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Numerical analysis of the photovoltaic system inspection with active cooling

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ABSTRACT

The use of solar energy may replace the present fossil fuel or gas to produce electricity. The goal of this study is to set up a simulation model to survey the performance of a photovoltaic thermal system (PV/T) based on the computational fluid dynamics (CFD) method. Ansys fluent software has been used for the simulation procedure. The electrical panel output and its efficiency were investigated numerically. In addition, the effect of variations in absorbed radiation on inlet fluid and absorber panel temperature on the system performance was investigated. The study was conducted for three cases, in a first case, where there is no refrigerant in the system and in the latter case, at constant fluid rate of the pump, whereas the third case with optimal pump operation. The numerical findings obtained from CFD simulators have been compared with the test records of the experimental results of the literature. The two results have a good agreement. From the obtained results, it can be noted that the system shows a good improvement for the electric net efficiency level of 3.52% with a lower reduction of the thermal system efficiency of 1.96% in comparison to the system when using the constantly high flow rate.

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1. INTRODUCTION

According to the fact that traditional energy sources (coal, oil, natural gas and nuclear fuels) are constrained and finite, and the energy producing sector is considering the main contributor to the environmental pollution, energy should be produced from renewables. The solar energy is an inexhaustible and completely environmentally friendly source of energy [1]. However, once the solar cell becomes illuminated, the effect of photocells and an electromotive force appears at its ends which is connected to the energy supply consumed and so the solar cell becomes a source of electrical energy [2]. In this way, just a small fraction of the energy of solar radiation is transformed into electrical energy, whereas most of it is converted into thermal energy that is a dedicated panel which brings about an increased module temperature which will cause some decrease in the electrical energy efficiency by about 0.5 %/K [3].

Photovoltaic has particular advantages as an energy source: once installed, it does not generate pollution and does not emit greenhouse gases, it has a simple scalability in relation to energy needs, and silicon has a high availability in the earth's crust [4]. Photovoltaic systems have long been used in technical applications since the 1990 s [5] Photovoltaic panels were produced for the first time in mass production at the end of 2000, after German ecologists and Euro solar received government funding for a 10-thousandth.

Technological progress and increased scale of production in any case reduced costs, [6] increased reliability and increased efficiency of photovoltaic installations [7].

Recently studies have shown that a sufficient mass flow with a low input point temperature can achieve a satisfying improvement in electrical efficiency [8]. The excessive thermal energy which is removed from the fluid may be used for the hot water preparation or as warm water in swimming pools, which increases the system's overall efficiency. The increasing fluid flow demands the addition of electricity from the system pumps, reducing the net electrical system efficiency [9].

This paper describes the control method of the pump output (fluid flow) with the objective of improving the efficiency of the PV system. However, the major problem is the inefficiencies of non-conventional energy sources as compared to conventional energy sources. So, the dynamic analysis of the system efficiency improvement is presented in this paper. We could also see how the energy performance of the system that uses the hybrid photovoltaic rises due to the thermal energy resulting from it and which can be used in the home setting, but due to the power demand of the electric pump the electrical efficiency decreases with a constantly high flow. For these reasons it is important to optimize the system using the only manageable capacity in the system with mass flows by monitoring the change in the dose to the panels and the panel temperature to obtain the highest net power, the thermal photovoltaic panels and the system optimize.

The mechanisms used for solar radiation, condensation and thermal transfer are modeled using the CFD method by Selmi *et al.* [10]. He observed that the use of forced flow water has a temperature lower than that of non-stream water. A simulated model was constructed to consider the simulated model validity. There was a high correlation between the experiment results and the results of the simulation.

Siddiqui *et al.* [11] have developed a numerical model in order to make a comparison between a PV/T hybrid system and a PV module. The thermic and the electrical sections have been combined to give a multi physical simulation model. The effect of some parameters was also investigated, including the absorbed radiation, the contact temperature resistance, the inlet speed and the input temperature. It was concluded that PV/T systems may be used in regions where solar radiation and the ambient temperature are both high

A dynamic model simulation was applied by Bhattarai *et al.* [12] in order to compare the performances of a metallic and tube PV/T system via a solar collector. The scientists have developed a one-dimensional simulation model by solving energy savings formulas for several sections of a systems at the same time. The results were in accordance with the numerical data that was measured in the experiments. It was detected that the thermal efficiency of daily solar collectors was approximately 18% greater than that of the PV/T system. Whereas the main energy saving in the PV/T system was greater than that of a PV collector.

