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An Experimental Investigation on the Performance Enhancement of Photovoltaic/Thermal Panel Using a Tracking System and Nanofluid (Al_2O_3)

***Abstract**- This work presents an improving of the photovoltaic / thermal efficiency by using a solar tracking system (2-axes) and AL_2O_3 mixed with water as working fluid. An integrated system (PV/T) consists of 36 mono-crystalline solar cell was designed and implemented with cooling water technique utilized copper pipes on the back PV side to flow cooling water at different mass flow rates . A (90) bulbs of (12V, 50W) are connected in series are used to simulate the sun light and controled by (3) AC to AC transformers to give different irradiation arrive up to (1000 W/m^2).The (AL_2O_3) was prepared and added to the water with different concentrations to decrease the temperature of PV and increase the rate of heat transfer to maintain good electrical efficiency and an increase in thermal efficiency.The experimental work has been conducted in (UMPEDAC) / Malaysia. The experimental results indicated that when using two- axes solar tracking system the output power generated was increased from (21.69W) to (30.69W). The power module generated is decreased when the temperature of PV surface increased from (64.05W at 24.7^{o}C) to (39.46W at 79.1^{o}C). It is proved that the temperature of PV surface is rising and that efficiency does not exceed 8%, if there is no water-cooling while under the influence of process cooling water, the efficiency increased to 9.6%. In addition, it founded that the optimum mass flow rat of water was (0.2) L/s. At using nanofluid (AL_2O_3-water) as a percentage ratios (0.1, 0.2, 0.3, 0.4, 0.5) % at constant mass flow rate (0.2) L/s, the temperature dropped significantly from (79.1^{o}C) to (42.2^{o}C). It is found that an optimum concentration ratio of nanofluid at 0.3% and the electrical efficiency of PV/T was 12.1% while the thermal efficiency was 34.4%.*

***Keywords**- PV/T cooling, Sun tracking system, Nanofluids applications, PV/T performance.*

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1. Introduction

Today, the applications of photovoltaic /thermal system (PV/T) for generation the electricity and hot water becomes very efficient. It is important to maintain the temperature surface of the photovoltaic as low as possible. The PV/T has many advantages comparing with other solar collectors, such as give electricity and heat in same time, very easy in maintenance and install, has long life in working (about 25year), etc. The main problem of PV/T is raising the temperature of PV cells. There are many methods to dissipate this heat; one of these active methods is a cooling technique by water and nanofluid .The application of sun tracking system, which is very important to increase the power of solar energy. The tracking system consist a serial communication interface to monitor whole processes on a computer screen and to plot data as graphic. System variables such as the current, the voltage and the panel position have been controlled by means of a microcontroller .The first mathematical formulation of PV/T collector was published by Florschuetz [1]. He modified the Hottel-Willier [2] the solution of analytical model for solar flat- plate thermal collector to apply the mathematical relations of photovoltaic/ thermal collectors. Many factors (heat removal and collector efficiency) of the Hottel-Willier model are still available to be utilized in the PV/T collectors. A dynamical model and 3 steady state models have been investigated by Zondag [3] constructed a prototype practical to validate the simulated result produced by this model. All models give good acceptance at with the experiment within (less than 5%) accuracy. Zakherchenko [4] showed that a thermal contact

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between thermal absorber and the cells of solar energy. Huang et al. [5] determined the efficiency of the photovoltaic and thermal power system and conventional solar thermal water. The primary-energy saving and thermal efficiency of the collector is (39%) and (66.2%), respectively. Abdulmunem [6] showed that using TiO_2 nanofluid experimentally comparative with conventional coolants (water, ethylene glycol) gives the best coolant in automobiles at Iraq summer season. Hussein et al. [7] were designed and implemented a hybrid PV/T, The module tested indoor by using Al_2O_3 nanofluids and investigated the improving in the electrical and thermal efficiency with using nanofluid.

This work will be devoted on enhancing the efficiency of a photovoltaic/thermal, which produces both electricity and heat concurrently by using double - axis of tracking, because it moves with the sun movement. This movement utilizes to keep the system directed towards the irradiation in a desired way. This provides an increasing in the electrical efficiency. However, there is a problem of heat inside the (PV/T) system needs to solution. The decreasing rate in panel surface temperature has a direct proportional relation with PV efficiency. Simultaneously, the output hot water is very beneficial for houses, buildings etc, as water heating system, The suitable solution for the problem of rising the temperature can be treating using two suggestion methods: - The first is using a cooling water technique to more effectively dissipate the heat from PV module and the second is using nanofluid (Al_2O_3 - water) with different concentration ratios to decrease the surface temperature. This work will review the experimental and theoretical tests for three cases and will discuss and analyze these results as follows: the first aspect aims to study the effect of sun tracking system to increase the power output from the solar panels, the second aspect is to show the effect of rising temperatures on the power generated from the solar panels at constant irradiation (1000W/m^2),and the third aspect is to show the effect of cooling process on the photovoltaic system (cooling water and nanofluid techniques). The current method of cooling system will absorb the heat from PV panel and lead to increase electrical efficiency of PV panel. The absorbed temperature may be used in another application (green house, chemical process, etc.). In other words, we have achieved double benefits from the PV/T system (thermal & electrical).

2. Mathematical Formulation

The model of the present work aims to make a comparison of efficiency using with and without nanofluid Drew [8], recommended the well-known Einstein′s relation for evaluating the viscosity of nanofluid:

$$\mu_{nanofluid} = (1 + 2.5\phi)\mu_{water}$$
(1)

Where ϕ can be from the relation: [9]

$$\phi = \frac{V_{NP}}{V_T} \quad (2)$$

The nanofluid thermal conductivity ($K_{nanofluid}$) evaluate from the relation: [10]

$$k_{nanofluid} = [\frac{k_p + 2k_f - 2(k_f - k_p)\phi}{k_p + 2k_f - (k_f - k_p)\phi}]k_f \quad (3)$$

The nanofluid density evaluate from the relation: [11,12]

$$\rho_{nanofluid} = (1-\phi)\rho_f + \phi\rho_p \quad (4)$$

The specific heat evaluates from the relation: - [9]

$$(\rho Cp)_{nanofluid} = (1-\phi)(\rho Cp)_f + \phi(\rho Cp)_p \quad (5)$$

The relation gives thermal diffusivity:

$$\alpha_{nanofluid} = \frac{k_{nf}}{\rho_{nf} Cp_{nf}} \quad (6)$$

The balance of the thermal energy for fluid flow in the pipe is express by the relation:

$$\dot{m} c_p \frac{dT_{fluid}}{dx} dx = q_c \quad (7)$$

Where q_c is the heat transferred to the fluid flow in the cooling pipes, The thermal efficiency can be defined:

$$Q = m \cdot C_P (T_o - T_i) \quad (8)$$

$$\eta_{th} = \frac{m \cdot cp\ (T_o - T_i)}{A_c G} \quad (9)$$

$$\eta_{th} = \frac{m^{\bullet} Cp \int (T_{out} - T_{in})}{A_c \int G(t) dt}$$

(10)

The total value of efficiency for electrical energy can be defined:

$$\eta_e = \frac{\int VIdt}{A_c \int G(t)dt} \quad (11)$$

The value of efficiency for electrical energy with temperature can be defined: [13].

$$\eta_e = \eta_o\left[1 - \beta(T_c - T_o)\right] \quad (12)$$

$$\eta_o = \frac{V_{mp} I_{mp}}{GA} \quad (13)$$

$$\eta_{total} = \eta_{th} + \eta_e = \frac{m^{\bullet} C_p \int (T_o - T_i)dt + \int VIdt}{A_c \int G(t)dt} \quad (14)$$

