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Beneficial effects of water circulation on PV glazing surfaces for improving solar electricity generation

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***Abstract*— In this study, it was explored the cooling from the front side glass of photovoltaic (PV) panels to enable an optimum operation in warm regions. Indeed, the loss of power and voltage is well known in the case of PV cells and modules with increasing temperature. In real operating conditions, thermocouples are placed on the glass of the PV module and on its back side. These experimental measurements have revealed temperatures reaching over 70 ° C without cooling; with deviations up to 12 ° C between the two faces. Water cooling on the front side of PV module is very effective for both sides and results in more stable and uniform temperatures compared to previous known technologies of backside cooling. From a simple and economical method of cooling according to an experimental prototype, it was noticed a decrease of over 20 ° C temperature for short cycles between 5 and 10 minutes saving the energy consumption of water pumping and demonstrating the importance of this method.**

***Keywords*— Solar Energy, Photovoltaic, Glazing, Temperature, water cooling**

I. INTRODUCTION

Photovoltaic solar energy is increasingly utilized in the growth of new cities and regions in the context of sustainable and ecological development. The Middle East and North Africa (MENA) region is one of the most advantaged in the world from its solar potential [1]. It was noticed a huge development these last years in several localities, as for example in Masdar City [2]. Where, the first PV power plant of 10 MW installed in 2009, has been expanded to 200 MW in 2014 and quickly pushed to 800 MW in 2016. This last power plant has been contracted from a Power Purchase Agreement (PPA) project allowing to break a cost record of generated solar electricity for 2.99 c$/KWh and as a first time cheaper than electricity of fossil origin [2]. Also, an important renewable energy program is planned in Algerian regions and where 22 GW of renewables power plants are targeted for 2030 containing a big part that will be generated from Photovoltaic technology (13.5GW) [3]. In these regions, two major issues are to be fixed: the sand dust accumulation and high ambient temperatures around sometimes 50 ° C. In this context, it is proposed the study of overheating and soiling of PV modules. These could be settled by implementation and experimentation of their front side by water spraying. A prototype at reduced scale is designed and tested with in situ measurements by thermocouples to demonstrate the effectiveness of this concept for PV glazing cooling. Also, it should be remarked that various other authors' studies [4, 5, 6] about cooling from the backside of PV module have already been addressed. The backside water cooling technic conducts to higher implementation costs and a drawback of the non-uniform temperature on the module creating a mismatch problem between the branches in the module itself. Conversely, by this study, it is proposed to realize front side water cooling of PV module which is simpler and cheaper method that should allow a uniform module temperature distribution and in the same time fixing the dust cleaning issues. Furthermore, in our previous study about soiling problematic, it was proposed an efficient answer through Nano coating [7].

II. EXPERIMENTAL

The principle of the developed prototype scheme is shown below on Fig.1 as well as in its real picture on Fig. 2. It is composed of a PV panel, a water circulation spraying system controlled from thermostatic actuator allowing to power a 12 V DC pump. A charge regulator is installed to assure management of energy storage in a solar battery of 150 Ah. A water tank and a filter are used. A data logger acquisition system that is plugged to a PC allows records of back and front sides temperature from K thermocouples hooked on PV panels. 12 litres of Distilled water is filled in the tank reservoir.

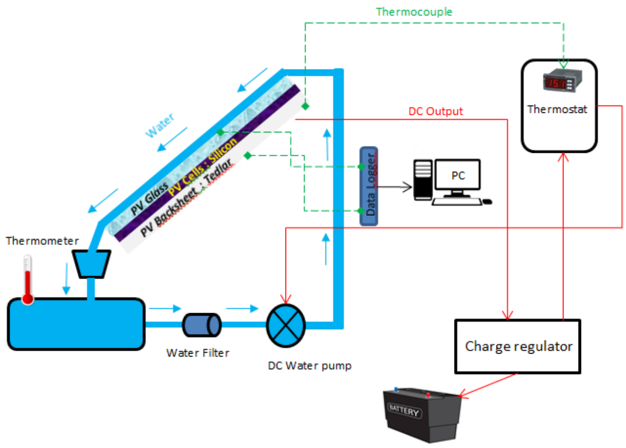

Fig. 1 Schematic principal of developed prototype

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Fig. 2 Outside Picture of realized prototype

