SIMULATION AND EXPERIMENTAL STUDY THE MANAGEMENT OF A PV /BATTERY / CHARGES OF AUTONOMOUS PHOTOVOLTAIC SYSTEM IMPLEMENTED IN SOUTH OF ALGERIA

L. ZAGHBA[1,2], N.TERKI[2], M.BENBITOUR KHENNANE[1] , A. FEZZANI[1], A.BOUCHAKOUR [1], I. HADJ MAHAMED[1], S. H.OUDJANA[1]

[1]Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Energies Renouvelables, CDER, 47133, Ghardaïa, Algeria
[2] Department of Electrical Engineering, University of Biskra, Algeria
Layachi40@yahoo.fr

Abstract – *Photovoltaic solar energy contributes significantly to sustainable development in remote and isolated areas of the electrical grid distribution. The stand-alone photovoltaic systems offer a very interesting solution for the electric power supply required for the development of these regions. In the process, they reduce the negative impact of diesel on the environment. This article focused on the experimental and simulation study, implementation and management of a PV / battery / charges to visualize the electrical parameters and to prolong the battery life of the system of a standalone photovoltaic system implemented in the wilaya of Ghardaia. The various components of this installation, wiring diagrams and tables were presented and discussed.*

Keywords: *stand-alone photovoltaic system; Electrical characteristic; batteries regulator; load; Energy Management.*

1.Introduction

A Photovoltaic (PV) is called standalone or isolated when it is not connected to an electrical grid distribution. The standalone PV system can provide power in places where there is no network. It is particularly suitable for applications as a pump in the garden, secluded area lighting, power telephone terminals along the highway, etc. For these applications it is not always possible to set up a classic supply grid, either because of technical constraints, either for economic reasons. The autonomous system must be capable of providing power to consumers during the year less light irradiation. If you need the current all year, the period of less irradiation is winter. During this period, it will take more panels to cover the same needs as in summer. The batteries give autonomy to the system for night applications or when the panels do not provide enough current.

This paper, focus a special strategy for a good management of a PV / battery / charges to prolong the battery life. An experimental and simulation study with Matlab/Simulink is presented under variable weather conditions and the results show the good energy management of the photovoltaic system.

2. Characteristics of the site

Characterization tests were performed at outdoor conditions of the testing site (Applied Research Unit for Renewable Energies). The site is located in Ghardaia about 600 km south of Algiers. Having the following coordinates, Latitude: 32°36’ N, Longitude: 3°81’ E and elevation of 450 m above sea level, this area is classified as an arid region. Based upon meteorological data the solar resources and temperatures are as follows: rate of sunny days varies between 77% and 80 % per year. The average daylight hours are approximately 5 hours in winter and up to 10 hours over the remaining seasons. The daily average irradiation on a horizontal surface varies between 6 kW/m2 per day and 7 kW/m2 /day [1][2][3][4].

3. Mathematical Model of PV cell

A general mathematical description of I-V output characteristics for a PV cell has been studied for over the past four decades. Such an equivalent circuit-based model is mainly used for the MPPT technologies. The equivalent circuit of the general model which consists of a photo current, a diode, a parallel resistor expressing a leakage current, and a series resistor describing an internal resistance to the current flow, is shown in Fig.1.The voltage-current characteristic equation of a solar cell is given as [5][14]:

$$I = Iph - Is\left(exp\left(\frac{V+RsI}{a}\right) - 1\right) - \frac{V+RsI}{Rsh} \quad (01)$$

IPH is a light-generated current or photocurrent, *IS* is the cell saturation of dark current, *q* (= 1.6 × 10-19 C) is the electron charge, *k* (= 1.38 × 10-23 J/K) is Boltzmann constant, *T* is the cell working temperature, *A* is the ideal factor, *RSH* is the shunt resistance, and *RS* is the series resistance.

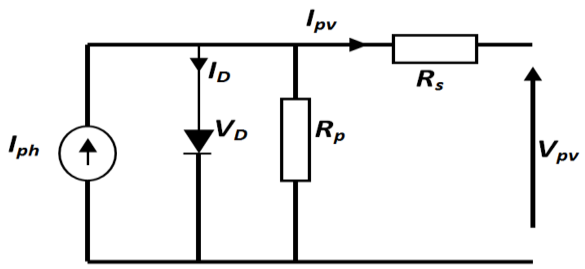


Fig. 1 Equivalent circuit of a PV cell.

4. System description

4.1 *The photovoltaic generator (GPV)*

The photovoltaic generator (GPV) is responsible for the conversion of solar energy into electrical energy. GPV installed consists of two photovoltaic modules monocrystalline silicon of a peak power of 55 each Wc (Fig. 6). Thus, the peak power of the PV generator is 110 Wp. the panels will be placed south. The angle of inclination is 32 ° to the horizontal plane that corresponds to the latitude of Ghardaia, which will capture the maximum solar radiation for the latitude of operations.

