Conception and realization of sun tracking system of photovoltaic array in the south west Algerian

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Abstract - *The increasing of the incident radiation on the photovoltaic module improves the most performance parameters and characteristics such as power output and performance. In this paper, our contribution is to develop a prototype of sun tracking and to study its performance, allowing the permanent orientation of the PV module opposite the sun during the day to increase energy output and effectiveness. The results obtained on the experimental site are achieved, or 27.48 % of energy gain, which explains that the monitoring system is able to deliver high power and a better conversion efficiency compared to a fixed module inclined 30° at the same latitude.*

Résumé – *L'augmentation du rayonnement incident sur le module photovoltaïque améliore la plupart des paramètres de performance et des caractéristiques comme la puissance produite et le rendement. Dans cet article, notre contribution est de réaliser un prototype de système de suivi du soleil et d'en étudier ses performances, permettant l'orientation permanente de la face du module PV au soleil pendant la journée, pour augmenter l'énergie de sortie, et l'efficacité. Les résultats obtenus sur le site expérimental sont atteints, soit 27,48 % de gain d'énergie, ce qui explique que le système de suivi est en mesure de délivrer une puissance élevée et un meilleur rendement de conversion par rapport à un module fixe incliné à 30° identique à la latitude du site.*

Keywords: Solar area - PV module - Sun tracking - Electronic control.

1. INTRODUCTION

Today, the photovoltaic technology represents an important scientific way to exploit the solar energy instead of the fossil energy, for this purpose, the technique to manufacture and to use the solar modules is oriented to optimize theirs maximum powers, however, several tasks were examined in order to explore the different parameters influencing as: the solar radiation, the physical characterization of module, the operating conditions of work, the maximum power point tracking, etc.

In this field, it has to save the theoretical studies and the experimental works on the solar area and the photovoltaic conversion; as M. Iqbal (1983) [1], Duffie *et al.* (1995) [2].

For valorizing the energetic gain, we cite the experimentation of pumping system realized by Barkat (Algeria) with a gain from 25 % [4]. An other realization in Egypt by A.A Zekry with a result from 24 % [3], a sun tracking in Japan with a year efficacy from 27 % compared with a fix system, and an automatic system in Spain reached 26 % from the gain of energy.

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Generally, the optimization of PV system's performances is narrowly linked to increasing the efficiency and the produced energy in objective to reduce the cost of the system.

Our purpose in this paper is to study and to measure the incident radiation and the produced quantities of energy from module at tracking mode compared with a fix mode under the operating conditions of site.

The realization of prototype for a sun tracking system with two axes (vertical and horizontal), permits the permanent orientation of solar module face to sun during a day, which allows to increase the gain of produced energy compared with a fix system oriented according to a tilt angle 30° toward the south.

The sun tracking has an essential advantage that provides the maximum output energy with high accuracy against any variation of incident light from the sun or climatic conditions change.

The sun tracking system is realized and experienced in '*Laboratoire de Physique des Semi-Conducteurs et Energies*', 'LPDSE' in University of Bechar.

2. DESCRIPTION OF TRACKING SYSTEM

The prototype was made of sample tools whose dispose in our research's laboratory; and formed by the following elements:

- A solar module.
- A mechanical system pivoted with two motors for rotation.
- An electronic command with devices to the measurement.

2.1 Photovoltaic module

The PWX500 is a bi-glass module, perfectly adapted to the climatic and hard environmental conditions, made of 36 polycrystalline cells of silicon.

Its cells are put in order of serial-parallel grid on total surface at 3672.72 cm^2.

The PWX500 module uses the technology of the cells multi crystalline Photowatt, its equivalent model is given in the figure 1.

