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Simulation Study of the Design of a Hybrid Photovoltaic-Thermal System (PVCT) by Exploiting Solar Concentrators

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Abstract: Photovoltaic conversion of solar energy by solar panels occupies an important place as a clean, renewable and widespread energy that can meet domestic and industrial needs in terms of electricity demand, but the efficiency of this conversion remains relatively low. Therefore, in this theoretical study, we constructed a model of a parabolic cylindrical solar concentrator which is fixed on the absorber tube with a 105*54 cm solar panel that receives concentrated solar radiation, to increase the electrical capacity of the panel on the one hand, and to avoid excessive temperature rise of the panel due to the concentration of solar radiation by the flow of the fluid in the absorber tube and the production of hot fluid on the other hand according to a hybrid photovoltaic-thermal system with solar radiation concentration (PVCT). The results showed that on July 15, the solar panel produced by the system (PVCT) a capacity exceeding 315 W over the entire duration of insolation and its maximum value reached 515 W, while on January 15, the solar panel produced a capacity of 515 W, in addition to the production of hot fluid that can be exploited in several domestic and industrial uses under a temperature reaching 60° C.

Keywords: *solar concentrator, hybrid photovoltaic concentrator, solar panels, solar thermal*

1. Introduction

As the global community intensifies its efforts to shift towards sustainable energy sources, solar energy has emerged as a pivotal contributor to this transformation. Hybrid photovoltaic/thermal concentrated solar power (CSP) systems represent an advanced approach to solar energy utilization, integrating photovoltaic and thermal technologies to produce electricity and heat from the sun. This integration takes advantage of the strengths of both PV and thermal systems, resulting in higher overall efficiency and energy efficiency compared to conventional systems that use either technology alone (Zhao et al., 2017)

Photovoltaic/thermal systems use solar concentrators to concentrate sunlight onto a smaller, more efficient surface area than photovoltaics, greatly increasing electrical output while simultaneously generating useful heat. This dual-generation approach not only maximizes the total energy harvested, but also improves the performance of the photovoltaics by reducing their operating temperature, a critical factor because the efficiency of photovoltaics declines with increasing temperature (Kalogirou, 2009). By extracting and utilizing thermal energy, hybrid photovoltaic/thermal systems can provide hot water or heating in addition to electricity, thus meeting multiple energy needs with a single system (Chow et al., 2010).

The concentrating technology in these systems is particularly useful in applications where space is limited, as it allows for higher power densities. Advanced optical designs, such as parabolic troughs and Fresnel lenses, are commonly used to achieve this concentration (Bellos & Tzivanidis, 2018). These designs focus sunlight onto a PV/T receiver, which typically consists of highly efficient PV cells coupled with heat absorbers, allowing for high-efficiency heat transfer and storage (Chow, 2010).

Moreover, the development of hybrid PV/thermal power systems is in line with the goals of reducing greenhouse gas emissions and dependence on fossil fuels. By providing a sustainable and renewable source of energy, these systems contribute to mitigating climate change and enhancing energy security. The economic viability of PV/thermal power systems is also improving with advances in materials and manufacturing processes, making them more competitive with conventional energy sources (Huang et al., 2016).

Therefore, the exploitation of concentrated photovoltaic (PV/T) hybrid systems becomes a complete solution to make the most of solar energy and combine electricity and heat production in a compact and efficient way. In many residential, commercial and industrial applications, paving the way for a more sustainable energy future.

In this theoretical study, a photovoltaic panel measuring 105 * 54 cm was exploited mounted on a cylindrical tube fixed in the focal axis of a parabolic cylindrical reflector,

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where the solar radiation is concentrated on the solar panel on the one hand, and on the other hand, where it is cooled by the liquid flow in the cylindrical tube, and through this modeling, we obtain by simulation the electrical energy and electrical efficiency of the concentrated radiation photovoltaic-thermal hybrid system (PVCT) and compare it with the non-focused solar radiation photovoltaic-thermal hybrid system **(PVT), while exploiting the** thermal study to calculate the fluid temperature, i.e. a winter day, January 15, and a summer day, July 15.