4.2 The charge regulator

The controller "automatic system" whose main function is to control the battery charging status: no overload or too deep discharge. When the battery is 90% charged, stop the charging current, the controller opens the switch between the battery and the GPV until it drops below 80% and recharge the battery during phases sunlight and not in use. When the state of charge drops to 30%, the controller opens the switch between the battery and the load until it reaches 40%. It also provides adaptation between the solar panels and uses trying to place the operating point of the maximum power point. The controller is an essential element for the life of the battery.

4.3 Inverter Model

The inverter, whose role is to ensure the DC-AC conversion, it provides power to AC receivers from direct current. A phase voltage inverter is used to interface the DC bus with the PMSM. It permits to change a dc input voltage from the DC bus to a symmetric AC output voltage of desired magnitude and frequency. The inverter provides a phase voltage system which follows the reference voltages PWM commands. The phase voltage can be expressed as the example below [5][14]:

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \frac{V_{pv}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} \quad (02)$$

V_{pv} is the input voltage. c_1, c_2 and c_3 are the PWM control signals.

4.3 Electrical Modeling of battery

The battery, whose role is to store energy and release it when the sunlight is insufficient; the mathematical model describes how the system of accumulation of electrical energy is shown in the following figure (Fig. 2).

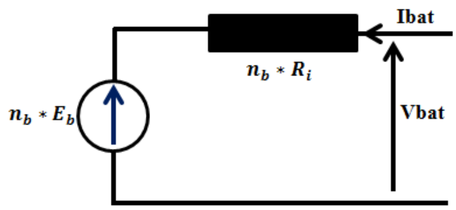


Fig.2 Energy management strategy

Then for n_b elements in series, we can write the equation:

$$V_{bat} = n_{bn}.E_b + n_b.R_i.I_{bat} \quad (03)$$

To size battery bank capacity, we adopted the following method [6, 7]:

- ✓ Calculate the average daily consumption (EC);
- ✓ Determine the number of days of autonomy (N) which is desired benefit;
- ✓ Determine the depth of maximum acceptable discharge the battery (D) according to the type of battery used;
- ✓ Determine the battery voltage U (V)
- ✓ Calculate the capacity (C) battery in ampere hours (Ah), using the following formula (04):

Then:

$$C = \frac{Ec.N}{D.U} \quad (04)$$

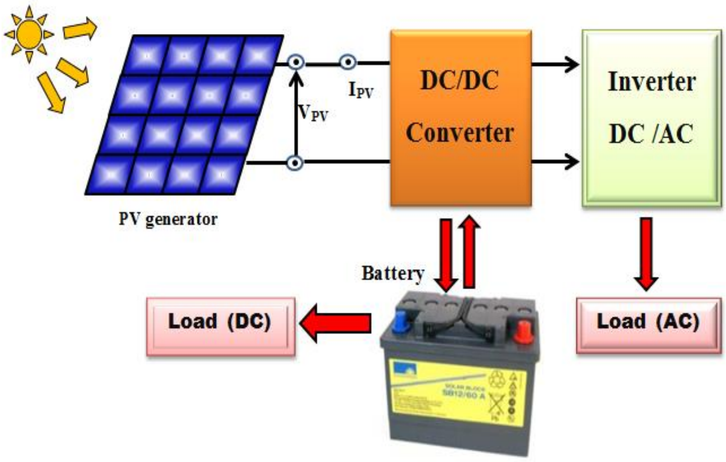
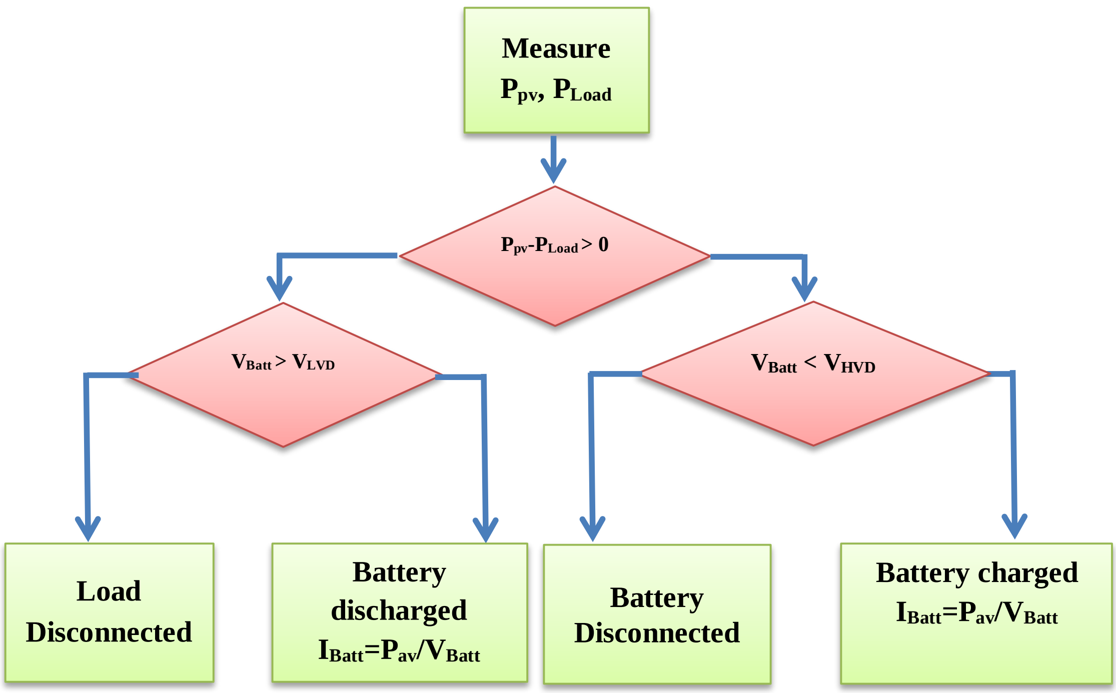