3. Experimental Work

I. Experimental system

An experimental system was designed to investigate the thermal and electrical performances of the PV/T. This system was constructed in University of Malaya (POWER ENERGY CENTER) (UMPDAC) in Malaysia. The photograph of the setup and the schematic diagram of the complete experimental set-up are shown in Figure 1. The solar panel type was used in this work to generate the electricity is mono-crystalline. A maximum power point tracker (MPPT) was used to modulate the power output from solar panel to be the maximum value. The experimental work includes three parts to investigate the efficiency of Photovoltaic/ thermal. These parts can be summarized as the following: the first part is to use a tracking system of solar to get the best and optimum angle between the photovoltaic surface and ray ratchet, the active sun tracking system is used in this study as shown in Figure 1. It consists of 2 motors and gear trains to direct the tracker as commanded by a controller responding to the solar direction. By differential illumination of electro, optical sensor control signal is used to drive the motor and orientation of the apparatus. Maintain the direction where illumination of electro optical sensors is equal and restore the balance the second part focused on the best angle and design of a laboratory device to study the effect of rising temperatures at constant irradiation (1000 W/m^2)on the performance of solar cells and the third aspect is studying the two cooling techniques of (PV/T) at constant irradiation (1000 W/m^2): cooling technique with water as working fluid at different mass flow rates, and cooling technique with nanofluid (AL_2O_3-Water) at different concentration ratios. For the first experimental part, the system relies on automatic tracking mechanisms instead of adaptive mechanism or predefined motion. Figure 2 shows two axes mount solar tracker. The main feedback of the control system is (LDR) and the microcontroller is the backbone of control system. For the second and third experimental part was designed to evaluate the efficiency of the Photovoltaic panel.

The present work is constructed to investigate and indicate experimentally the effect of temperature on the electrical efficiency and power output during its working. The (Vmpp) & (Impp) are (18V) and (3.611A) at (1000 Watt/m^2) and (25^{o}C) respectively. The maximum power output of single module can reach (65 Watt/m^2). A (0.5HP, 0.37kw,2.3A) and (5 – 35) l/min AC water pump was used to cool the PV panel by circulating working fluid (water-nanofluid) inside piping systems made for this purpose . Four liters and the material of piping system are copper with 21mm inner diameter and 1mm thickness and seven rows. To make cooling for water before entering PV/T system, the (40cm*35cm) aluminum air-water heat exchanger with (35cm diameter&12 volt) DC cooling fan is used. Ninety bulbs in series are connected and controled by three AC to AC transformers. 4 liter were prepared of (AL_2O_3) -water nanofluid with particles size of (30 nm) at five concentration ratios (0.1%, 0.2%, 0.3%, 0.4%, 0.5%), as shown in Figure 3. The preparing of nanofluids has been done in the laboratories of University Malaya Malaysian.

II. Measuring devices

A data taker type DT80 was used to record the readings at 1-minute interval. Five analog channels are measured the temperature of PV modules, inlet temperature, outlet temperature and irradiation. Irradiation was measured with an (LI-COR PY 82186) pyranometer .This instrument can measure the radiation in the spectral range (285 to 2800 nm). The response time of this instrument is 1s; therefore, the (1) minute interval which is used in this experiment is perfect to get a stable value from the pyranometer .The PV surface temperature and inlet, outlet working fluid temperatures measured by using a k-type thermocouple.

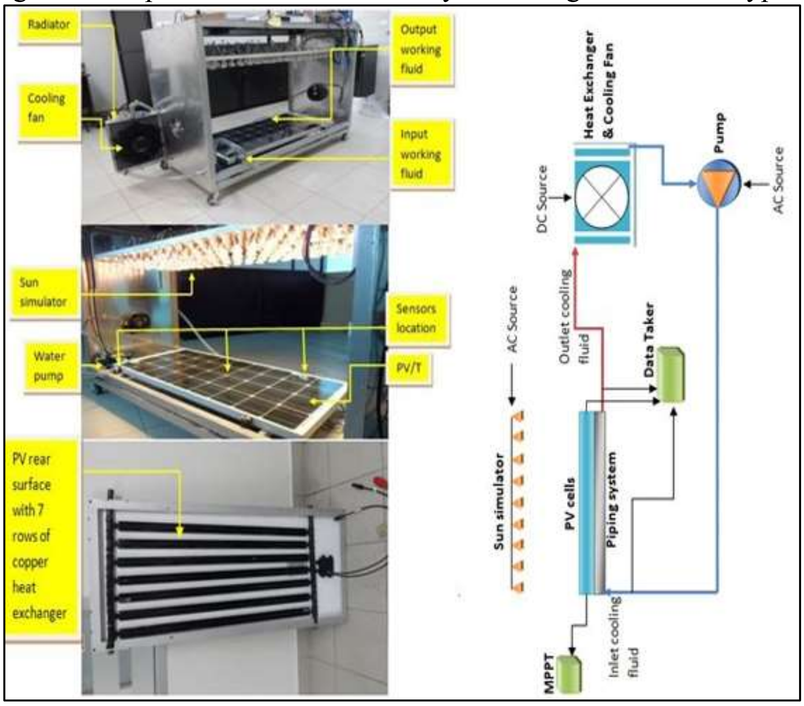


Figure 1: Photograph and schematic diagram of the overall of PV/T system

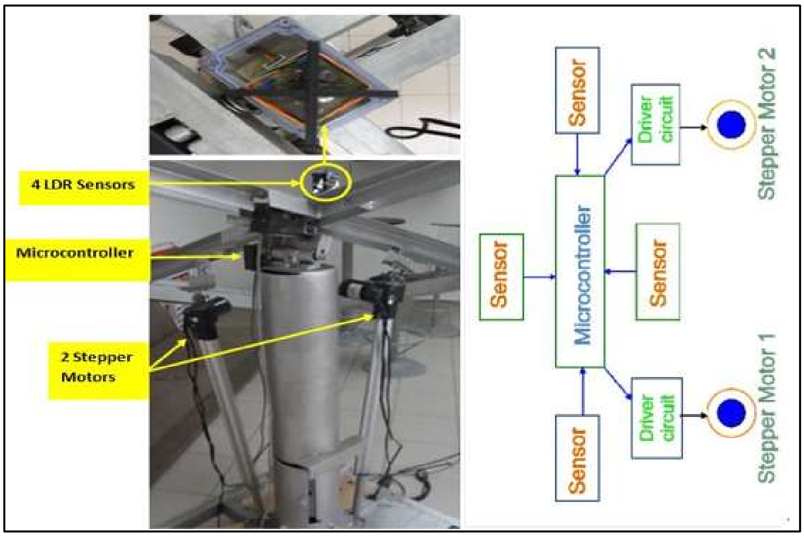


Figure 2: Solar tracker system (2- Axes) and schematic diagram of its work

Figure 3: five samples of (AL_2O_3-H_2O_3) nanofluid concentration ratio

4. Discussion of the Results

I. Effect of using tracking system

Figure 4 shows the difference between the maximum powers generated from PV panels with & without tracking system. This test was carried from (11:15 AM to 4:45PM) on (17th Feb-2014.). Two solar panels were used with the same properties (65W) and started the tests at the same time. One panel was with a tracking system and the other without tracking system at horizontal plane. The results give us good improvement in panel performance with using automatic tracking system because the tracking system keeps the PV panel faced with the sun and that led to the sun beam be perpendicular to PV panel surface. That gives less loses with absorbed radiation and led to generate power more than power from panel without tracking system about (30%).