2. PTC Geometry

The PTC consists of a parabolic cylindrical reflector with a cross-sectional equation

$$y = \frac{1}{4f}x^2 \quad (1)$$

wherefis the focal dimension and for the dimensions of the PTC: length L, aperture width w, and reflector ̊edgeheight hc, the focal dimension f is given by the relation [1,2] :

$$f = \frac{w^2}{16.h_c} \quad (2)$$

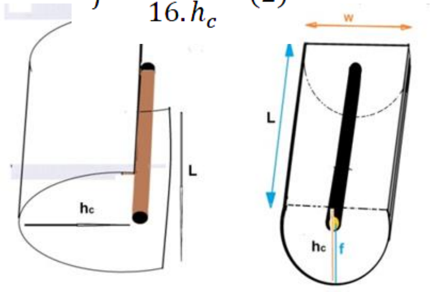

Fig1. the dimensions of the PTC

3. Acceptance angle θ_R

It is the angle between the vertical axis (OZ) and the line connecting the focus and the reflector edge and is given by the relation [3,4,5] :

$$\theta_R = \arctan\left[\frac{\frac{w}{f}}{2 - \frac{1}{8}\left(\frac{w}{f}\right)^2}\right] \quad (3)$$

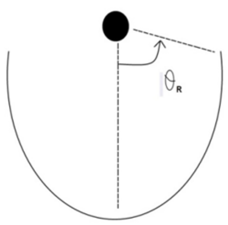

Fig2. Edge angle θ_R of the PTC

4. Optical study

The PTC receives direct solar radiation I through the aperture area $A_{ap}$where

$$A_{ap} = L.w \quad (4)$$

The direct solar radiation is focused by the reflector towards the receiver

The part of the receiver that concentrated radiation reaches has an area of

$$A_{r,Icr} = 2\theta_R.D_r.L \quad (5)$$

And the radiation concentration in this part has an area of

$$C_r = \frac{A_{ap}}{A_{r,Icr}} = \frac{L.w}{2\theta_R.D_r.L} = \frac{w}{2\theta_R.D_r} \quad (6)$$

As for the part of the receiver that receives direct, unfocused radiation $A_{r,I}$,its area is

$$A_{r,I} = (\pi - 2\theta_R)D_r.Ls \quad (7)$$

Optical efficiency

The Optical efficiency of the PTC is related to the reflection coefficient $\rho^0$of the reflective surface and the interception coefficient γand the angle of incidence of solar radiation i and its expression isgivenas [6,7] :

$$\eta_{opt} = \rho^0.\gamma.\cos(i) \quad \mathbf{(8)}$$

5. Mathematical modeling of the PV solar cell

Given Equivalent circuit of a real solarcell PV Figure (03)

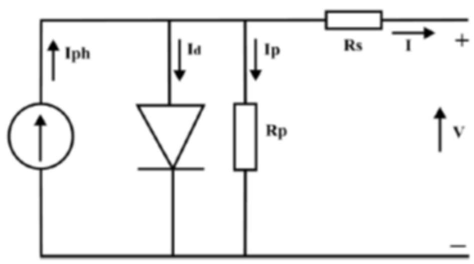

Fig3. electronic diagram of pv cell

$$I_d = I_s\left[\exp\left(\frac{q\,(V + IRs)}{N_sKAT_o}\right) - 1\right] \quad \mathbf{(9)} \quad [4]$$

$$I = Iph - I_s\left[\exp\left(\frac{q(V + IRs)}{N_sKAT_o}\right) - 1\right] \quad \mathbf{(10)} \quad [8,9]$$

$$I = Np * Iph - Np * I_s \left[\exp\left(\frac{q(V + IR_s)}{N_s KAT_o} \right) - 1 \right] \quad (11) \quad [9]$$

$$Iph = [I_{sc} + Ki\,(T_o - T_r)] * \frac{G}{G_{ref}} \quad (12)$$

6. Methods and techniques

In this theoretical study, we relied on modeling a hybrid solar photovoltaic-thermal concentrator system (PVCT) so that the solar concentrator PTC is chosen according to the dimensions and properties shown in Table (01) and a cylindrical solar photovoltaic panel is installed on we relied focal axis of the reflector where the solar panel carries the properties shown in Table (02) and the solar panel is to cooled according the photovoltaic-thermal hybrid system through the flow of fluid through the absorber tube Figure (04)