Fig. 3 Global block of a standalone PV system

Energy management strategy [7]



Pav : Photovoltaic power
P_{Load}: Load power (the consumer)
V_{LVD}: Low Voltage Disconnect: when the batteries voltage correspond to the lower limit (discharged)
V_{HVD}: High Voltage Disconnect: correspond to the superior limit when the batteries are fully charged

Fig.4 Energy management strateg

II. SIMULATION RESULTS

The following simulation were presented for different insolation levels from 200 to 1000 W/m2 at fixed temperature of 25°C for two days as shown in Fig.5.

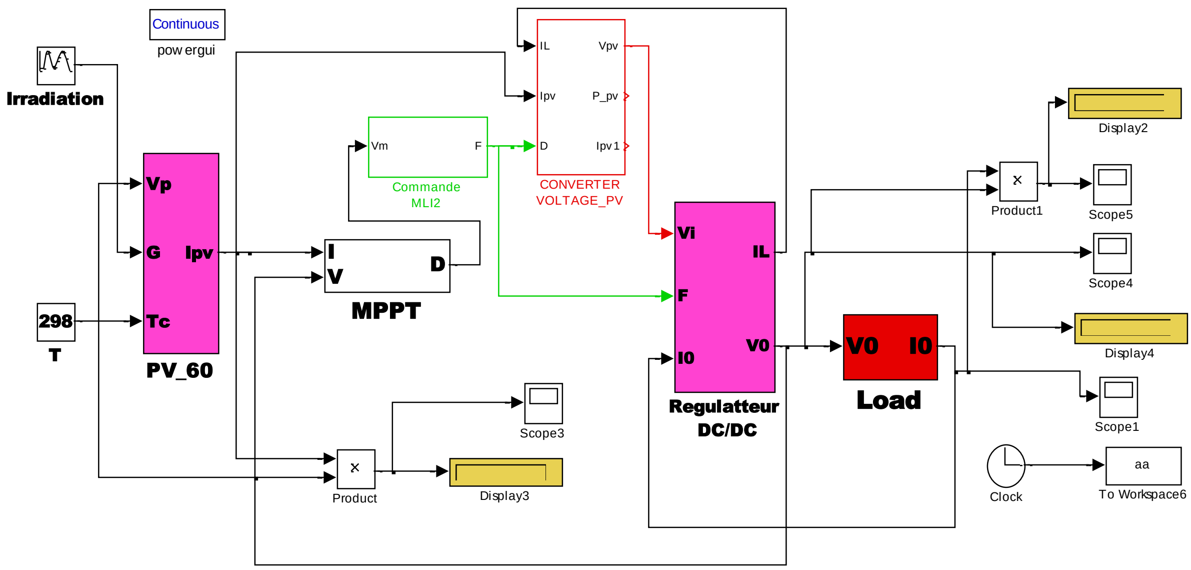


Fig.5simulation for an Autonomous photovoltaic System Matlab/SIMULINK

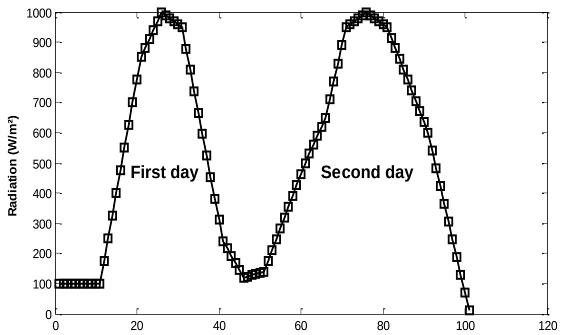


Fig.6 Irradiation variation profile

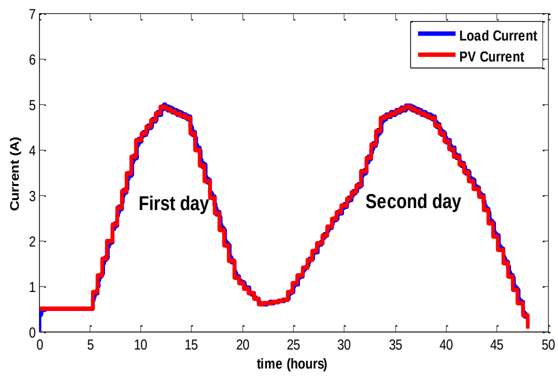


Fig.8. Average hourly current generated by a solar panel and the Load for two days

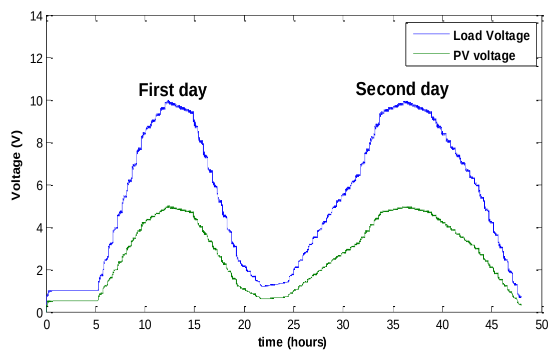


Fig.7. Average hourly voltage generated by a solar panel and the Load for two days

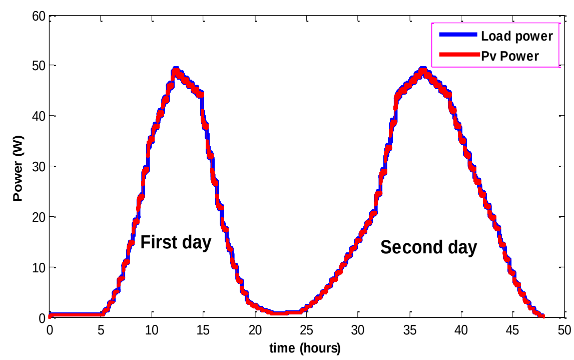


Fig.9. Average hourly power generated by a solar panel and the Load for two days

III. EXPERIMENTAL RESULTS AND DISCUSSION