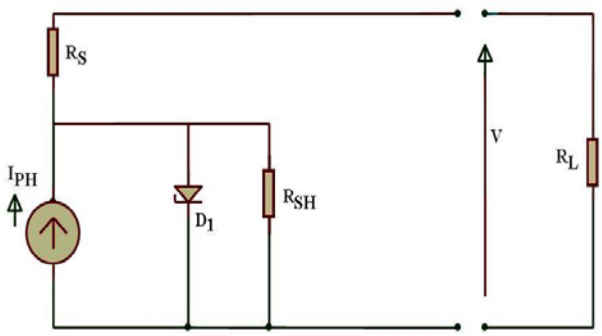

Fig. 1: Equivalent electric circuit of the solar cell

For extracting a best result, we have based on the technical data specified from the manufacturer as illustrated in the **Table 1.**

2.2 Description of piloting system

The mechanical system is realized by a metallic support for PV module, pivoted with two electrical motors consuming a weak power; controlled by analogical electronic circuit.

Table 1: PV module's characteristics under the standard conditions

Electrical and thermal characteristics	Values according to Manufacturer
Nominal power	50 W
Nominal voltage	17.2 V
Nominal current	2.9 A
Short-circuit current	3.1 A
Open circuit voltage	21.6 V
Efficiency	12.19 %
Weight	9.2 kg
Current temperature coefficient	1.3×10^{-3} A/°C
Voltage temperature coefficient	-72.5×10^{-3} V/°C
Normal operating cell temperature	0.43 %/°C
Serial resistance	0.55 Ω
Number of cells	36
Surface of cell	102.02 cm^2
Standard Conditions	1000 W/m^2, 25 °C, 1 m/s

The radiation is detected by the quadruple of sensors (4 photo resistances) against the four geographical sides and measured by the pyranometric probe, then two bearings for rotation (kind 6204) to minimize the friction factor.

The switches of final course of motors allow to determinate the limit positions of system show in the figure 2.

This piloting mechanism allows to orient the PV module from the east to the west around a vertical ax with angle (α) and to slope toward the sun at each time with a tilt angle (β) around horizontal axe.

The components of the system are chosen according to theirs characteristics in objective to acquire some advantages:

- The consumed power of the system must be more weaken.
- The sensibility of sensors is too high and the accuracy of the optimal angles permits to acquire a great quantity of incident radiation.
- The resistant couple is proportional to the speed.

3. ORIENTATION AND TILT OF THE PV ARRAY ACCORDING TO THE SUN POSITION

The site of Bechar is described geographically by: Latitude- 31.38°, Longitude- 2.15° W, Altitude- 806 m, Albedo- 0.2.

Therefore, in our site, the sun is present at 8h05 in winter (21 December) and sets at 19h50 in summer (21 June), so the average solar day is 10 hours.

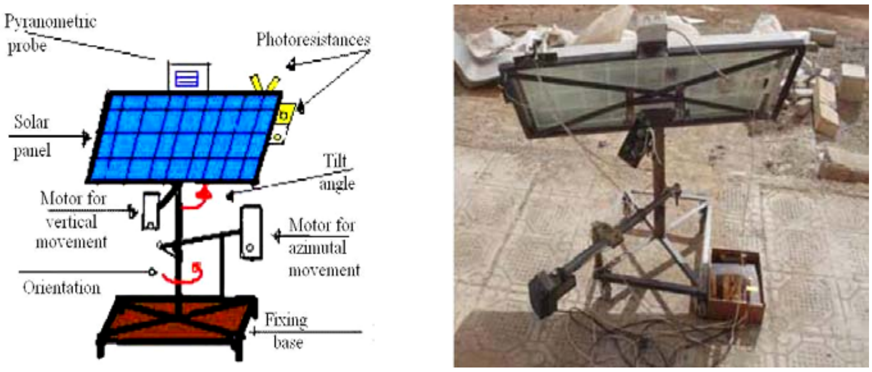

Fig. 2: Sun tracking system

The tilt of module (β) varies according to two factors:

- Latitude of site
- The season of the year.

For the fix mode, PV module is sloped with 30° toward the geographical south and 0° with azimuth angle, but by tracking system the PV module is pivoted with an angle 15°/h from the east to the west during all the day, and adjusted automatically at optimal angle at each time according to the sun movement.