Figure 5 show that more effect of tracking system is on Impp generating from PV panel as a power source and no difference in Vmpp. The net result in maximum power is increasing in this magnitude as the power equation (Pmax=Impp*Vmpp). In the results, the use of a tracking system gives good agreement in the power generated from PV cells and that led to increase PV panel efficiency. The tracking system makes irradiation perpendicular to PV surface. To see the effect of the tracking system exactly; we must see the effect of PV panel tilt angel on the performance in the laboratory at constant irradiation (1000W/m^2) with four angles (0, 15, 30, and 45) deg without the effect of surroundings such as wind, humidity, dust, cloud, etc. The (0 deg) in our device gives us perpendicular irradiation on the PV panel surface. Figure 6 shows that when we change the PV tilt angle from (0 – 45) deg, the PV temperature drops with increasing tilt angle. Increasing the tilt angle leads to increase the losses in absorbed irradiation. This leads to decrease in PV temperature, because the silicon cells temperature increase with increasing irradiation. While at (0 deg) there are no losses in irradiation or the losses are eliminated in comparison to other angles and at higher absorbed irradiation the silicon cells will be heated. Figure 7a shows that the maximum power generated from PV panel drops at increasing of tilt angle and it is maximum at (0 deg). This angle gives more absorption radiation and leads to more power generation. After (16 minute) the power generation at the angle (15 deg) is more than (0 deg) as shown in Figure 7b. The explanation of this behavior is that at the same time (16 min and more) the temperature of PV panel at (0 deg) is more than (15 deg). This rising in temperature gives us more dropping in power generation at (0 deg) compared with (15 deg).

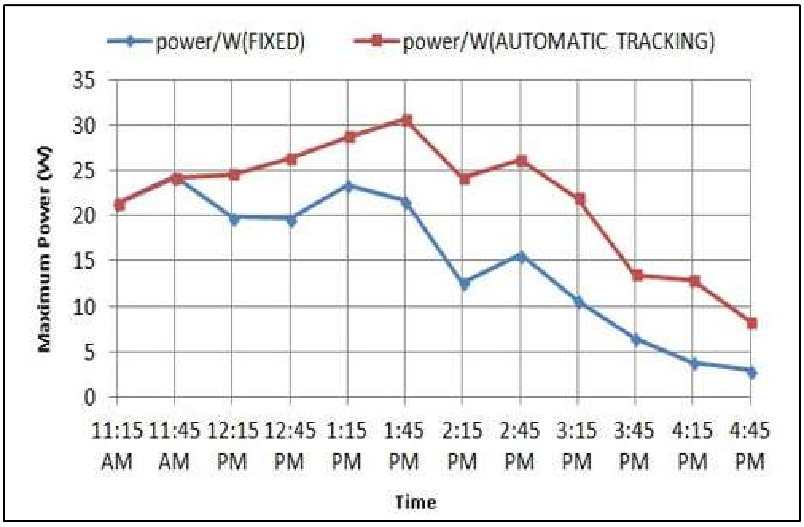


Figure 4: Maximum power generated from PV panel with & without tracking system

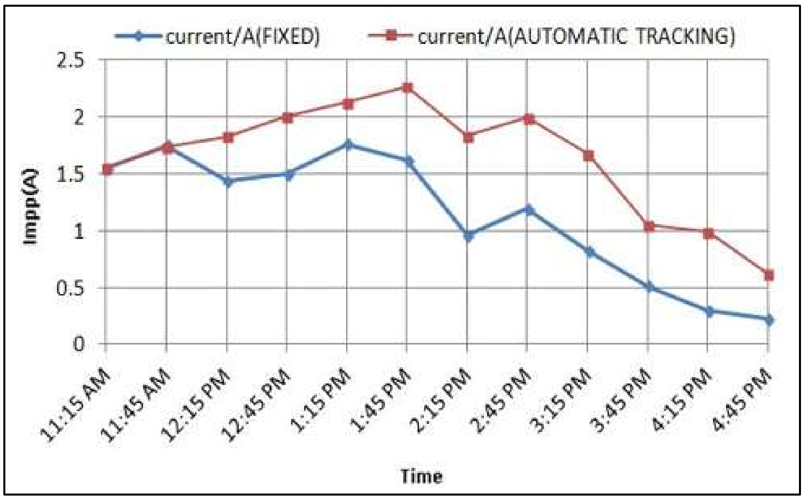


Figure 5: Impp generated from PV panel with & without tracking system

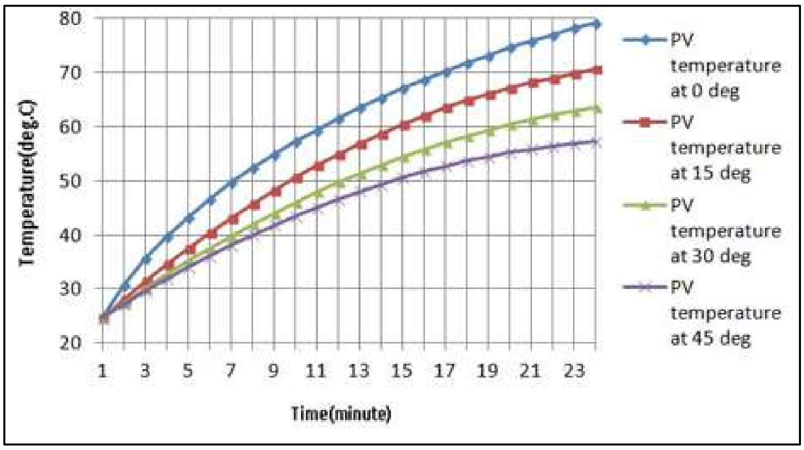
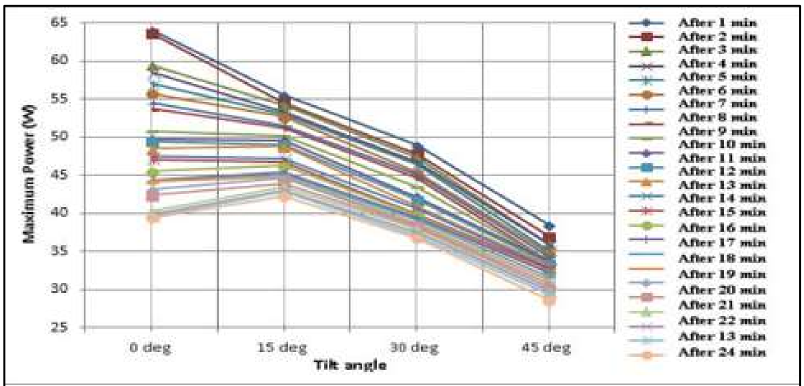
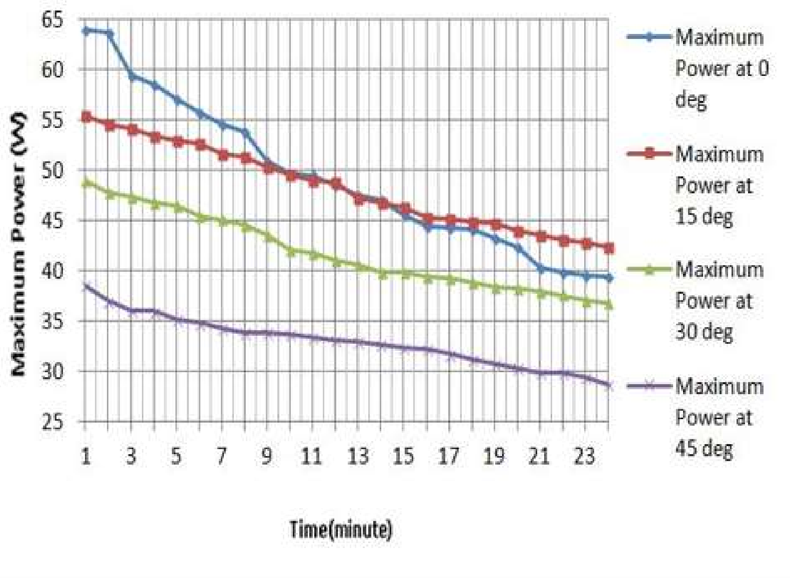