TABLE I THE SOLAR PANEL CHARACTERISTICS, TE 500 (55 W), FROM TENESOL TOTAL ENERGY AT (25 C° AND 1000 W/M2)

Electrical Characteristics Te 500	
STC Power Rating P_{mp} (W)	**55**
Open Circuit Voltage V_{oc} (V)	**22.2**
Short Circuit Current I_{sc} (A)	**3.50**
Voltage at Maximim Power V_{mp} (V)	**17.5**
Current at Maximim Power I_{mp} (A)	**3.20**
Cells	**36**

5. Influence of temperature

To characterize PV cells, we used the model of one diode, -presented above -, to provide the values of voltage (V), current product (I) and the power generated (P). We present the IV and PV characteristics in Figures 10 and 11 respectively of PV panel Tensol TE 500 CR+/55, for G = 1000W/m2 given, and for different values of temperature. If the temperature of the photovoltaic panel increases, the short circuit current Isc increased slightly, to be near 0.1 A at 25°C, while the open circuit voltage Voc decreases, the temperature increase is also reflected in the decrease of the maximum power supplies. The temperature increase is also reflected by the decrease of the maximum power.

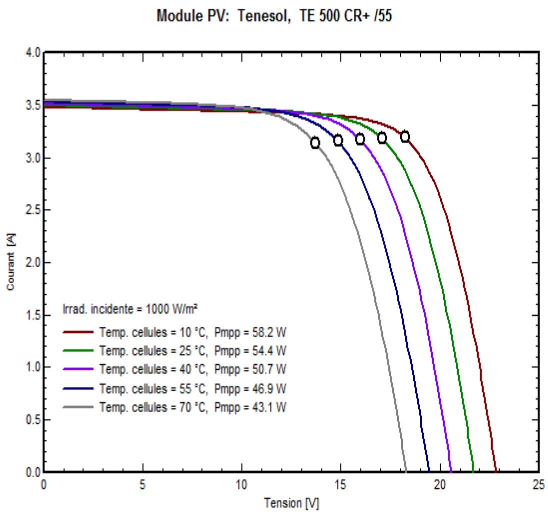


Fig .10. I-V Characteristics at constant irradiation and varying temperature.