3.1 Analogical electronic control

The electronic circuit to power on and to control the system is as following [6]:

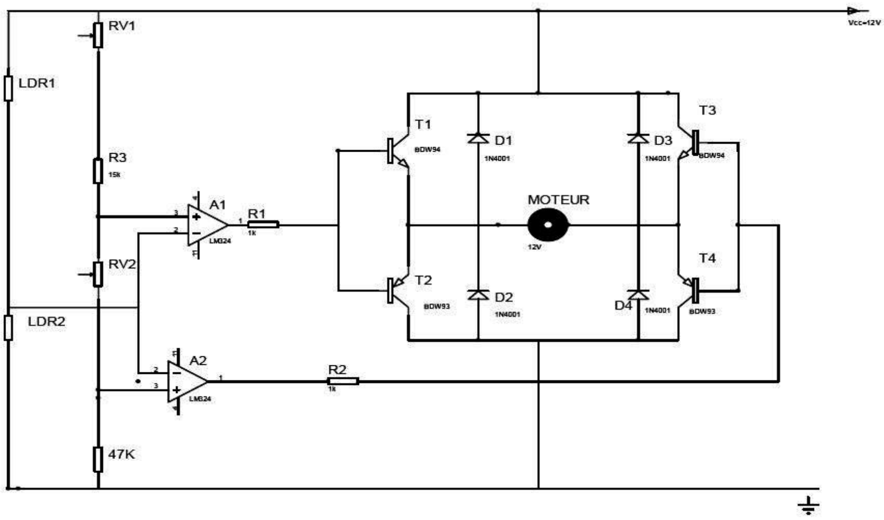

Fig. 3: Electronic circuit for system

T_1=T_3=BDWX93C, A_1,A_2=1/2LM324, T2=T4=BDWX94C, D_1=D_2=D_3=D_4=1N4001

The base element of this electronic circuit is the comparator LM324 which detects the difference of voltage between its reverser input and no reverser input, produced from the difference of illumination on the surface of the sensors.

At this moment, LM 324 provides a signal to the power amplifier of transistors for turning motor at when the PV module is trained to positioning face the sun until the light is identical on the sensors like initial stage.

3.2 Application method

The experimentation was applied with two methods:

- Fixing PV module with a tilt angle 30° toward geographical south.
- Moving the PV module with the sun tracking system by which the tilt angle and the azimuth angle vary simultaneously according to the movement of the sun.

The measurement was taken under an average temperature of 27 °C, and the speed of wind was very weak. In these conditions, we investigated to obtain two results:

- Characterization of solar module and the design of other parameters.
- Optimization of the produced power of module, using the sun tracking system.

4. RESULTS AND DISCUSSION

The comparison between these two modes of orientation, for extracting the performances of each mode, it can be determinate in the table below.

Table 2: Results and performances for orientations modes (obtained on 03/04/2008)

Orientation mode	Parameters (optimal value)	8h30	12h15	17h20
Fix mode	Irradiation (W/m^2)	236.5	956	293.5
	Voltage (V)	14.5	14.7	14.4
	Current (A)	0.56	2.38	0.71
	Power (W)	8.12	34.98	10.22
	Efficiency (%)	9.35	9.97	09.48
Two-axes mode	Irradiation (W/m^2)	790.02	958	848.5
	Voltage (V)	15.5	14.3	14.9
	Current (A)	2.23	2.7	2.46
	Power (W)	34.56	38.61	36.65
	Efficiency (%)	11.92	10.98	11.76
	$\text{gain} = \frac{n - n_0}{n_0}$ (%)	27.48	10.13	24.05

In the fix mode, at the 8h30, the maximum produced power (8.12 W) is very inferior than the nominal power of the PV module designed by the manufacturer (50 W).

In spite of the ambient temperature is agreeable and under 236.5 W/m^2 of irradiation, thus explains that the insufficiency of solar irradiation on the surface of the sensor.