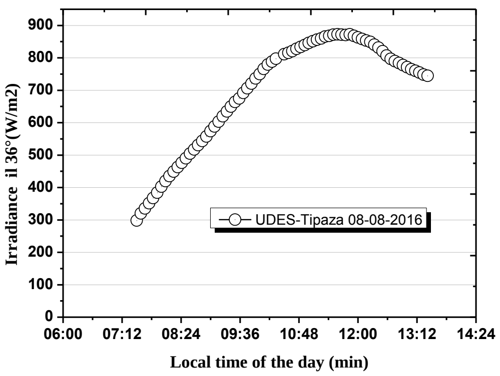

Fig. 3 Direct Irradiance 36° UDES-Tipaza site (08-08-2016)

III. Results and Discussions

In this work, a 150W PV module of 1.08m2 area is applied, of model PS-M60S-150 from Philadelphia Solar Company. The Figure 3 presents the recorded direct radiation corresponding to an inclination of 36 ° during the experimentation in a summer day. Also, the metrological data are reported on Table 1.

TABLE I
METROLOGICAL CONDITIONS

Meteorological test condition	Value
Irradiance (W/m2)	870
Wind speed (m/s)	3.22
Relative Humidity (%)	72.8
Air Temp_Avg (°C)	26.52
Air Pressure (hPa)	1010.6

The Fig. 4 shows the different cooling cycles practiced on PV module. The figure 5 indicates the measuring points repartition in times. It should be noted that a water spray from DC pump flow (5.9 l / min) was maintained for 6 minutes to allow both the removal of dust but also cooling the PV panel which is the subject of this first study. Dust and their effects are studied separately in another paper [7]. One starts the cooling of the PV module at 11:42 am, experimental measurement results with solar analyzer and the curve IV and PV are shown on curves of Figure 6, the table 2 summarizes the evolution of PV module electrical properties during the cooling cycle. The variation in the temperature between front and rear face of the PV module is shown in Fig.6-c, it is noted from this curve that the front face becomes colder than the rear face after cleaning; a deference of 3 ° C is recorded between both sides.

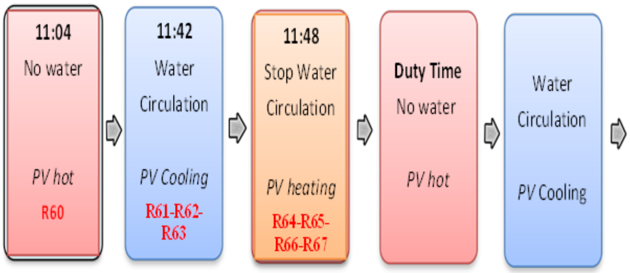

Fig. 4 Example of front side water cooling-cleaning cycles for the PV module

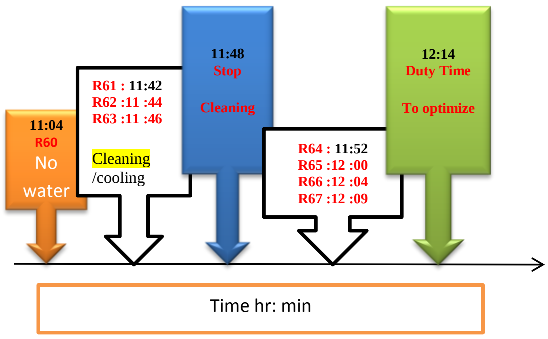

Fig. 5 Time repartition of water cooling-cleaning cycles and data acquisition

Initially, the PV panel is kept to be heated from sun radiation for 40 minutes in the meteorological conditions summarized in Table 1. Then, the temperature of front side is stabilizing at about 70 ° C, this is higher than that of the rear face temperature of 55 ° C; this represents a difference of 15 ° C.

Water circulation cycle time of 6 minutes is applied to allow an inversion in the difference tendency for making the front side cooler than the rear with a gap of about 4 ° C. The curve 6-c shows that spraying of water for 6 minutes allows achieving a stable bearing for the temperature of the front and rear sides.