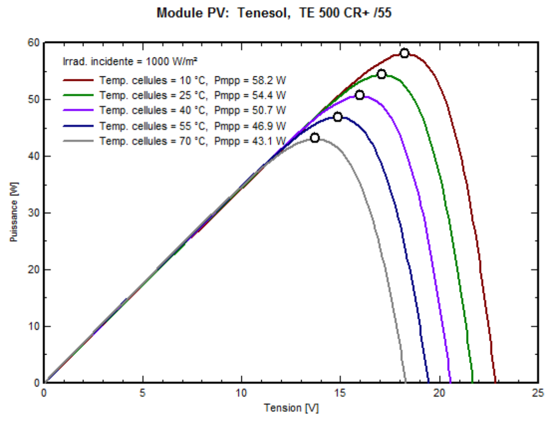


Fig .11. P-V Characteristics at constant irradiation and varying temperature.

6.Influence of irradiation

Now, we present the I-V and P-V characteristics in Figures 10 and 11 respectively of the PV panel Tensol TE 500 CR+/55 at a given temperature T = 25 ° C for different solar illumination levels (Figure12-13).

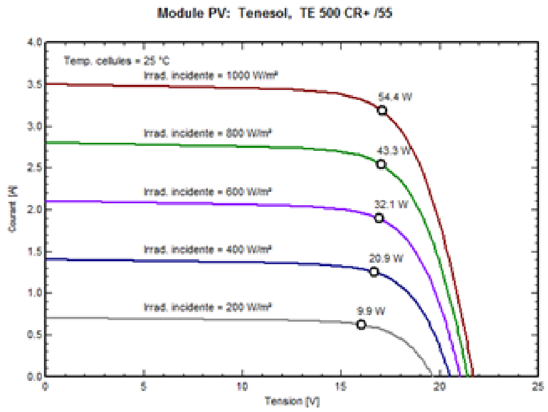


Fig .12. I-V Characteristics at constant temperature and varying irradiation.

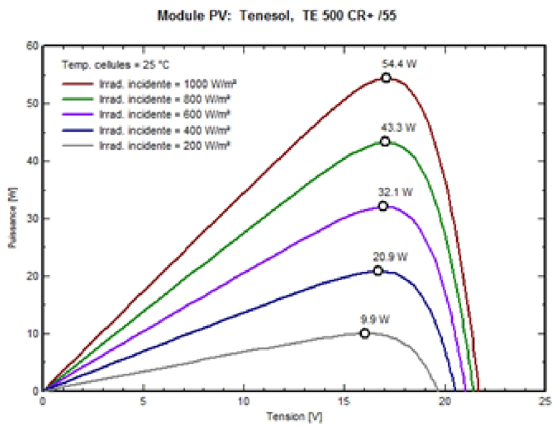


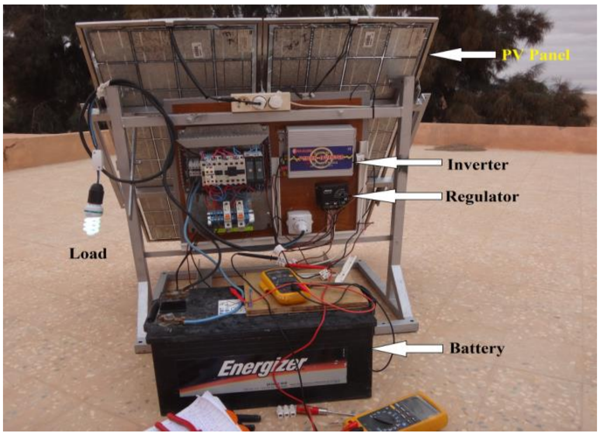
Fig 13. P-V Characteristics at constant temperature and varying irradiation.

7. System description

Fig.6 shows the standalone photovoltaic system used in this paper. It includes photovoltaic panel with DC/DC converter, batteries and variable load. The system aims are to ensure a maximum operating of the photovoltaic array and to make a decision on switching between different components (PV/Battery/Load) with correct operating of the battery to protect it against overcharge and deep of discharge[8] [11][12][13].

The characteristics for each compound are:
- PV array of the type *TE500*.
- Inverter DC/AC, SI 300 HPE
- Regulator (type: Steca)
- Energizer battery (12V), 225Ah as a capacity.