In other meaning, the fix position can't hold a great quantity of irradiation because the PV module surface is not perpendicular toward the sun at each time.

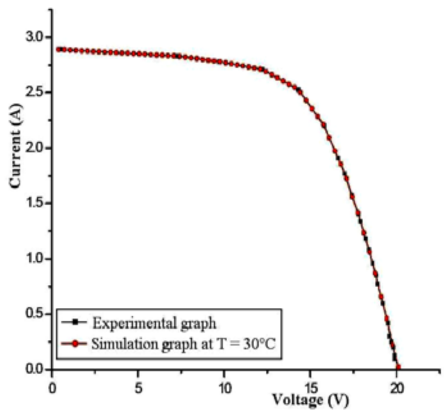

Fig. 4: Characteristic $I(V)$ of the panel

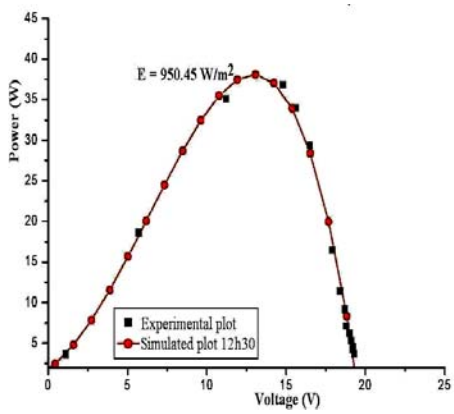

Fig. 5: Characteristic $P(V)$ of the panel

At the same time in the morning, the sun tracking system allows to hold a double flow of irradiation (790.02 W/m^2).

Therefore, the produced power grows up to 34.56 W with the efficiency 11.92 %, and obtained a gain of 27.48 %, show the $I(V)$ and the $P(V)$ characteristics curves in figure 6 and 7.

According to the analysis of the solar panel's performances, we can conclude that:

- The influence of the orientation and the inclination angles is important; the fix panel can not deliver the maximum of electrical energy.
- The $I(V)$ and the $P(V)$ characteristics of the solar panel turning around two axes, illustrate the improvement of the maximum power and the efficiency of the conversion at 11.92 % compared with the fix panel.

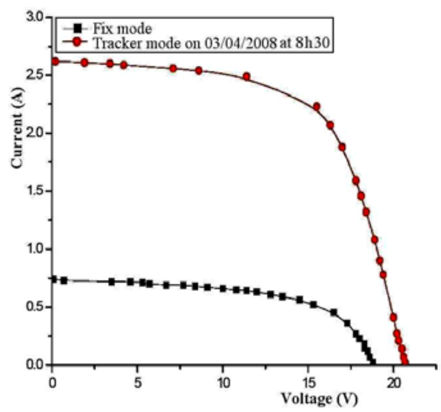

Fig. 6: Characteristic $I(V)$ in the beginning of the day

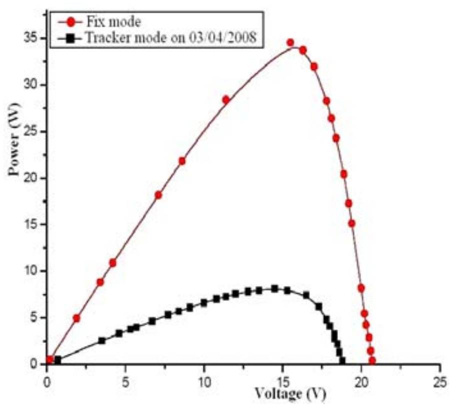

Fig. 7: Characteristic $P(V)$ in the beginning of the day

At the time 12h30, the fix PV module obtained an important energy (34.98 W) while the irradiation increased until 956 W/m^2 and was vertical on its surface.

However the sun tracking system put out 38.61 W under illumination 958 W/m^2.

In this case, the irradiation is vertical on the PV module surface in the two modes, there is no difference between them, over that.