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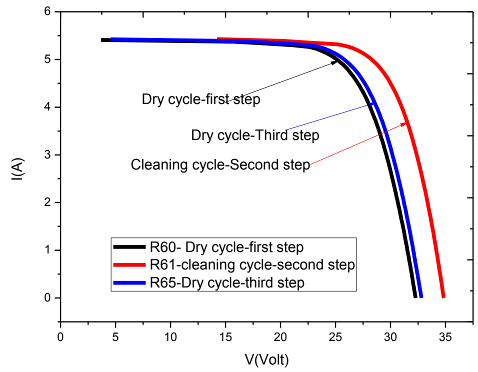
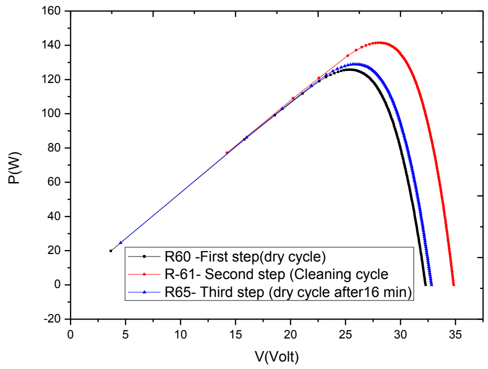


a



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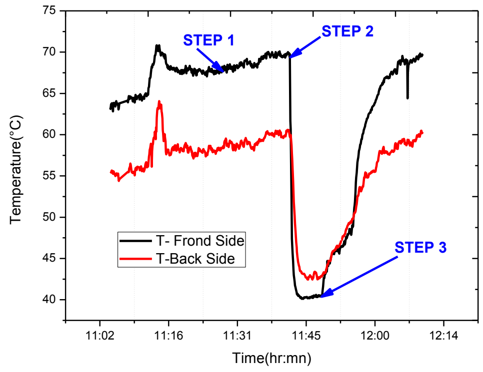

c

Fig. 6 Experimental results, a) I-V curve, b) P-V curve, c) font and back side PV module temperature
a) R61 b) R62 c)R63 at irradiance intensity of 870W/m²

In addition, for the sake, water saving and energy the flow of water spraying is stopped after 6 minutes. The PV module shows a heating cycle and reaches the initial temperature at the end of 30 minutes; the reached temperature is 70 ° the front and rear 55 ° C. The goal of this first approach is to determine the optimal time of the "duty cycle" to allow an energy gain by integrating all cooling-cleaning energy consumed by the pump. The analysis should be doing the calculation of consumed energy by pump, which is E_{pum} during 6 minutes equivalent to 0.1 hour. The 12 V DC pump current is 3.2 A. The experimental measurements were used to measure pump supply current I_{pump} = 3.2 A for a flow rate of 5.9 L / min. So, the real power of the pump is 12 X 3.2 = 38.4 W. The energy consumed by a 6 minute cooling cycle is 3.84 Wh.

E_{pump} = Pump Power X water circulation time ($12xI_{pump}$) X 0.1 = 3.84 Wh.

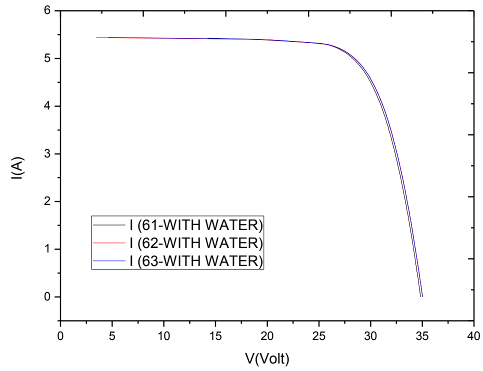

Fig. 7 I-V propriety of PV module under water cleaning cycle R61/R62/R63

Thus, the energy gained from PV modules by cooling must be estimated. For that purpose, P-V and I-V curves are plotted on Figures 6 a-b and 7 by using the measuring equipment Prova 200. Also, Table 2 summarizes these results. Therefore, it is attained a peak power of 141.4 W for cooled module and 125.6 W when the module is stabilized in the heating phase. The immediately energy recovered is $E_{cool\_recorvred}$ and formulated by:

$E_{cool\_recorvred}$ = (141.4-125.6) X 0.1= 1,58 Wh

TABLE III
PV ELECTRICAL PARAMETERS VERSUS COOLING CYCLES

PV Electrical parameters	PV heating R60	PV Cooling R61	PV Module After stop R65
V_{oc}(Volt)	32.30	34.84	33.82
I_{sc}(A)	5.443	5.461	5.459
P_{max}(W)	125.6	141.4	128.9
η(%)	13.35	15.04	13.71
FF(%)	0.714	74.3	71.3

This energy gain can cover the supply of the DC pump that will be common to a string of several panels. The number of PV panels on the PV string will depend on the module width, water flow rate, pressure and diameter of the water circuit. Our first experimental estimation shows that we can have 7 PV of

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the studied model PS-M60S-150 of 150 W panels in a common string.