Cerón *et al.* [13] have also developed a 3D model for collectors with flat sheet metal plates and tubes. In this investigation, different thermal transfer heat transfer systems were considered in a stable combination simulation. The numerical findings were evaluated by means of experimental results and standardized heat transfer correlations. In addition, different convection thermal transfers for the water fluid within the tubes have been calculated on Nusselt.

Aste *et al.* [14] have reported a new PV/T roller bonding design. A simulated design was also obtained by resolving the relevant energy budgets of the system to assess the electrical and thermal performance. An experiment with a PV/T prototype has been installed and monitored by Haurant *et al.* [15] during 18 months. They also supplied a model simulation of the PV/T system as described in TRNSYS. The simulation software. The simulated results and observed data have been compared. A high degree of agreement between the simulation results and the results of the experiments was observed.

The thermal photovoltaic panel system is composed of a photovoltaic-thermal panel, which in the study has a surface area of 24.89 m, a water reservoir and a circulating pump. The photovoltaic panel transforms solar energy into electricity. The heat part of the system is the absorbing plate which is responsible for transferring the resulting thermal power from the solar panel to the fluid. The exchange of heat occurs in the water tank, where the hot water is supplied in the top part of the tank, while cold water is carried to the tank floor. The cool water via the circulation pump delivers with the pre-defined mass flow to the base of the panel.

The thermal photovoltaic solar system is so designed so that simple photovoltaic solar cells can be added directly above the solar absorber. This system consists of a cover of glass that loses its light at the absorbers, photovoltaic cells that convert the energy of the solar dosage to direct electrical energy and the plate of the absorbers which plays a heat transfer role from the collector to a fluid that passes through a tube. The block diagram of the photovoltaic-thermal system is shown in Figure 1.

This pump is part of a PV-thermal system which has the task of keeping the required flow through the panel background. Thus, realizing the resulting thermal energy from the panel and cooling it. To keep the desired flow, the electrical power required by the pump is provided by (1) [16].

$$Pp = \frac{Km^3}{2A_C^2\varphi^2\eta} \quad (1)$$

where: K is the coefficient of total loss, m: is mas of flow rate, ρ is the fluid density, Ac is: pipe cross-section area and η is the Pump efficiency.

From (1), it is clear that the only changing parameter is the flow rate mass of the fluid, while all other parameters remain constant and are dependent on the system and fluid physical characteristics. Electric power required to run the pump is in fact an extremely nonlinear function that rises to the cube as the flow fluid mass increases.

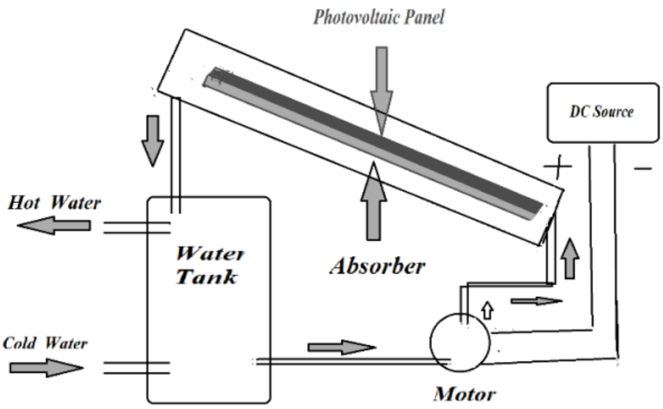

Figure 1. Functional scheme of photovoltaic-thermal system

Any temperature changes shall cause some changes in the characteristics of photovoltaic cells. To investigate the characteristics of cells it is important that you know how the temperature influences the following parameters: I_{sc} short circuit current, current of cell I, open loop voltage U_{oc}, Pm maximum power and efficiency of the cell η. Efficiency is common to decrease by approximately 0.5% for the increase of the panel temperature of 1 ^oC. The rationale is that the temperature increase will cause some decrease in the prohibited strap width, which causes a slight increase in the saturated current, but because of the temperature rise the kinetic energy of the particles is increasing, which results in a reduction in the electric field of the P-N compound. The decrease in the electric field causes the electrics and cavities to recombine more quickly, ultimately resulting in a decrease in open circuit voltage

The variation in temperature mainly influences the quantity of open- circuit voltage. The I_{ks} short circuit current is temperature dependent and may be written as [17].

$$I_{Ks} = AT^3 \exp(-\frac{qU_{Ok}-E_g}{KT}\pi r^2) \quad (2)$$

Where A: collector surface, T: collector temperature, q-elementary charging (1.602x10 C), open voltage circuit U_{ok}, width E_{g-} of the forbidden belt (eV). K-Boltzmann constant (1,3806 x 10 J/K).