The efficiency and the gain are very approached, in consequence, their current - voltage and power characteristics are approached in figures 8 and 9 below.

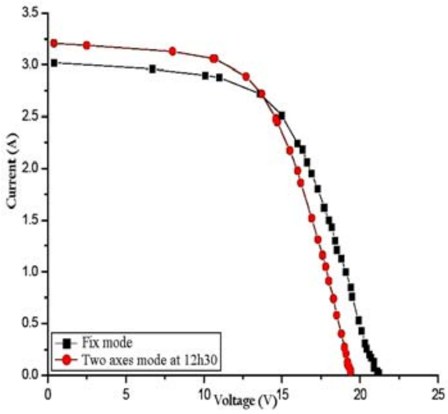

Fig. 8: Characteristic $I(V)$ at 12h30

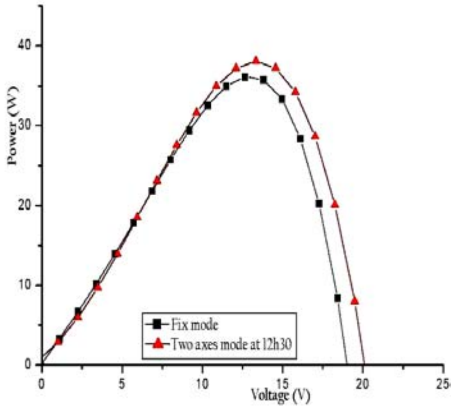

Fig. 9: Characteristic $P(V)$ at 12h30

In the evening, at 17 h20, the fix PV module decreases its output energy 10.22 W, according to the decreasing of the irradiation on the surface (293.5 W/m^2), otherwise the sun tracking system kept its production 36.65 W with 848.5 W/m^2.

In this case, the divergence is similar to the characteristics curves in the morning. The current-voltage and power characteristics are shown in the figures 10 and 11 below.

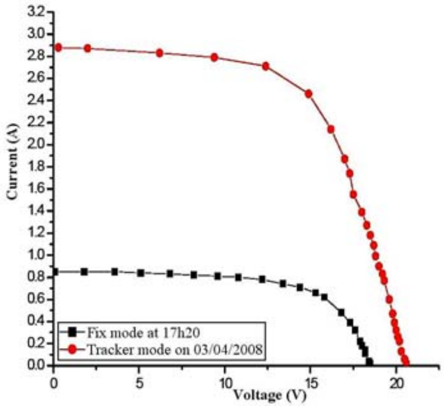

Fig. 10: Characteristic $I(V)$,
end of the day to 17h20

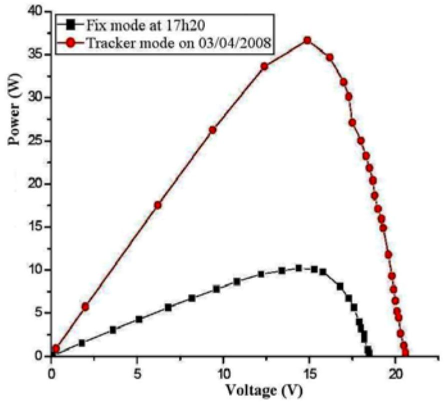

Fig. 11: Characteristic $P(V)$,
end of the day to 17h20

According to the results of the last figures, we concluded that the tracking system of that panel allows optimizing the maximum power compared with the fix mode.

We can deduct the variation of the instantaneous efficiency by function of the radiation according to the relation:

$$\eta = \frac{V \times I}{S \times E} = \frac{P_{max}}{S \times E} \quad \text{with} \quad S = 0.367 \ m^2 .$$

S : Surface of the module and E : Incidental radiation

According to the analysis of the panel's performances, we can conclude that:

- The panel's movement permits to increase the quantity of the incidental energy on the surface of the panel and also the power delivered by the sensor.
- The $P(V)$ characteristic of panel turning around two axes, indicates the perfection of the maximal power converted, as well as the efficiency is elevated until 11.76 % under a radiation of 848.5 W/m^2, it is due to the influence of the variable orientation angle.