Figure 6: Effect of tilt angel on PV temperature at 1000W/m²



(a)



(b)

Figure 7: Effect of tilt angel on PV maximum power at 1000W/m^2 with change of: (a) angle, (b) time

II. Effect of rising surface temperature

To simulate the effect of the sun tracking system on the photovoltaic efficiency, a device was constructed. This laboratory device gives us rising of temperature at constant rate at constant irradiation from solar lamb's simulator. Figure 8a shows that the power generated from PV panel decreases when PV panel temperature rises at constant irradiation (1000W/m^2). Figure 8b and 8c show that the temperature affects both Impp & Vmpp but the effect of rising temperature on Vmpp is more than Impp. The result of rising temperature leads to decrease power generated from PV panel. This will give a reduced electrical efficiency of PV panel. The tracing from MPPT at the starting and the ending of the test denoted the changing in photovoltaic efficiency as increasing of temperature as shown in Figures 9 and 10.

III. Effect of water cooling technique

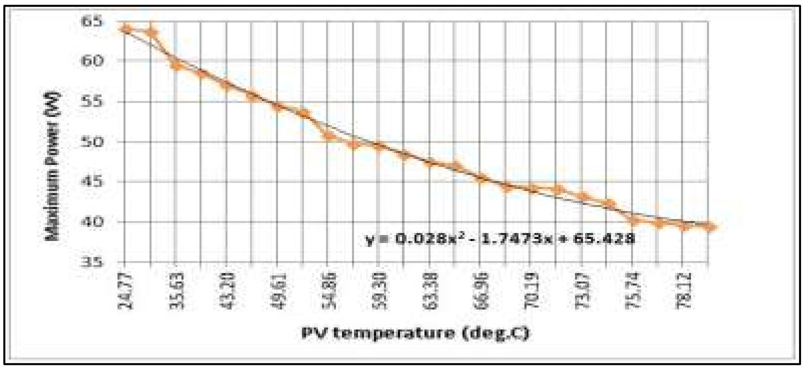
To enhance the photovoltaic efficiency it must be cooling to absorb the heat that affected solar cells. This hybrid system is called PV thermal system (PV/T). The maximum time for each test is (24 minute) and the temperature at starting of these tests is around (24^{o}C).The thermal performance of this system is shown in Figures 11 and 12 by using water with different value of water flow velocity (0.1, 0.2, 0.3)L/s. When it uses (0.1L/s) will get the best thermal gain. The value of (0.2L/s) gives the best performance for thermal efficiency of this PV/T. This mass flow rate of working fluid and thermal performance will have effect on electrical performance. It is noted that all performance is enhanced under cooling process such as Impp & Vmpp compared with the process without cooling treatment because decreasing in temperature lead to increase in power generation. The MPPT gives us traces for this enhancement of electrical efficiency under the cooling technique at change water mass flow rates as in figures (14, 15 and 16).

IV. PV/T Performance with (AL_2O_3 –Water)

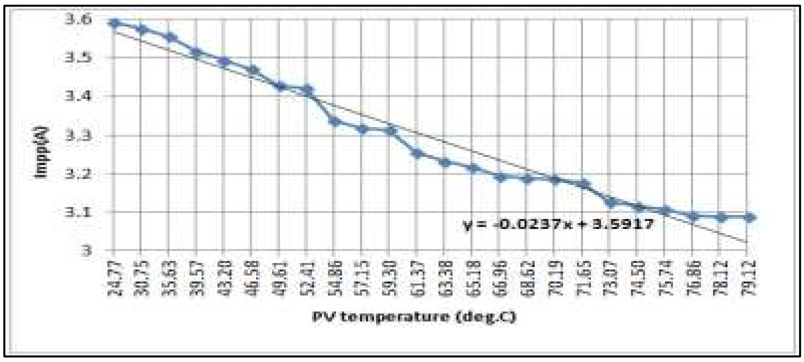
The thermal conductivity of aluminum oxide is higher than water; (39W/m.k) for AL_2O_3 while for water (0.596W/m.k), this advantage gives us a rising in the thermal conductivities of working fluid. All physical properties of working fluid will change such as viscosity, density, specific heat. All these properties depend on concentration ratio of nanoparticles on the base fluid (water). Figures 17, 18, and 19 show that the effect of concentration ratio on maximum power, Impp, and Vmpp, respectively. Thermal gain increases with increasing concentration ratio since the thermal conductivities increases as shown in Figure 20. This leads to increase thermal efficiency as shown in Figure 21. The nanofluid tests at (0.2L/s) gives good thermal performance and acceptable electrical performance under water test of PV/T. Figure 22 shows that (0.3%) concentration ratio gives good cooling. When it increases more than (0.3%) the temperature will increase because the density and viscosity will increase with rising concentration ratio. When the surface temperature decreased with using of AL_2O_3 the electrical was maximum value. That gives better maximum power generation at (0.3%) nanofluid concentration ratio; because this ratio gives good cooling for PV panel. PV temperature will be increasing with increasing concentration ratio up to (0.3%). The MPPT gives traces of PV performance at the end for each test of using nanofluid at different concentration ratios as in Figures 23, 24, 25, 26 and 27.

V. Electrical efficiency comparison

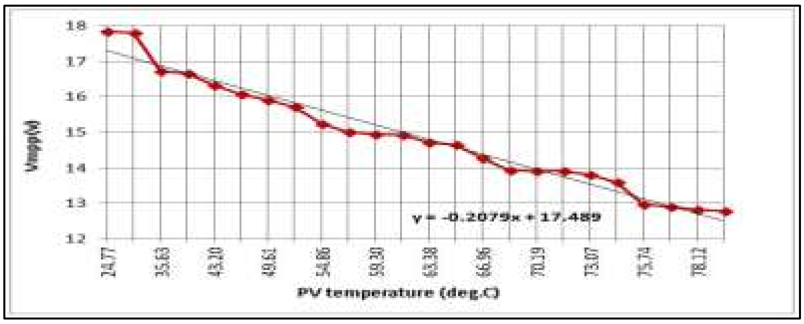
Figure 28 explains the comparison between the experimental results obtained in this work with the theoretical results of equations (10 and 11). Small difference is seen in the figure, not exceeding (2%) at maximum temperature of (79 ^{o}C). The difference is (1.25%) at temperature of (63 ^{o}C). This difference is considered acceptable and the procedure is correct.