Table 1. Dimensions PTC

Length L	105 cm
Width W	160 cm
Diameter of the absorbent	4.3 cm
Geometric concentration C	11.85
Acceptance angle	126.8°

Table 2. Solar Panel Properties

Model No :	FFXS-100W
Solar panel size :	1050*540*2.5
Voltage at max	17.6(V)
Current at max	5.68(A)
Short circuit	6.25(A)
Open circuit	20.8(V)
Numberof cells and	32pcs(4*8)
Operating Temperature	- 40ºC-+85ºC

The results of this hybrid system (PVCT) were compared with the same hybrid system subject to direct solar radiation without concentration (PVT)

This study was conducted based on the meteorological and climatic data of the Ouargla region (southern Algeria) and the coordinates of the region and its properties are given in table (03), for the study were chosen the winter day of January 15 and the summer day of July 15 to compare the results and the behavior of the PVCT hybrid system on these two days

The simulation process for the photovoltaic and thermal systems was carried out according to the MATLAB program, taking into account the following simplify ingassumptions:

1- Neglecting the shapedefects of the PTC inverter

2- Installing the solar panel on the absorber tube accuratly tight to maintain the cylindrical shape

3- Neglecting the thickness of the solar panel in the thermal study

4- Considering the study days January 15 and July 15 as clear days free of clouds and dust

7.Thermal study of the PVCT system

The surface of the PV installed on the absorber tube receives concentrated solar radiation on the area$A_{r,Icr}$ while receiving direct solar radiation with out foc using on the remaining area$A_{r,I}$, and heatistransferredtowards the absorber tube and then to the fluid using different heat transfer patterns (conduction, convection, radiation) and the heat balance equations are given for the different surfaces (solar panel *PV*, absorber tube *r*, fluid *f*)

7.1.Surface of the solar panel (PV)

$$\rho_{PV}.e_{PV}.Cp_{PV}.\frac{dT_{PV}}{dt} = I.\frac{A_{ap}}{A_{PV}} + h_r(T_{Sky} - T_{PV}) + h_{Cv1}(T_a - T_{PV}) + h_{cn}(T_r - T_{PV}) \quad (13)$$

7.2. Surface of the absorbing tube (r)

$$\rho_r.e_r.Cp_r.\frac{dT_r}{dt} = h_{cn}(T_{PV} - T_r) + h_{Cv2}(T_f - T_r) \quad (14)$$

7.3.Fluid

$$G.Cp_f.dT_f = h_{Cv2}(T_r - T_f) \quad (15)$$

7.4.The thermal efficiency of the hybrid systemis as

$$\eta_{th} = \frac{G.Cp_f(T_{fs} - T_{fe})}{I.A_{ap}.\eta_{op}} \quad (16)$$

HELLP syndrome and its class 1, 2, and 3 subgroups, respectively. The results will graphically present.