(a)



(b)

Fig.14 Structure of a stand-alone PV system

In order to validate the set of blocks of the regulator designed in this work, we have tested the prototype (Fig 14), during three days, from 22/01/2015 to 25/01/2015, when irradiance undergoes rapid changes during charging solar batteries. In Figures, we represented the typical statements of results radiometric quantities: irradiance and temperature (*G*, *T*), electrical quantities (V_{pv}, I_{pv}, I_{bat}, I_{bat}, V_{ch}, I_{ch}).
The system is made of sensors, allowing us to obtain the weather conditions, parameters measured are as follows:

- Solar radiation measured at horizontal plane;
- Solar radiation measured at entitled plane;
- Air temperature;
- Cell Temperature.

Also, other sensors enable us to measure different electrical quantities such as:

- AC and DC Current;
- DC and AC voltages.

The different elements constituting our acquisition system are shown in Table II.

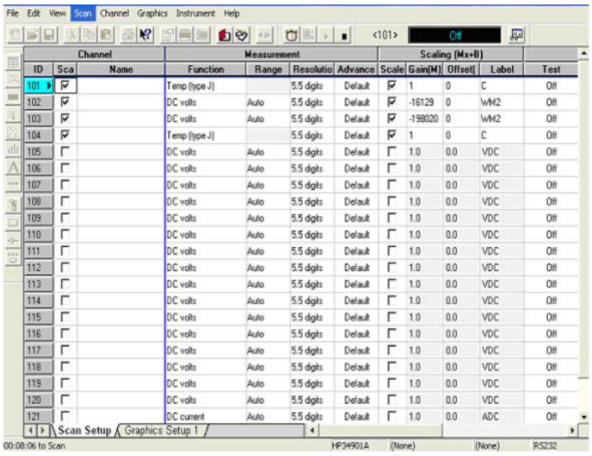
TABLE II. THE MEASURED AND THE SENSORS USED

Measured parameters	**Signal Type & Channel measurement**	**Sensors**
Global Radiation on Inclined plane 32°, G *(W/m2)*	DC Voltage *(mV/* 101	Pyranomètre CM 11 S= 18.58 µV/(W/m-2)
Array VoltageV_{PV} *(V)*	DC Voltage (V)/102	regulator Steca
Load Voltage V_L *(V)*	AC Voltage (V)/103	Inverter Steca
Batteries Voltage V_{BAT} *(V)*	DC Voltage (V)/104	regulator Steca
Array Current I_{PV} *(A)*	DC Current (V)/105	Capteur a effet hall
Load Current I_L *(A)*	AC Current (V)/106	Capteur a effet hall
Batteries Current I_B *(A)*	DC Current (V)/107	Capteur a effet hall
Temperature T_{amb} (*C°*)	Mesure direct en *°C*	HeavyWeather ProWS 2800

These data are recorded thanks to Agilent 34970A® data logger, it performs signal conditioning, amplification, analog and contains a digital processor.
All data are transferred and stored in the computer using provided software named "Benchlink®".

8. Using Benchlink®data logger software

The software BenchLink® Data Logger, provided with the instrument, makes it possible to communicate with the data acquisition through a computer. This software gives in a fast a flexible way the possibility to configure channels and launch or end scanning; all these tasks are gathered on a spreadsheet. Thereafter all measurements can be transferred and saved in a file for their further treatment [9][10].



Channel			Measurement				Scaling (Mx+B)				
ID	Sca	Name	Function	Range	Resolutio	Advance	Scale	Gain(M)	Offset(	Label	Test
101	☑		Temp (type J)		5.5 digits	Default	☑	1	0	C	Off
102	☑		DC volts	Auto	5.5 digits	Default	☑	-16129	0	WM2	Off
103	☑		DC volts	Auto	5.5 digits	Default	☑	-198020	0	WM2	Off
104	☑		Temp (type J)		5.5 digits	Default	☑	1	0	C	Off
105	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
106	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
107	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
108	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
109	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
110	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
111	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
112	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
113	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
114	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
115	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
116	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
117	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
118	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
119	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
120	☐		DC volts	Auto	5.5 digits	Default	☐	1.0	0.0	VDC	Off
121	☐		DC current	Auto	5.5 digits	Default	☐	1.0	0.0	ADC	Off

Fig.15 Example of configuration set

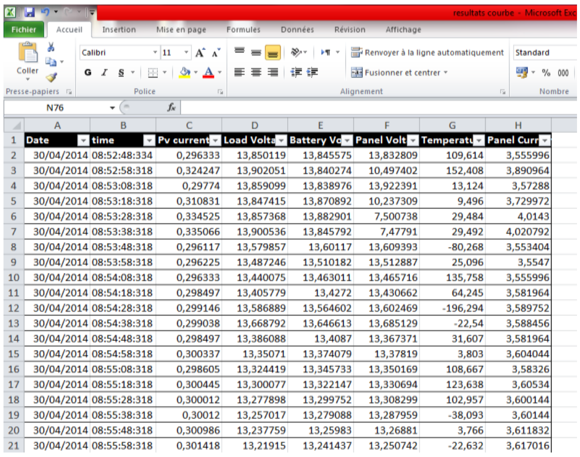
We can always view our measurement instantaneously using the option graphic setup. An example is given in figure 16:

Fig.16 Example of measurement display

9. Exporting measured data

In order to be able to present the different measurements on spreadsheets or on graphical forms, it is necessary to transfer these data to a file in order to be treated lately, for example exporting this data to an Excel file, knowing that this software is familiar to many people it has a built-in statistical and charting capabilities facilitate a variety of analyses. The software gives us the possibility to do so, we just need to click on export data, then the data can be pasted when opening an excel file [9].