2. METHOD

2.1. Calculating the total irradiance for the panel

The electrical power of the PV panel is frequently caused by the high dosage of solar energy. Solar dosage on the I_{tt} inclined surface may be expressed as the sum of the following 3 components [18].

$$I_{tt} = I_{b,T} + I_{r,T} + I_{d,T} \quad (3)$$

where: $I_{b,T}$ is direct sunlight is on the sloping surface, $I_{r,T}$ is the diffused solar radiation on the sloping surfaces and $I_{d,T}$ is the reflection of solar radiation on the sloping surface.

$$I_{b,T} = I_b \cos\Theta \quad (4)$$

$$I_{d,T} = I_d cos^{2} \frac{\beta}{2} \left[1 + F\, sin^3 \frac{\beta}{2}\right] \quad (5)$$

$$I_{r,T} = \rho\, (I_b cos\Theta z + I_d)\, sin^2 \frac{\beta}{2} \quad (6)$$

where I_b: is direct solar maturation (normal), I_d: is horizontal diffuse solar maturation, I_r: is the collector processing in relation to the surface horizontal, ρ: soil albedo, F: modulating factor, Θ: is the angle between the direction of the sun and the normal inclined surface, Θ_z: the zenithal angle of the sun, the angle of inclination of the surface β,

$$\cos\theta = \cos\theta\, z\, cos\beta + \sin\theta\, z\, sin\beta \quad (7)$$

The modulation factor *F* can be calculated as [14].

$$F = 1 - \frac{I_d}{I_t} \quad (8)$$

where: I_t is the total solar dose on a horizontal surface and is calculated as [19].

$$I_t = I_b\, cos\Theta\, z + I_d \quad (9)$$

Angels that determine the optimum panel location are illustrated in Figure 2.

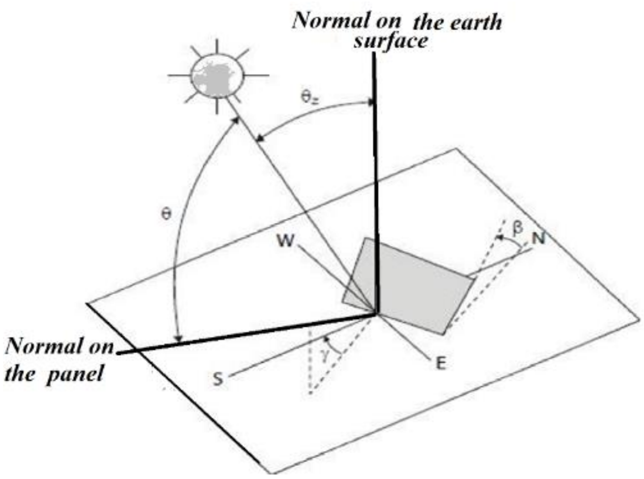

Figure 2. The angels that determine the optimum position for the panel [15]

2.2. Calculation of photovoltaic heating system

One factor that affects the operation of the PV panel is temperature. A part of the sun radiation falling on the system is absorbed largely by the panels and turns into electricity and surrenders, the other part becomes the inner energy of the panel material and the temperature of the entire system increases. This warmth is passed on to the fluid circulating through the absorber tubes. The heat transfer processes that take place are convection, conducting, radiation. By taking all these parameters into account the heat exchange modulus equation is calculated as (10) [20].

$$C_{Mod} \frac{dt_{Mod}}{dT} = q_{Lw} + q_{Sw} + q_{Con} - P_{Out} - Q_t \quad (10)$$

where: C_{mod} is the heat capacity of the modules, dt_{Mod}: is the temperature of the module, q_{Lw}: is the power of the long-wave radiation, q_{Sw} :is the charge of the long-wave radiation, q_{Con}: is the power conduction heat convection, Pout is the derived power of the power modules and Qt is the heat power absorbed by the fluid. For the precise balance, it is required to know each specified component in (10), as:

2.2.1. Module thermal capacity (C_{Mod})

To establish the thermal capacity of the module you need to know the panel structure itself. In this case, the panel is made up of three layers: the glass cover, the monocrystalline photovoltaic cells and the absorption cover. It assumes that the temperature of the panels is uniform across all three layers. Each individual layer has their own thermal capacity and the module's thermal capacity is defined as the sum of all the individual strata and depends on the material type of each layer and the deformation thickness [21].

$$C_{Mod} = \sum_{K=1}^{m} A d_K \rho_K C_K \quad (11a)$$

$$C_{Mod} = \sum_{K=1}^{m} A d_K \rho_K C_K \quad (11b)$$

where: A is the surface of the panel, d_k is the thickness of the individual layer, ρ_k is the density of every layer, C_k is the thermal capacity of the individual layer. The characteristics of each individual layer are shown in Table 1. The surface area of the panel is 24.9 m^2.

Table 1. Characteristics of every single layer of the photovoltaic panel [22]

Layer	ρ_K(kg/m3)	d_k(m)	C_K(J/kgK)	C_{Mod} (j/k)
Monocrystalline	2330	0.0003	677	11780
Absorbing layer	1200	0.0005	1250	18637
Glass cover	300	0.003	500	112027
				143 (kJ/k)

2.2.2. Heat transfer by convection (q_{Conv})

Convection heat transfer is defined by Newton's cooling regulations between the front panel and the surrounding air [23].

$$q_{Conv} = -h_C A(-T_{Mod} - T_{Amb}) \quad (12)$$

where: h_C is the transferring factor that represents the combination of forced and natural convection. Where there is no air, we can ignore the forced convection factor. Natural convection coefficient between ambient air and the system is defined by (13), (14).

$$h_{C,free} = 1.31\sqrt[3]{T_{Mod} - T_{amb}} \quad (13)$$

$$b_{C,forceed} = 5.6 + 3.8v \quad (14)$$

where v: is wind speed.

During the mean day the heat transferred by convection is equal to the sum of forced and naturally occurring convection and is given by (15) [24].

$$q_{Conv} = A\left(h_{C,free} + b_{C,forceed}\right)(T_{Mod} - T_{amb}) \quad (15)$$

2.2.3. Electrical output power from panel

The electrical output power obtained from the panel is a function of the total ripening of panel and the temperature of the panel. It decreases as the temperature increases and it increases as the temperature decreases. The electrical power obtained from the panel is calculated from the known table that shows the value of electrical power at a certain temperature of the board. The row vector representing the total power of the module ranges from 1 to 1501 W/m^2, whereas the column vector represents the temperature of panel ranges from 30-70 ^oC

2.2.4. Heat power obtained on the fluid

The product of absorption-transmission is the product of absorption factor and transmission factors. Absorption factors are defined as the ability of the body absorbing the sun's maturation, whereas transmission factors are defined as the amount of solar dosage that passes through the body of the panel. The system has a pipe absorber through which cold water flows and draws the heat energy from panels, which results in a decrease in panel temperature, and therefore the greater electrical power panel efficiency achieved.

Simultaneously, the thermal power obtained is the thermal energy that can be used for preparing domestic hot water in the house, which considerably improves the efficiency of the overall system. The heat power of the Qu panel in accordance with Hottel-Willier's equation is [25].

$$Q_u = A[L_{tt}\,(\alpha\tau) - U_L\,(T_{Mod} - T_{amb}) \tag{16}$$

where: UL stands for total loss of heat, ατ is the absorbing transmission product.

From (16), one can see that thermal removal factor is a very non-linear function. All the variables, apart from mass flow, are constant depending on the construction and the physical characteristics of the system itself. Heat dissipation rate is extremely low as flow increases. Thus, under (1), the electrical output of the pump is cubical as the flow increases, so it may be concluded the efficiency of the entire system will decrease with high fluid flow.

3. RESULTS AND DISCUSSION

3.1. Simulation results before optimizing the system functioning

Before displaying simulation results, it is necessary to define all the parameters used in the system. Tables 2 and 3 show the main thermal PV system parameters and their values. Figure 3 shows the dependence of total panel dosing of on the total radiation that falls on titled panel surface, while the Figure 4 demonstrates the panel temperature dependence of the fluid flow. Figure 5 shows the dependency of the net energy output of the panels on fluid flow, and Figure 6 illustrates the efficiency of the panel in relation to the fluid flow. From the simulation it becomes clear that the temperature in the panel decreases at a flow of up to 15 Kelvin for the warmest part of a day (from 10 h to 16 h). By reducing the panel surface temperature, the panel's electrical efficiency increases by 1.5% over the same period during the day, as can be seen in Figure 6.