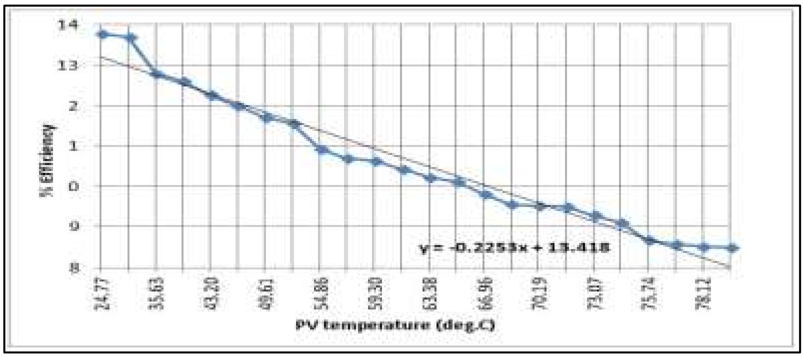
(a)



(b)



(c)



(d)

Figure 8: Effect of rising temperature on (a – maximum power- Impp, c-Vmpp, d- electrical efficiency) generated of PV panel at 1000W/m^2

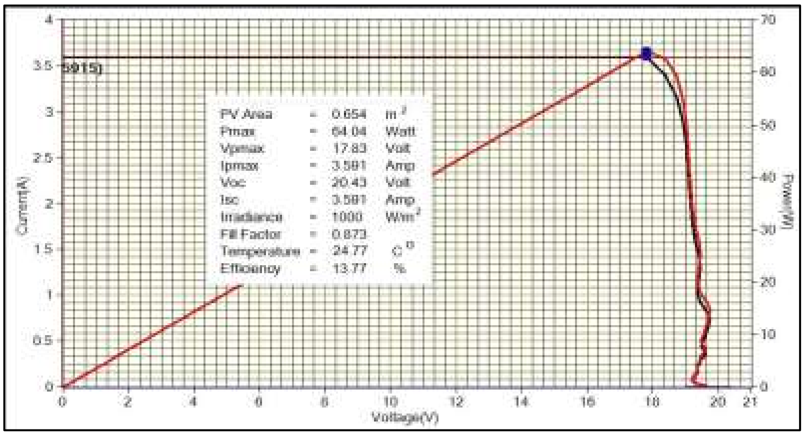


Figure 9: MPPT trace at start of testing the effect of temperature on PV panel performance

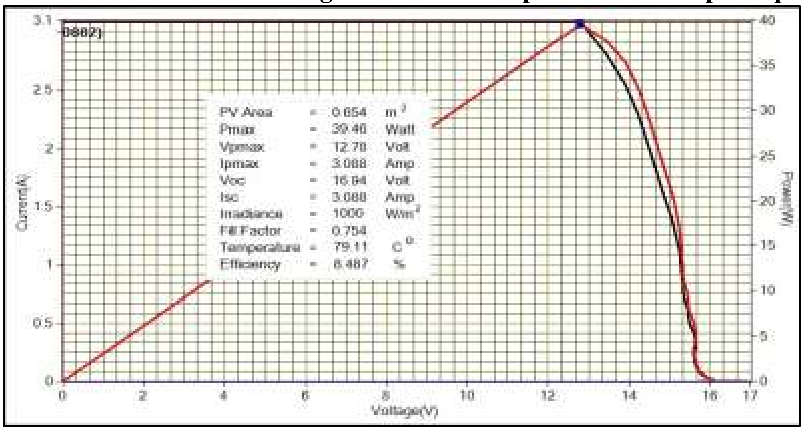


Figure 10: MPPT trace at end of testing the effect of temperature on PV panel performance

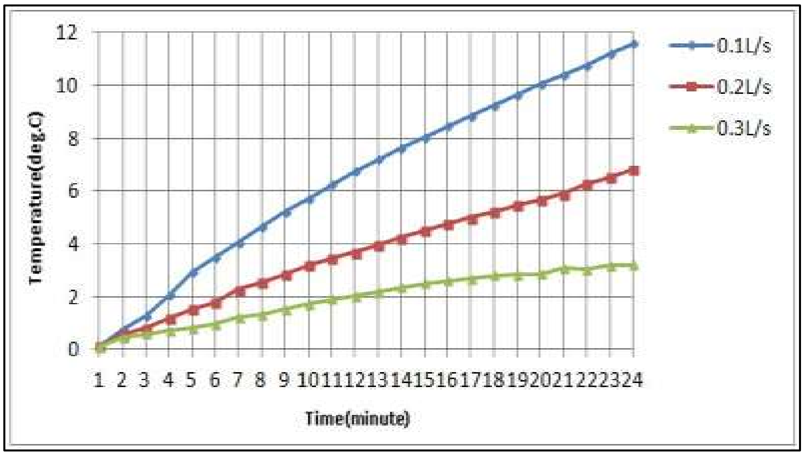


Figure 11: Effect of water mass flow rate on thermal gain

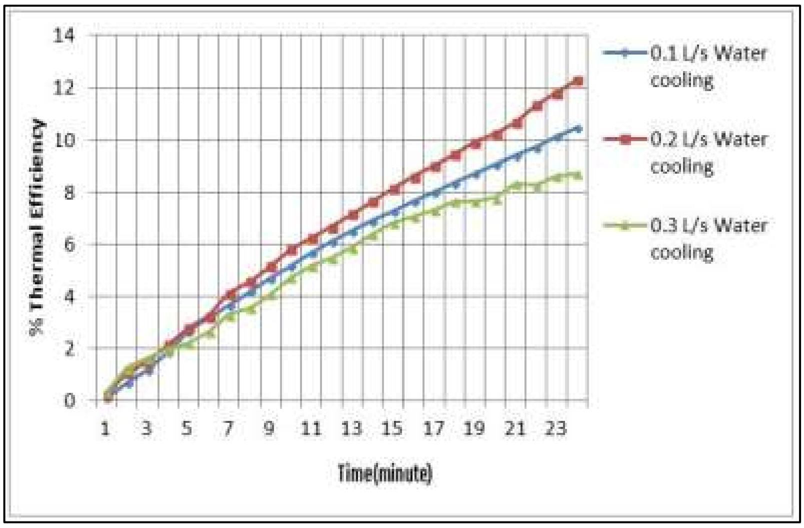


Figure 12: Effect of mass flow rate on thermal efficiency

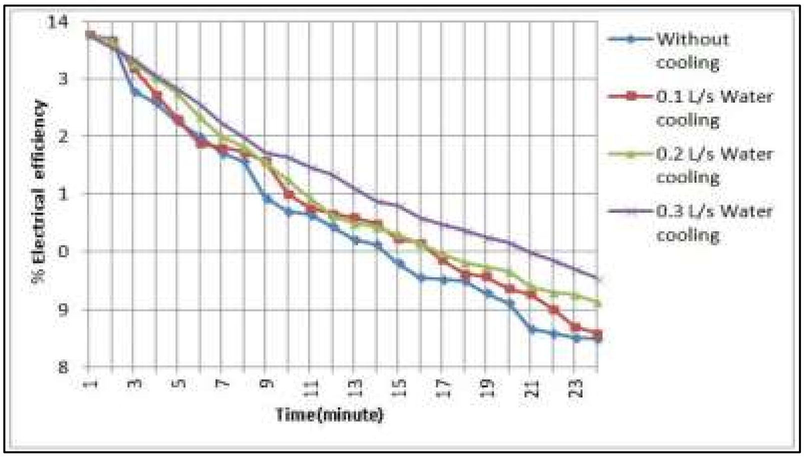


Figure 13: Effect of water mass flow rate on electrical efficiency of PV panel

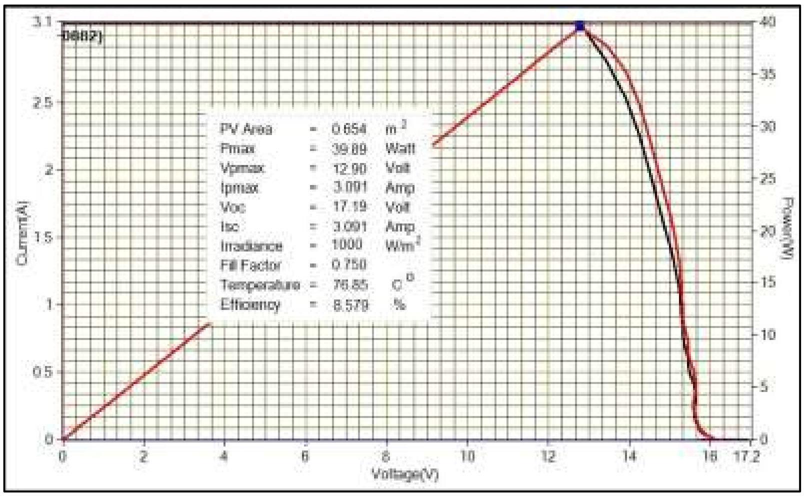


Figure 14: MPPT trace at end of testing the effect of water-cooling at (0.1L/s) on PV panel performance