N.B: It is important to note that, when we have used the RS-232 interface in order to export data, we always needed to stop the scanning, whereas with GPIB interface we can transfer data without stopping the scan, this still an important advantage for our recordings [9]. An example of measurement presented on spreadsheet is given in Figure 17.



	A	B	C	D	E	F	G	H
1	Date	time	Pv current	Load Volta	Battery Vo	Panel Volt	Temperatu	Panel Curr
2	30/04/2014	08:52:48:334	0,296333	13,850119	13,845575	13,832809	109,614	3,555996
3	30/04/2014	08:52:58:318	0,324247	13,902051	13,840274	10,497402	152,408	3,890964
4	30/04/2014	08:53:08:318	0,29774	13,859099	13,838976	13,922391	13,124	3,57288
5	30/04/2014	08:53:18:318	0,310831	13,847415	13,870892	10,237309	9,496	3,729972
6	30/04/2014	08:53:28:318	0,334525	13,857368	13,882901	7,500738	29,484	4,0143
7	30/04/2014	08:53:38:318	0,335066	13,900536	13,845792	7,47791	29,492	4,020792
8	30/04/2014	08:53:48:318	0,296117	13,579857	13,60117	13,609393	-80,268	3,553404
9	30/04/2014	08:53:58:318	0,296225	13,487246	13,510182	13,512887	25,096	3,5547
10	30/04/2014	08:54:08:318	0,296333	13,440075	13,463011	13,465716	135,758	3,555996
11	30/04/2014	08:54:18:318	0,298497	13,405779	13,4272	13,430662	64,245	3,581964
12	30/04/2014	08:54:28:318	0,299146	13,586889	13,564602	13,602469	-196,294	3,589752
13	30/04/2014	08:54:38:318	0,299038	13,668792	13,646613	13,685129	-22,54	3,588456
14	30/04/2014	08:54:48:318	0,298497	13,386088	13,4087	13,367371	31,607	3,581964
15	30/04/2014	08:54:58:318	0,300337	13,35071	13,374079	13,37819	3,803	3,604044
16	30/04/2014	08:55:08:318	0,298605	13,324419	13,345733	13,350169	108,667	3,58326
17	30/04/2014	08:55:18:318	0,300445	13,300077	13,322147	13,330694	123,638	3,60534
18	30/04/2014	08:55:28:318	0,300012	13,277898	13,299752	13,308299	102,957	3,600144
19	30/04/2014	08:55:38:318	0,30012	13,257017	13,279088	13,287959	-38,093	3,60144
20	30/04/2014	08:55:48:318	0,300986	13,237759	13,25983	13,26881	3,766	3,611832
21	30/04/2014	08:55:58:318	0,301418	13,21915	13,241437	13,250742	-22,632	3,617016

Fig.17. Exported data under Excel format

10. Weather data collection

A data acquisition system was installed in order to ensure the data collection of the various climatic parameters. For irradiation measurement, a CM11 Pyranometer type with a sensitivity equal to 18.58 10-6 V/Wm-2 was used. The solar irradiation and the ambient temperature profiles measured are shows respectively by Fig. 18 and Fig. 19. This weather data are really influenced the proper functioning of the PV panel(Yielded reduction at high temperatures).In the graphs below, the measurement results are presented in real time, with a sampling Δt = 1mn.