The gap of the radiation between two modes gets at 553.52 W/m^2 compared with fix mode oriented by 30° toward the south.

The test of the panel at the end of the day permitted us to raise the $I(V)$ characteristic illustrated on the figure 10, that indicates an important change of the values in the current and in the voltage compared with fix mode, at functioning peak {14.9 V, 2.46 A}.

The $P(V)$ characteristic on figure 11 of the panel pivoted following two axes, specifies that under the radiation of 848.5 W/m^2 and an ambient temperature of 27 °C.

The maximal power gets at 36.65 W, more that the fix panel, the voltage of the opened circuit arrives at 20.6 v and the current of the short circuit reached 3.09 A .

The radiation on the surface of the panel in tracking mode is bigger than the fix mode at the beginning and the end of the day, other wise at the mid-day interval, the gap of the radiation is weak and the gain in energy is not considerable for two axes.

The gain in energy of tracking system gets at 27.48 % compared with fix mode, that presents the concordance with the results of gain { 24 % to 27 %} published by studies very recent [6].

The figure 12 presents the characteristics of measure of the power converted by the PV module in three different periods of the day.

The 03 graphs are nearly confounded. From that, we can conclude that the experimentation of tracking system proved a daily efficacy of about 1.5 once more that the fix system's oriented to 30° towards the south.

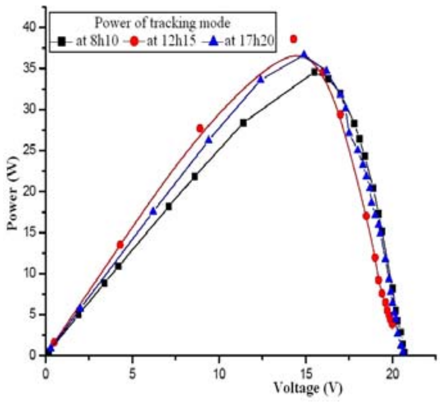

Fig. 12: Characteristics $P(V)$ of panel in tracker mode

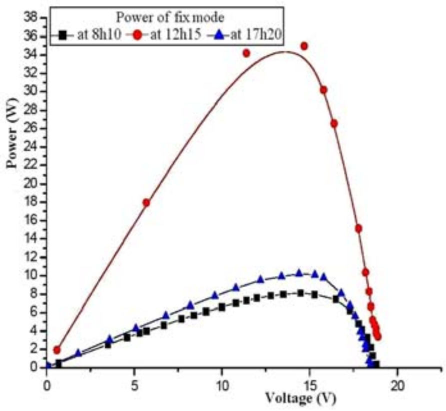

Fig. 13: Characteristics $P(V)$ of panel in fix mode

But the characteristics of the figure 13 are especially different that of 12h30 which is near in comparison at that panel in tracking mode.

The maximal power converted in tracking mode follows the variation of the solar radiation (as is indicated in the **Table 2**) and in consequence the improvement of the efficiency of the conversion.

5. CONCLUSION

The obtained results explain that the solar panel around two axes can deliver a maximal power and can have a best efficiency of conversion compared to a panel with fix inclination under the climatic and geographical conditions of the site.

The comparison between the orientation's modes proves that the tracking system is characterized by the following advantages:

- The inclination and the orientation are variables according to the movement of the sun at each time.
- The radiation received by the panel is important than the radiation in fix mode and the production of the power is maximal according to the incidental radiation.
- The tracking system has a great importance especially in the morning and at the end of the day where the tilt angle of the fix system is very far from the optimal position of sensor; and the gain in daily energy is very important in order of 28 %.
- The panel is piloted automatically with a grand accuracy if the tracking system becomes more performing.
- The system can be made with a cooling means to maintain the temperature appropriate to panel's cells.

We can conclude that the fix solar module can't generate the maximum of electrical energy, it necessary to pivot it in a direction or two directions of orientation to observe the variation on its electric performances.

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