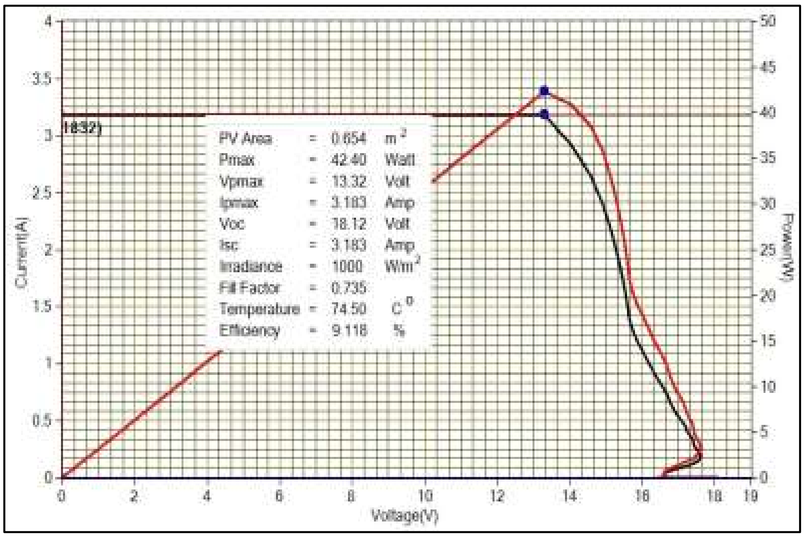


Figure 15: MPPT trace at end of testing the effect of water-cooling at (0.2L/s) on PV panel performance

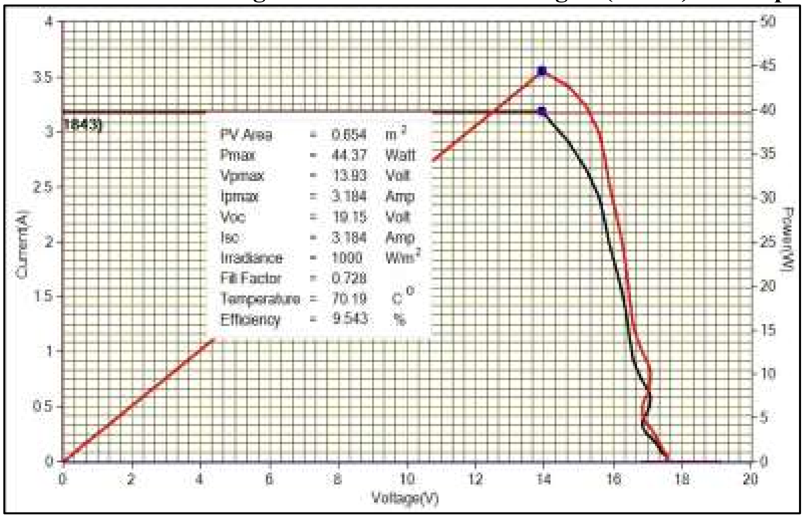


Figure 16: MPPT trace at end of testing the effect of water-cooling at (0.3L/s) on PV panel performance

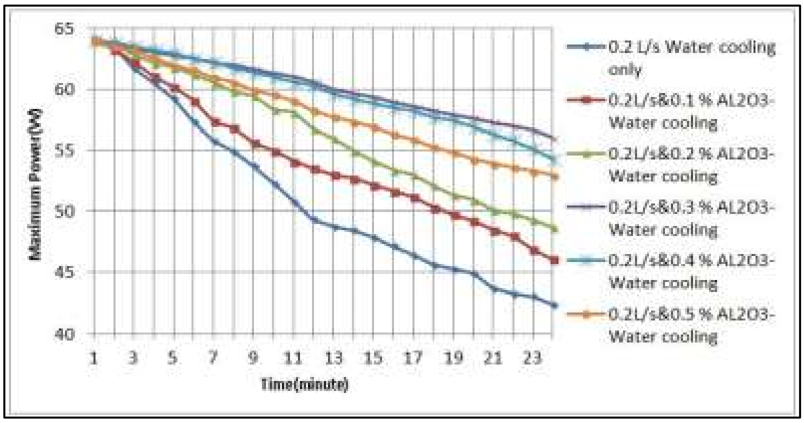


Figure 17: Effect of nanofluid concentration ratio at constant mass flow rate on maximum power

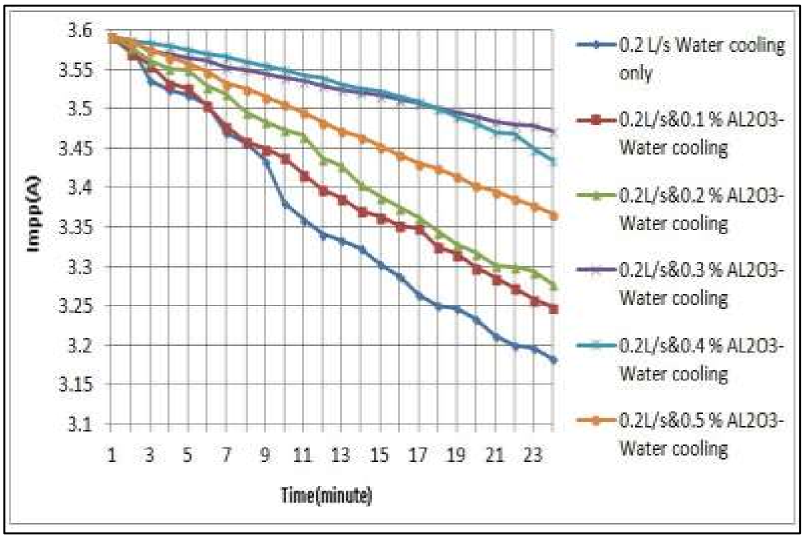


Figure 18: Effect of nanofluid concentration ratio at constant mass flow rate on Impp of PV panel

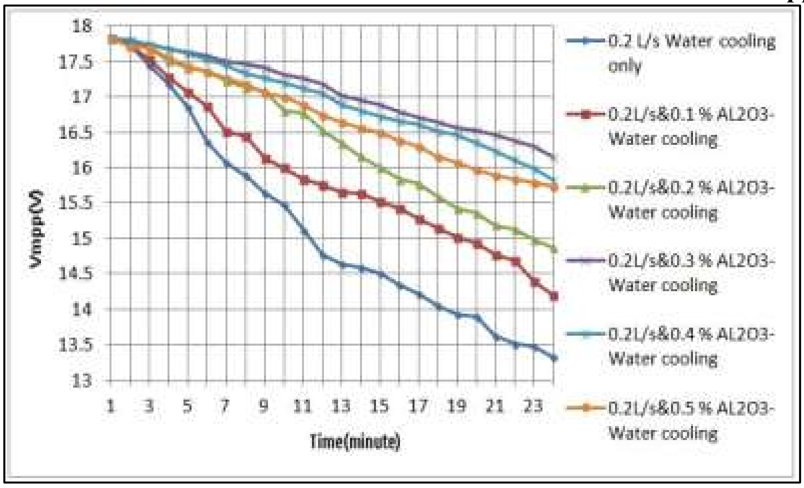


Figure 19: Effect of nanofluid concentration ratio at constant mass flow rate on Vmpp of PV panel