For net electrical efficiency, Figure 5 illustrates the system is energy efficiency at full capacity only for the warmest part in the day. When the panel temperature does not rise above 40 ºC it becomes energy efficiency and therefore economically cools down the panel at the maximum steady flow because small amounts will fall onto the board in the morning or early evening.

Table 2. Main photovoltaic panel parameters used in this system [18]

Parameters of panel	Value	Parameters of panel	Value
total area (A)	24,895 m2	absorption factor	(α) 0.7
coefficient of total emission factor module (ϵ)	0.9	Transmission-absorption factor	0.53
heat loss	5 W/m2K	geometric factor	0.92

Table 3. Main pump parameters used in this system [21]

Pump parameters	Value	Pump parameters	Value
Coefficient of mechanical losses (K)	15	pipe radius (r)	0.011 m
fluid density (ρ)	1000 kg/m3	maximum power	50 W
Thermal capacity (c)	4186 J/kgK	input temperature in panel	18 ºC

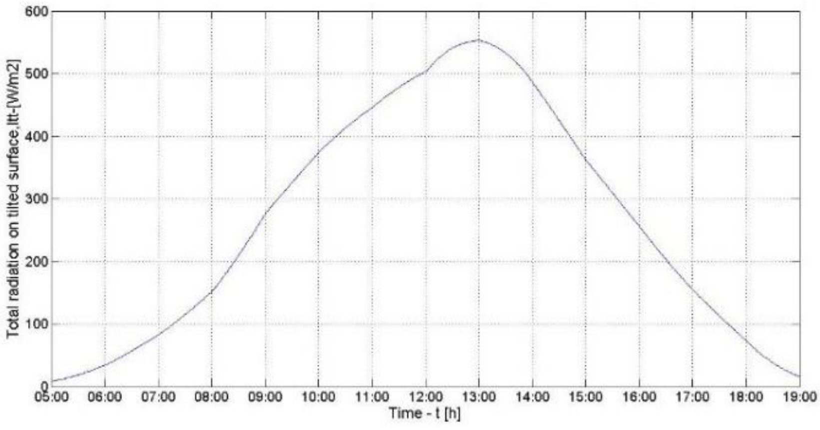

Figure 3. Total radiation falls onto the surface of the titled panel

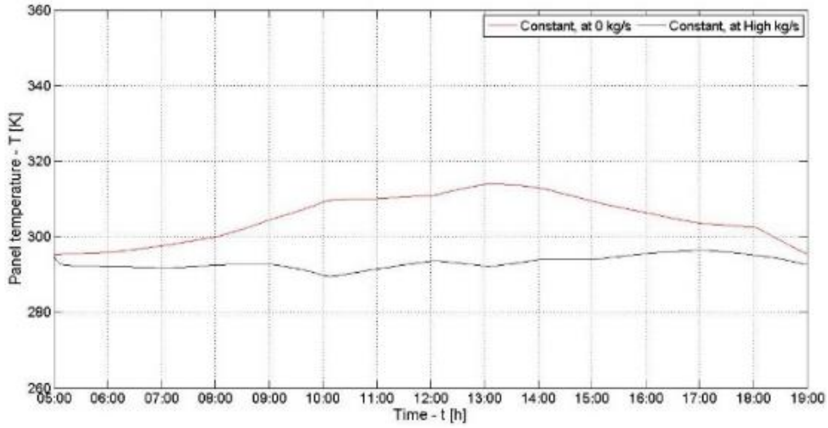

Figure 4. Photovoltaic thermal panel temperature prior to system optimization

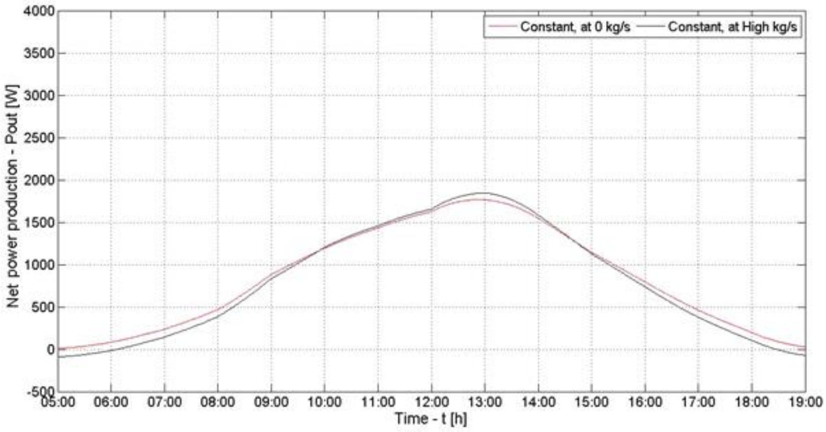

Figure 5. Net electrical output power of the PV panel prior to system optimization

Due to the low dosage of the panel, the power obtained on the modules is reduced, whereas the electrical power built into the pump remains consistently high, leading to inefficiency of the overall system. Thus, it is clear that the net electrical efficiency is negative in the mornings and in the evenings, so it will be necessary to spend the electricity from the mains to get the desired pump operation. It is therefore necessary to optimize your system so that the mass flow of fluid into the system controls the overall ripening of the panel throughout the day.