8.Analysis and discussion of the results

8.1.Solar radiation intensity

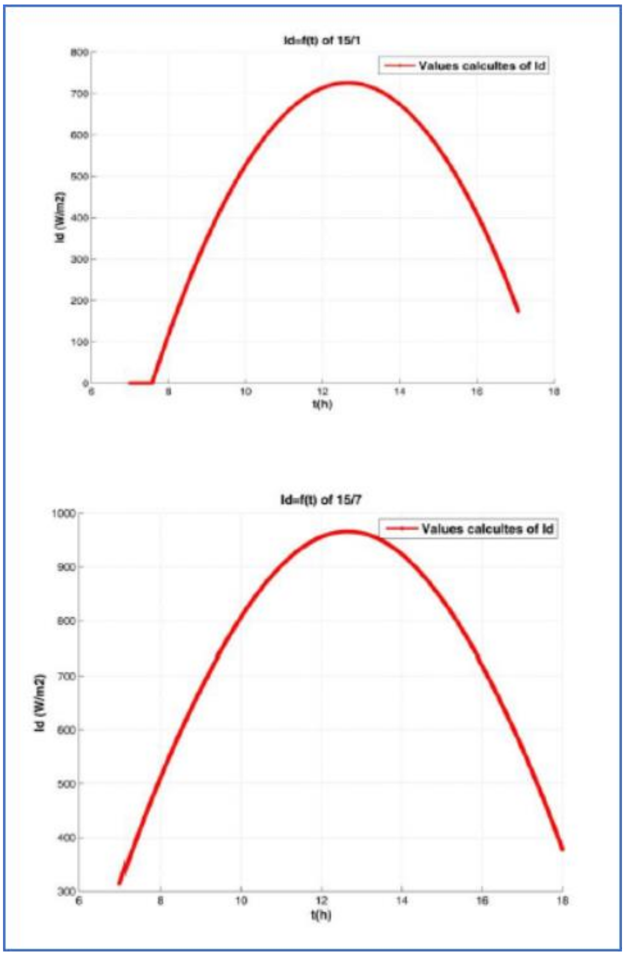

Fig4. Variation of Solar Radiation Intensity during the time

Show the figure (4) the solar radiation intensity increases in Ouargla region from sunrise to reach it speak at noon and then decreases until sunset, where itre a ches it speak on January 15th: 730 w/m2, while on July 15th, it reaches 970 w/m2

8.2.Current intensity as a function of voltage

Show the figure (5) In the absence of solar radiation concentration, We note thatthe maximum current intensity at midday on January 15this 5.4 A, while at the same time on July 15this 7.2 A. The open circuit voltage at midday on January 15threached 21.2 V, whileitreached 20.8 V at thesame time on July 15th.