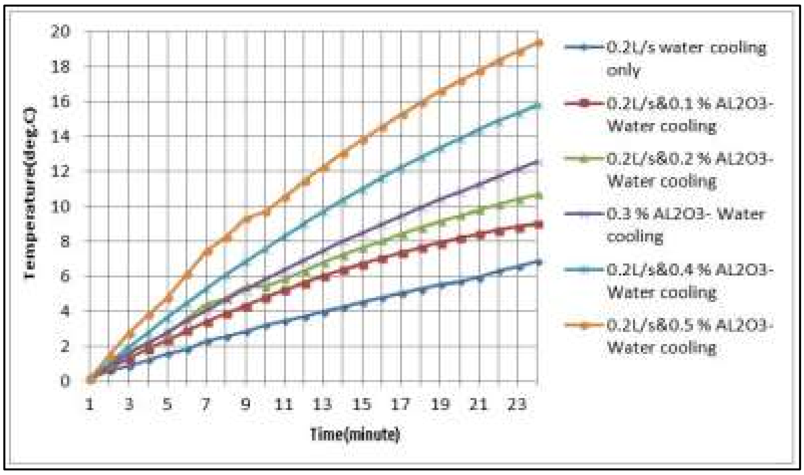


Figure 20: Effect of nanofluid concentration ratio at constant mass flow rate on thermal gain

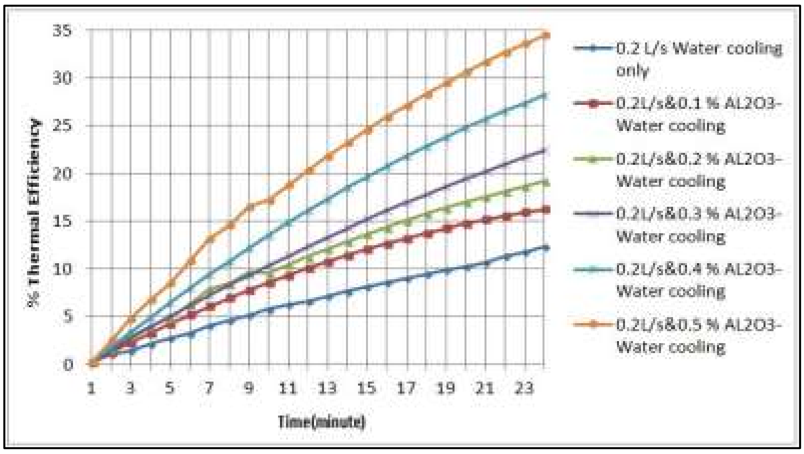


Figure 21: Effect of nanofluid concentration ratio at constant mass flow rate on thermal efficiency

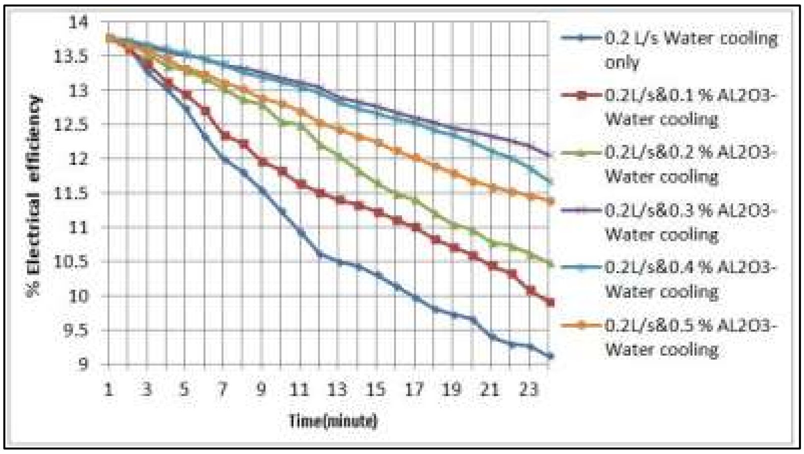


Figure 22: Effect of nanofluid concentration ratio at constant mass flow rate on electrical efficiency of PV

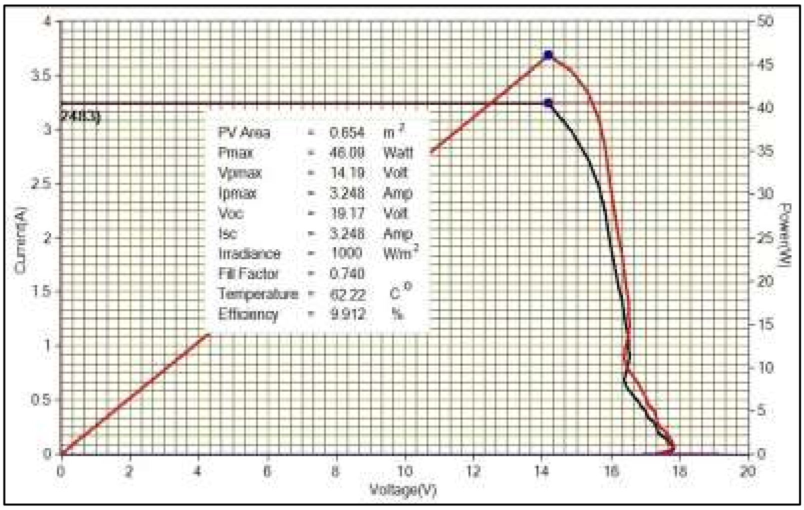


Figure 23: MPPT trace at end of testing the effect of nanofluid cooling at (0.1% concentration ratio) on PV Panel performance

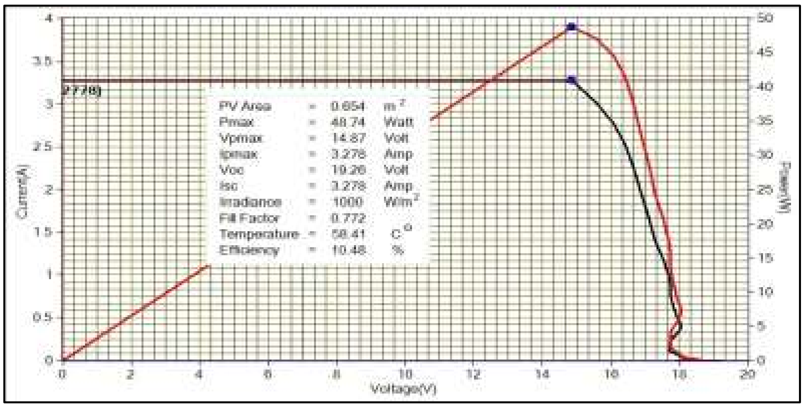


Figure 24: MPPT trace at end of testing the effect of nanofluid cooling at(0.2% concentration ratio) on PV panel performance

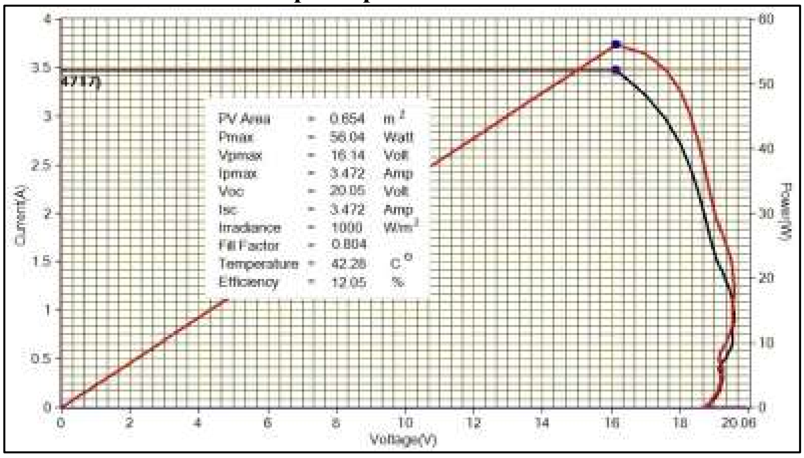


Figure 25: MPPT trace at end of testing the effect of nanofluid cooling at (0.3% concentration ratio) on PV panel performance