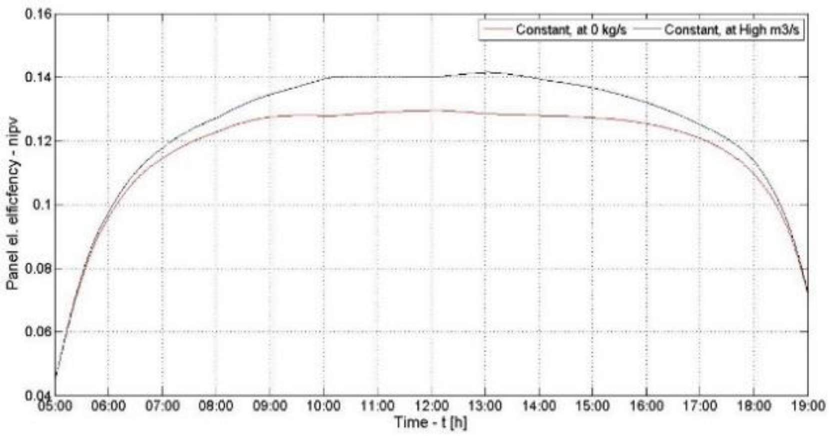

Figure 6. Efficiency of the photovoltaic panels before system optimization

3.2. Results of system simulation after optimization

Using the finite algorithm, which is included in the work scheduling solutions, we achieved the optimal stream values in a 15-minute resolution. The optimum flow obtained for the resolution in a minute is illustrated in Figure 7. The system energy budget is shown in Table 4, shown for the day when using only one photovoltaic module, when a hybrid system (constant high flow) is employed and when using an optimized flow.

Table 4. Energy balance of the system

Module	Electrical efficiency (%)	Thermal efficiency (%)	Total efficiency	Output heating energy (kW/h)
PV	21.4	0.000	12.22	0.00
PV/T	8.15	62.72	71.72	59.54
PV/T with optimizing flow	31.51	60.50	74.75	56.28

The optimized flow algorithm is achieved as shown in Figure 7, with the optimized flow controlling the change in overall dose to panel, and therefore changing the temperature of the panels throughout the day. As a result, the resulting current has a shape of parabola, which is expectable because the lowest current is required in the morning and evening when panel temperature is at its minimum and requires minimal cooling, while the highest current is in the afternoon when the panel temperature is highest. This results in a noticeable improvement in net panel power gained and total system efficiency, which are illustrated in Figures 8 and 9.

Figure 7. Optimized flow of the fluid across the panel at one minute resolution

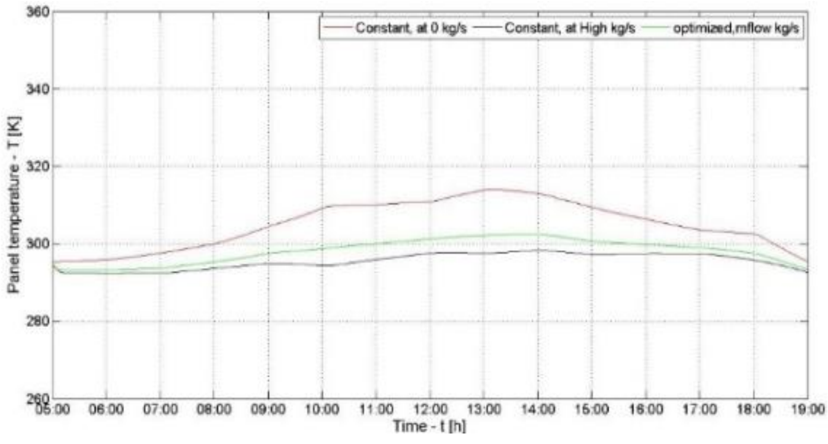

Figure 8. Temperature of the photovoltaic heat panel after the system optimization

