradicate or at least decrease the use of this form of energy in the world. Scientists convinced industries the transitions from fossil fuels to renewable energy.

Organisations such as Paris COP21 and the United Nations Organization are trying to raise awareness about the dangerousness and pollution of the atmosphere that can cause the use of fossil fuels. They are trying to highlight the serious unpredictable and irreversible consequences the use of fossil fuels can provoke to our dear environment. Consequences such as melting of the ice at the North Pole, the increase in sea level, floods, lack of rain, droughts, erosions and the appearance of the hole in the ozone layer allowing ultraviolet and infrared lights to penetrate the atmosphere and thus causing serious illnesses such as skin cancer are to be expected. Step by step Mankind is leading himself and the planet to its complete annihilation. Energy transition to the green and clean energy is inevitably needed more than any other time in history.

Even though industries and companies have difficulty to abondon the use of fossil fuels, the World Bank and the International Energy Agency are encouraging them to use renewable energy in order to fight againts the phenomenon of global warming. Renewable energies refers to a clean, unlimited,proper, endless, inexhaustible and affect no harm to our planet. One of the source of renewable energies is solar energy which depends on the solar radiations. Solar photovoltaic module is the main element that absorbs the solar radiation and transforms it into electricity. Electric production from the PV module has no emission of greenhouse gases into the atmosphere. Furthermore, PV module is also cheap and most people can afford and use it in the roof of his house. PV modules can also be applied in the large installations. Solar PV module operates efficiently and is very reliable. PV modules are the futur.

Nevertheless, there are places in the globe where the ambient temperature T can reach up to 50 °C. This rising temperature decreases the electric production of the PV modules. In other words, the PV module efficiency decreases when the atmospheric temperature increases , thus the PV module do not produce enough electricity to supply the loads.

As mentioned at pages 20-23, as the operational temperature T starts to rise up, the voltage V and also the power P of the PV module immediatly decrease, thus proportionally the electric efficiency η begins to decrease. On the contratry, the rising of the operational temperature has a positif effect on the current because when the temperature T increases the production of current I increases slightly. This is a temperature influence on the PV module production of electricity. There are also other external factors such as solar irradiation level S that can influence the PV module production of electricity. To protect PV module against the undesired temperature effect, PV module cooling techniques are presented and examined from pages 24-63.

Over many years scientists developed cooling techniques to eliminate the influence of ambient temperature on the electric production of PV module. There are several and different methods of cooling systems. Every cooling technique is different from another in terms of the equipments used, whether it operates automatically or manually, the performance, the reliability, the efficiency, the time of response, the cost and period of time to recover investments. The users should consider these characterisitics before installing any cooling systems. PV module with or without cooling system operates differently and thus the performance is also different. The similarity about all the cooling methods is that when applying the temperature on the surface of PV module starts to decrease thus the efficiency begins to increase. That was the objective of the cooling mecanism and it is achieved successfully.

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APPENDICES

APPENDIX 1. Comparison between all cooling systems

APPENDIX 1. Comparison between all cooling systems

There are several cooling techniques of PV module to decrease the temperature. Some of them are mentioned in this paper. In this section, comparison of the previous PV panel cooling methods are made.

COOLING SYSTEMS	ADVANTAGES	DISADVANTAGES	COST	EFFICIENCY
Direct current brushless fan and DC water pump cooling systems	These systems are intelligent and run automatically. The DC water pump cooling method is more efficient compared to the air cooling by the fan. Midi Logger GL220 allows the users manually to save real-time data on his computer and also to start, stop and change cooling conditions for the DC brushless fan to start ventilating. PIC18F4550 microcontroller allows the system to be utilized for other applications.	Water is sprayed in one part of the layer of glass . Waste of energy due to the spraying Users should study first which temperature sensors are suitable with great accuracy for the measuring process. Regular maintenance of the devices	Medium	Increased (6.7%)
Ground Coupled Central Panel Cooling System	Can be applied for the huge central Need less maintenance Low-cost technique for large systems	The blower needs to be powered separatly	Cheap	Increased (Not given)

APPENDIX 1. Comparison between all cooling systems (Continued)

Floating Tracking Cooling Concentrating System	Produces very high efficiency The unavailability of lands can be solved by planting FTCC system The FTCC technology mounted with hydroelectric basins avoids much waste of energy Pumping facilities utilised to store energy keep away the system from electric grid stress	Takes span of 5 years to recover investment period The phenomen of evaporation of water that occurs leads to waste of water which causes waste of energy Only one part of the PV module is cooled because the sprinklers can not spray water to all its surface	Expensive	Increased ($5\% > \eta < 14\%$)
Hybrid photovoltaic/thermal system using Zn-H_2O nanofluid cooling technique	Zn particles provides great heat transfer improvement This nanofluid absorbs efficiently heat from PV surface Output hot water can be used for other domestic applications	Other nanofluids are not as efficient as Zn-H_2O, so the users have no other options	Medium	Increased (7.8%)
Pin fin-heat sink cooling technique	Operates with very good efficiency There are various geometrical designs for the pin fin-fin heat sink, so the users have a wide range of choices Dissipated heat can be used for other domestic applications	The system can be set to fire because of the thermal resistance	Expensive	Increased (Not given)

APPENDIX 1. Comparison between all cooling systems (Continued)

Forced water circulation cooling technique	Operates with very good efficiency Hot water produced in the ouput of the Flat-plate collector can be used for the domestic applications	As water flows in the upper surface of PV module a lot of energy losses occures in the PV module	Medium	Increased (14% - 16%)
Solar panel with water immersion cooling technique	This cooling technique can be applied to a large central in the lake or artificial basins only if the PV module is immerged with a 1-3 cm depth It is seen as an environmental friendly cooling system, so no harm to our ecology Electrical efficiency is increased on sunny days	Deep in the water the PV module does not receive enough solar radiations from the sun, so the output power and the output voltage decrease with time, thus the electrical efficiency decreases. Electrical efficiency is the worst on cloudy days	Cheap	Increased (Not given)