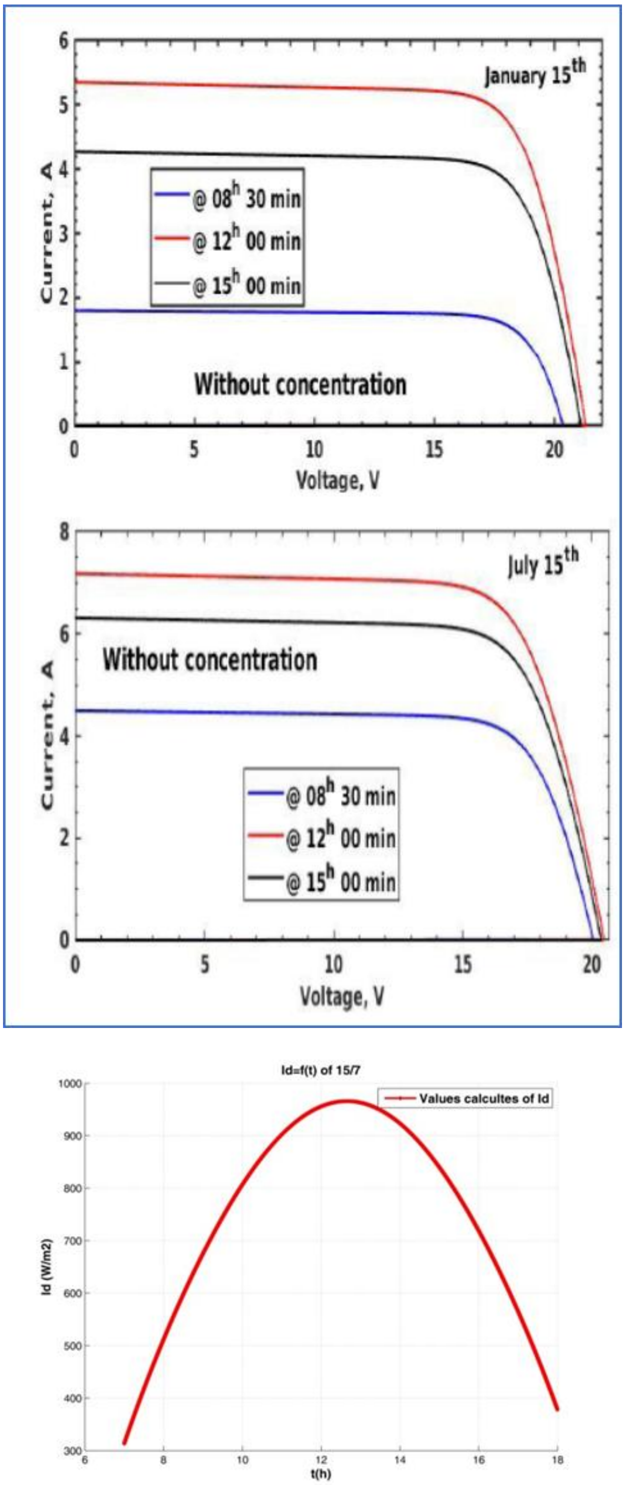

Fig5. Variation of current with voltage

8.3. Power as a function of voltage

Show the figure (6) and (7) we note that in the absence of the concentration of solar radiation, the maximum power at midday on January 15threached 87 W, it reached 110 Wat the same time on July 15th. When solar radiation is concentrated by PTC, the maximum power on January 15th increases until it reaches 515 W at noon ;then decreases.

While on July 15th, the maximum power remains stable between 400 W and 500 W throughout the sunning period, and at noon it reaches 515 W.