TABLE 3. 8000 SERIES DIAPHRAGM PUMP (12 VDC) CHARACTERISTICS

Model	**8000-443-136**				
Description	**1.8 GPM open flow, EPDM valves, Santoprene® diaphragm, 60 PSI Demand Switch, 1/2" MPT-Male ports, Poly Housing**				
Voltage	12 VDC				
PSI	20	30	40	50	60
BAR	1.4	2.1	2.8	3.4	4.1
GPM	1.57	1.48	1.38	1.30	1.23
L/min	5.9	5.6	5.2	4.9	4.6
Amps	4.2	4.9	5.6	6.9	7.2

Fig. 8. Water pump 12 V DC applied to spray water on PV module

First of all, we will have to cover the energy needs of the DC pump that assure cleaning-cooling of PV panels. Considering that its power is 38.4 W and viewing that the peak power gap between the cooled and heated panels is 15W, each DC pump could be will powered by a PV field generator of 38.4 / 15 = 2.56 ≈3 PV panels of 150W PS-M60S-150 to ensure its energy needs. During the heating phase, that lasts about 30 minutes the module allows to make energy gains from its initial state. The estimate of this gain will be by done a linear fit approximation as shown in the following Figure 9.

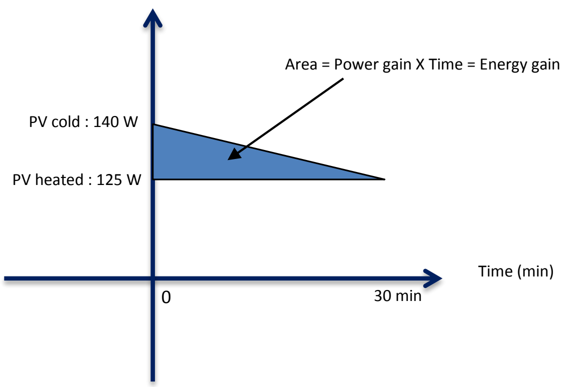

Fig. 9. Estimation of Energy gain during heat cycle from a linear fitting

There is an Energy gain during heating phase E gain_heat of (140-125) X0.5heure Watt / 2 = 3.75 Wh in the experimental test of condition during a summer day presented here (irradiance = 870 W / m2) for each 150W panel.

E gain_cool is defined by:

$E_{gain\_heat} = (P_{cool} - P_{heated}) \text{ X } 30 \text{ min}$

How many panels per string will be supplied by the considered DC pump? As previously explained, our first calculations showed that we can easily feed 7 PV panels (1m wide by panel) per each DC pump. Now, we can assess the gain on a PV power plant of 1 MW as for example.

-The 7 panels = 7 X 150 = 1050 W.

-The 7 panels on the heating phase-saving: 3.75 X 7 per duty cycle. One day we will consider 4 duty cycles which gives 4 X 3.75 X 7 = 105 Wh / day.

The evaluated 1 MW PV power plant will consist of 1 000 PV module strings 7 X 150 W. Gained energy from end of cooling to heating phase will be 105 Wh X 1000 / day = 105 KWh / day. Over the year, we will collect additive energy of 38325 KWh / year = 38,325 MWh / year, considering a rate of 1500 hours sunshine in STC per year and corresponding to our localities. This plant would produce 1500 MWh / year and this technique allows 2.5% of gain for annual energy production. For a FIT of 15 Da / KWh, there is an additional revenue of 15 X 38 325 = 574 875 Da per year. This added profit is a very important gain and allows keeping the PV power plant cleanest throughout all the year and avoid power losses due to soiling which can reach up to 30% in the dusty regions as like areas near the desert.

VI. CONCLUSION

The study of overheating and soiling of PV modules showed that these issues could be settled by implementation and experimentation on their front side by water spraying. A prototype at laboratory reduced scale is designed and tested. It showed an interesting profit gain from water cooling and keeping the PV power plant the cleanest on whole of the year and avoids power losses due to soiling which can reach up to 30% in the dusty regions as like as areas close to the desert.

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