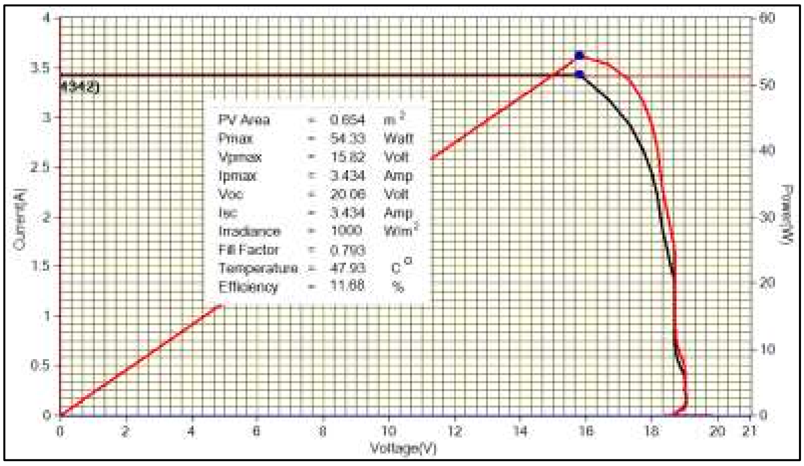


Figure 26: MPPT trace at end of testing the effect of nanofluid cooling at (0.4% concentration ratio) on PV panel performance

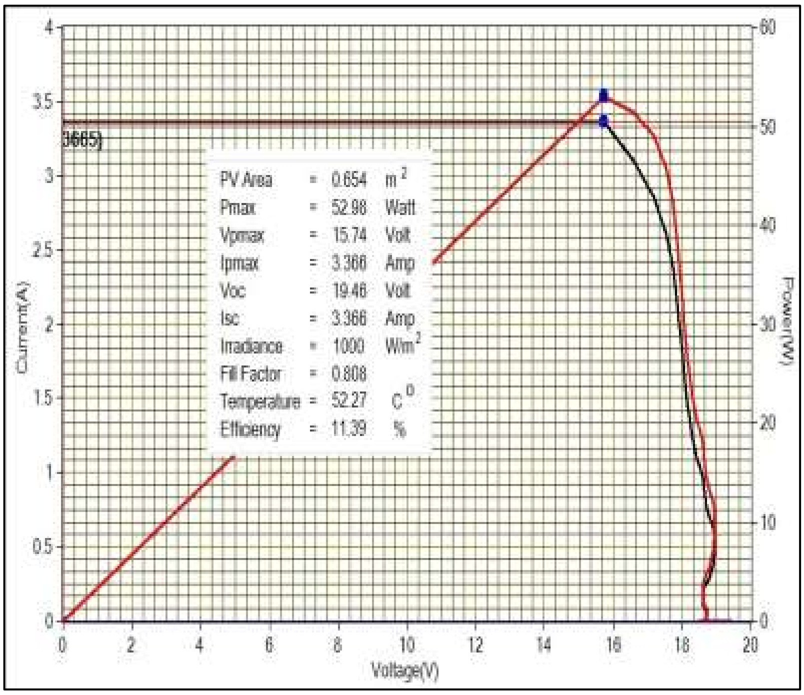


Figure 27: MPPT trace at end of testing the effect of nanofluid cooling at (0.5% concentration ratio) on PV panel performance

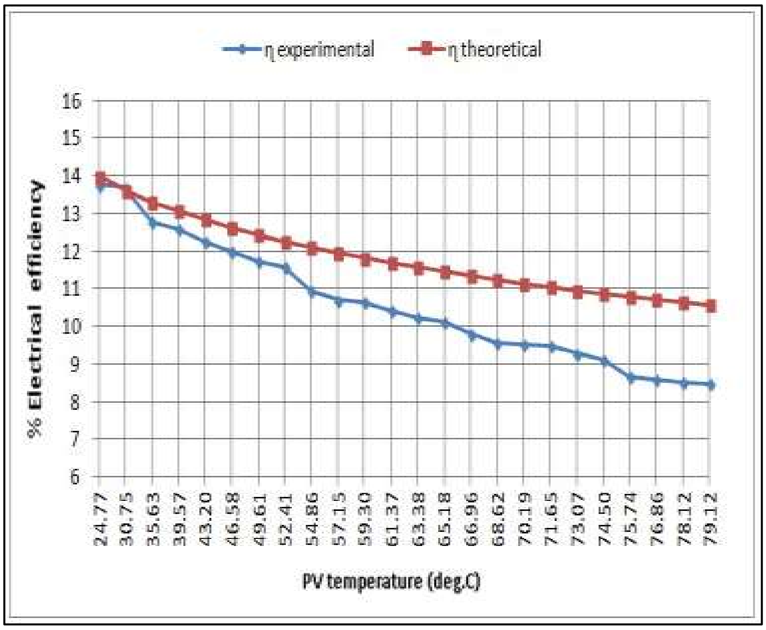


Figure (28): Comparison between theoretical and experimental result of PV electrical efficiency

5. Conclusions

This work produced the following conclusions are withdrawn:-

1-This work indicated that using a tracking system in following the sun position is very important because it can increase the electrical efficiency of photovoltaic cells about (30%).

2-This work approved that the mass flow rate of cooling water are affecting on the electrical efficiency value since the increase of water velocity in the tube will result in increasing the amount of heat transferred. The optimum mass flow rate of water in our study was (0.2 L/s) for both thermal and electrical efficiency.

3-It is very evident that using of (AL_2O_3) as the working solution which has the potential to increase the thermal efficiency of the collector subject to good preparation and operation of the nanoparticles and the base fluid.

4-This work is proved that the prepared nanofluid of aluminum oxide material (AL_2O_3) enhanced the PV/T performance and the optimum concentration ratio can be mix with water was found 0.3%.

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Nomenclatures

A= PV module area (m^2).
Ac= Collector area (m^2).
C_p=Specific heat capacity (kJ/kg.c).
C_{pf} = Base fluid heat capacity (kJ/kg.c).
C_{pnf} = Nanofluid heat capacity (kJ/kg.c).
C_{pp} = Nanoparticles heat capacity (kJ/kg.c).
G = Irradiation (1000W/m^2) for standard condition.
I_{mp}= PV current at maximum power point (A).
K_f = Base fluid thermal conductivity (W/m.c).
$K_{nanofluid}$ = Nanofluid thermal conductivity (W/m.c).
K_ρ= Nanoparticle thermal conductivity (W/m.c).
$\dot{m}$ = Mass flow rate (kg/s)
MPPT = Maximum power point tracer.
ϕ= Nanoparticles volume concentration ratio.
T_c = Cell temperature (^oC)
T_{in} = Cooling fluid inlet temperature (^oC),
T_o = Standard condition temperature (25^oC),
T_{out} = Cooling fluid outlet temperature (^oC),
V_{mp}= PV voltage at maximum power point (V)
V_{NP} = Volume of the nanoparticles (m^3)
V_T =Total volume (m^3)
β = Silicon cell temperature coefficient (β=0.0045 $^oC^{-1}$).
η_o = Nominal electrical efficiency under standard condition.
η_e = Electrical efficiency.
η_{th} = Thermal efficiency.
η_{total} = Total efficiency.
$\mu_{nanofluid}$ = Nanofluid viscosity (kg/m.s).
μ_{water} = Water viscosity(kg/m.s).
ρ_f= Base fluid density of the (kg/m^3).
$\rho_{nanofluid}$ = Nanofluid density(kg/m^3).
ρ_p = Nanoparticles density (kg/m^3).

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