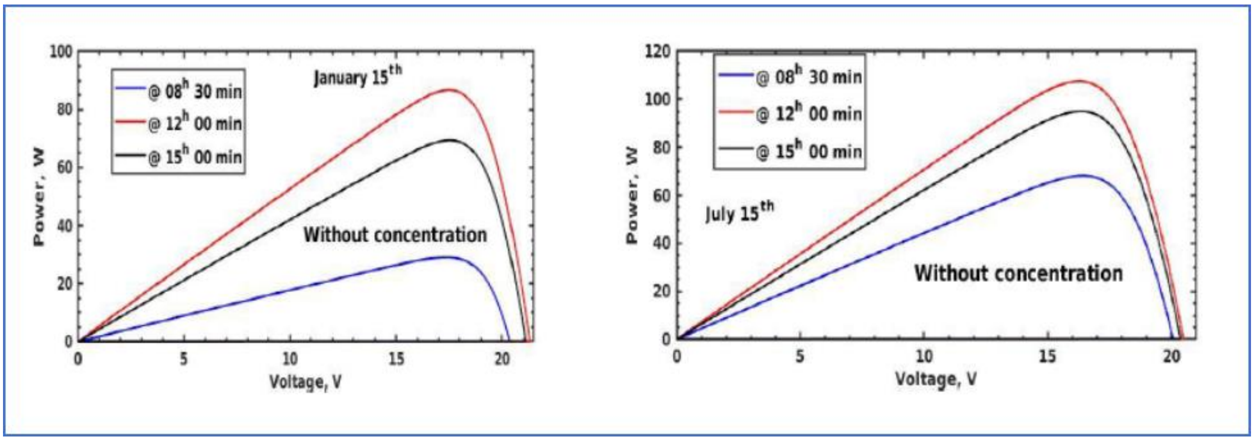

Fig6. Variation of power with voltage

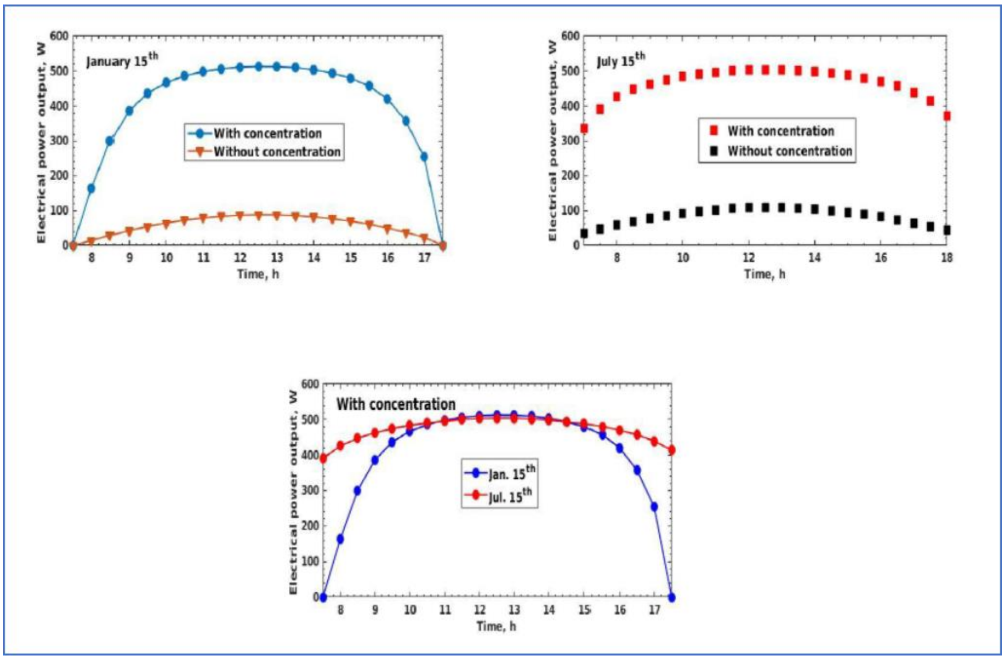

Fig7 . Variation of electrical power output with time

8.4. Electrical efficiency

By showing Figure (8), we notice that in the case of concentrating solar radiation by PTC, the electrical efficiency on January 15 starts from 21% then decreases, and due to the rise in temperature until noon, it reaches 12% then increases again in the afternoon. On July 15, the electrical return starts from 16% then decreases due to the rise in temperature until noon, it reaches 8% then increases again in the afternoon..

When solar radiation is not concentrated, the electrical efficiency on January 15 stabilizes during the insolation period at 18%, unlike the concentrated case, where the efficiency decreases until the afternoon, while on July 15 it stabilizes during the insolation period at 20%, unlike the concentrated case, where the efficiency decreases until the afternoon due to excessively high temperatures.