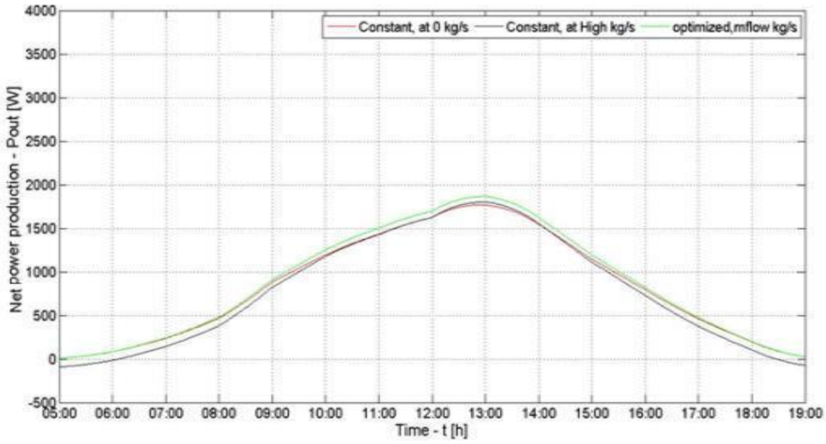

Figure 9. The Net electrical output of the photovoltaic module after system optimization

From the obtained optimized fluid flow across the panel, we obtained the results for simulations showing module temperature, solar photovoltaic system net power, overall electrical efficiency of the system at zero flow, at maximum flow and at the optimized flow. The optimized algorithm aims to achieve the maximum net power from the system. For the observed system, a maximum value must be set for the function that indicates the difference between the output on the panel and the required power in the pump. Because the only controllable variable in the given system is mass flow, an optimized algorithm should implement by that variable.

The control of the mass flow would be obtained with the 15-minute resolution of the pump's electrical power. From the simulation results obtained, it is clear that there has been a noticeable improvement in terms of the electrical efficiency of the overall system and the obtained net power system. There is no more efficiency loss. For the daytime period when a small dose is on the panel, since a small current then goes through the system.

During the evening and early morning hours, the flow rate is about 0.1 kg/s, so the amount of electric power required to start the pump is just a few watts, for the flow of 0.1 kg/s. The pump power required is around 1.52 W. At the hottest time of the day, when the panel temperature is also at its maximum and the panel is being cooled most extensively, the flow rate rises to 0.4 kg/s, which requires a power pump of about 40 W.

From the results obtained, it can be seen that through optimizing the system algorithm, we can achieve the desired system management, i.e. allowing the panel mass flow to be matched by variables which affect the resulted panel electrical power, the total dose and a panel temperature. As a result, there is much better system management in the daytime period when small dose is compared to a constant high flow and high-quality behavior in the hottest part of the day when compared to the non-cooled system.

4. CONCLUSION

The aim of this research is to study the possibility of a photovoltaic-thermal water system by using a mathematical module. On this article an experiment is currently underway to analyze numerically the photovoltaic- thermal fluid-cooled system using CFD computational fluid dynamics method. A model of a basic thermal-photovoltaic system made up of a water tube and an absorbing absorber plate to produce the complete heat analysis module was simulated in this research. In order to obtain numerical results, a combined heat transfer analytical method has been applied. Impacts of temperature change of incoming water and solar absorbed sunlight have been considered.

Both temperature distribution on the absorber board and the outlet water temperature have been estimated in temperature curves. The results obtained showed that the system delivers a significant improvement in the net electricity efficiency of 3.52% and a slight reduction in thermal efficiency by 1.96% over the system when using a constantly elevated flow. Whereas with respect to the photovoltaic module proper the net electrical efficiency improved by 0.35%. Results obtained from CFD simulators were compared with experimental results from the documentation. The numerical simulation results match the results of the experiments measurements in the documentation.

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