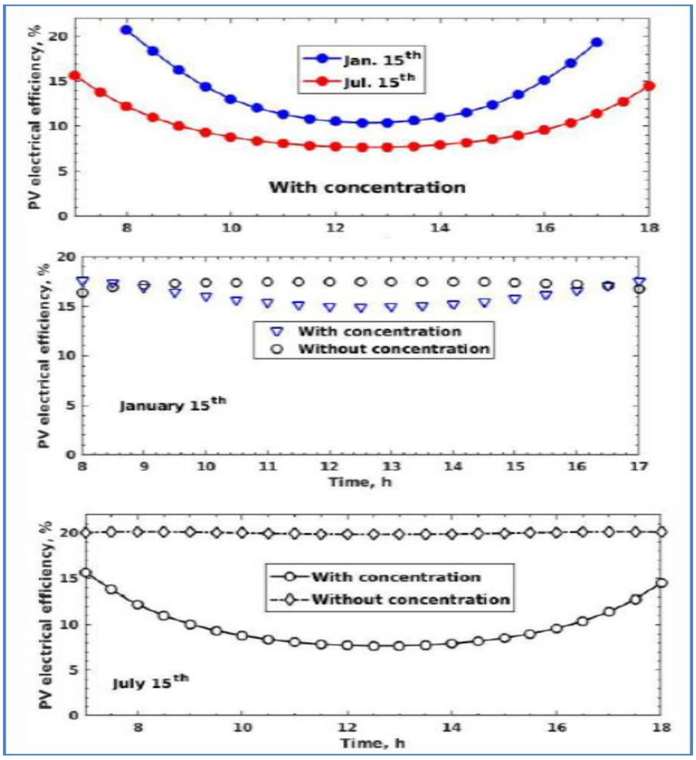

Fig8. efficiency curves

8.5.Fluid temperature in the hybrid system

Show the figure(9) for a fluid flow rate of 0.05 Kg/S, the fluid temperature increases from sunrise to reach a peak at noon where it reaches 27°C on January 15, while it reaches 63°C on July 15, then decreases in the afternoon until sunset where the fluid can be used in various thermal applications with closed or open cycles, and at the same time the solar panel is cooled to increase the electrical efficiency

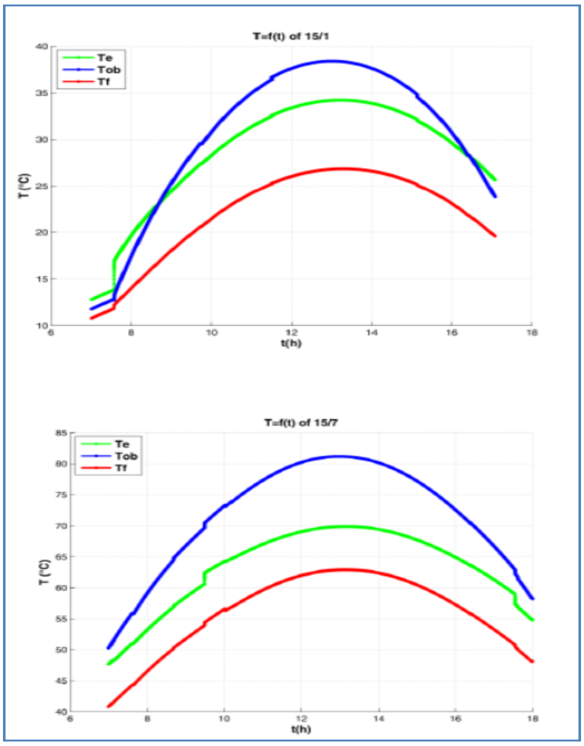

Fig9. Fluid temperature curves

9.Conclusion

n this theore ticalinquiery, a photovoltaic solar panel was modeled and numerically simulated according to two hybrid systems, one integrated with a solar concentrator(PVCT) and the second without concentrating solar radiation (PVT). The results were compared between the two systems on two typical days, a winter day and a summer day.

Were ached the following results::

1 On July 15th, the solar panel produced a power exceeding315 W according to the (PVCT) system over the entire sun exposure period, and its maximum value reached 515 W, while the same solar panel produceda maximum power of 110 W in other words an increase of 368.2%according to the (PVT) system without concentrating solar radiation

2 On January 15th, the solar panel according to the (PVCT) system produced a maximum power of 515 W, while the same solar panel according to the (PVT) system without concentrating solar radiation produced a maximum power of 87 W, an increase of 591.9%.

3 On July 15th, the electrical output of the solar panel according to the (PVCT) system starts from 16%, then decreases to reach 8% at noon, then increases afternoon.While the electrical output in the case of the (PVT) system is stable at 20% during the sun ning period. This decrease in the output in the (PVCT) system is due to the rise in temperature swhen concentrating solar radiation, especially at noon.

4 On January 15th, the electrical output of the solar panel according to the (PVCT) system starts from 21% then decreases to reach 12% at noon then increases afternoon while the electrical output in the case of the (PVT) system is stable at 18% during the sun ning period. This decrease in the output in the (PVCT) system is due to the rise in temperature swhen concentrating solar radiation, especially at noon.

5 When using solar concentration systems, they must becombined with a hybrid photovoltaic-thermal system where the excessive heat of the solar panel is absorbed due to concentration on one hand and the hot fluid is produced for use in thermal applications on the other hand, especially in winter.

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