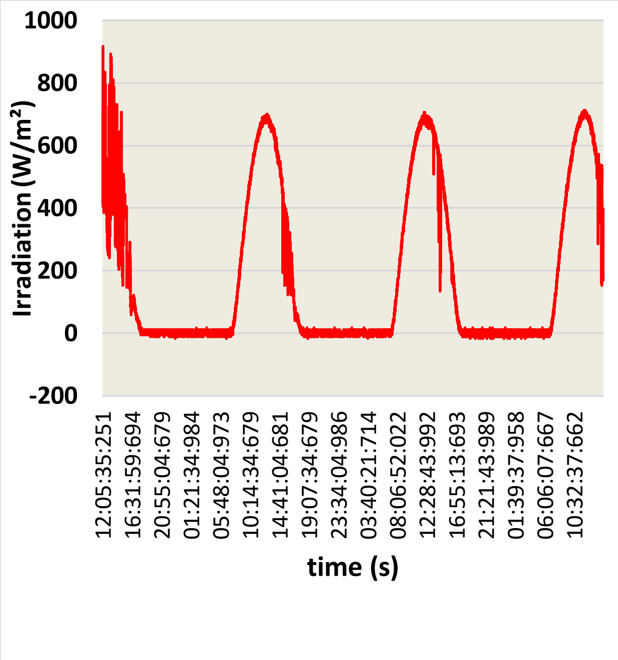


Fig. 18 Solar irradiation profile (3 days)

Temperature data are real data measured on the site of Ghardaia. These values are in ° C.

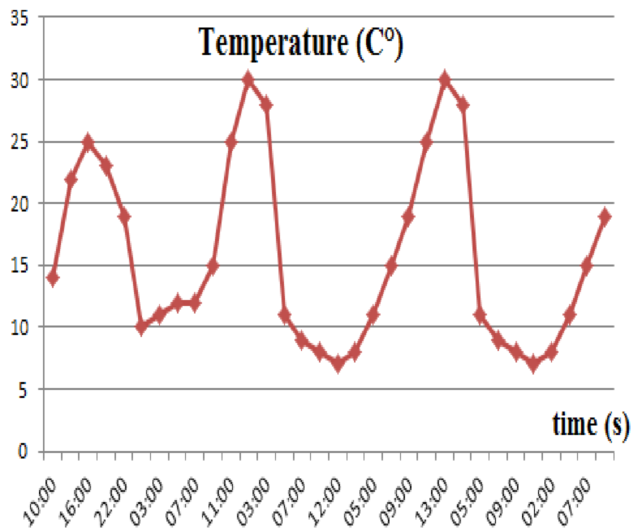


Fig. 19 Cell temperature profile

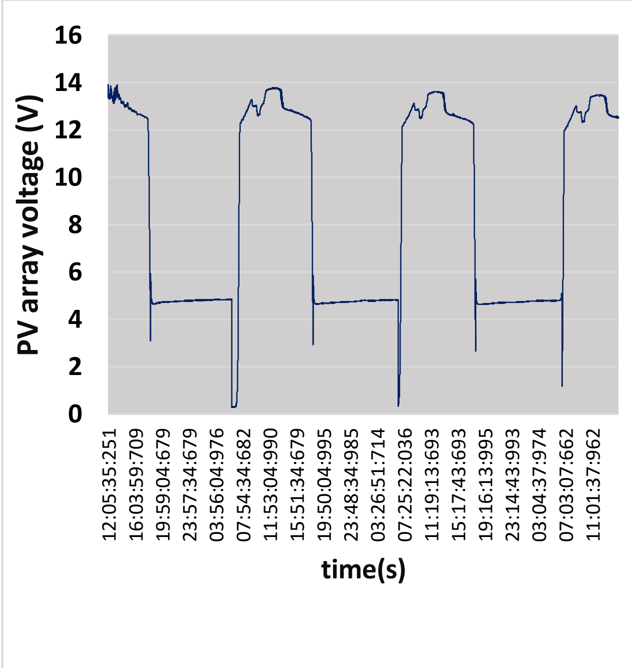


Fig. 20. PV panel voltage profile (V)

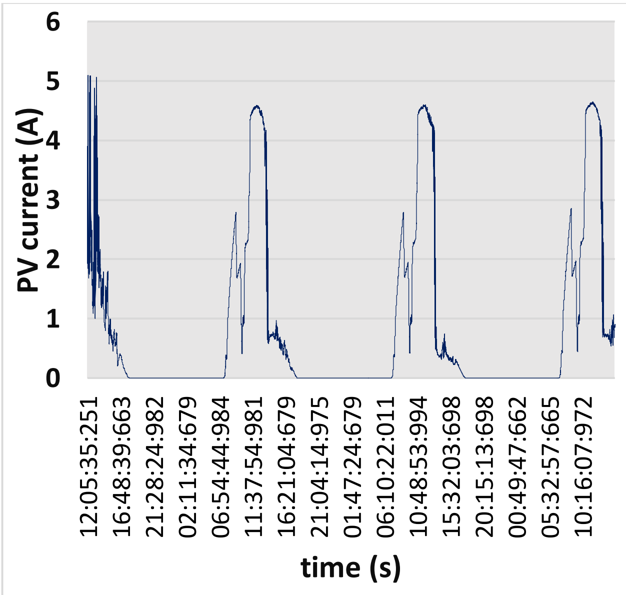


Fig. 21. PV panel current profile (A)

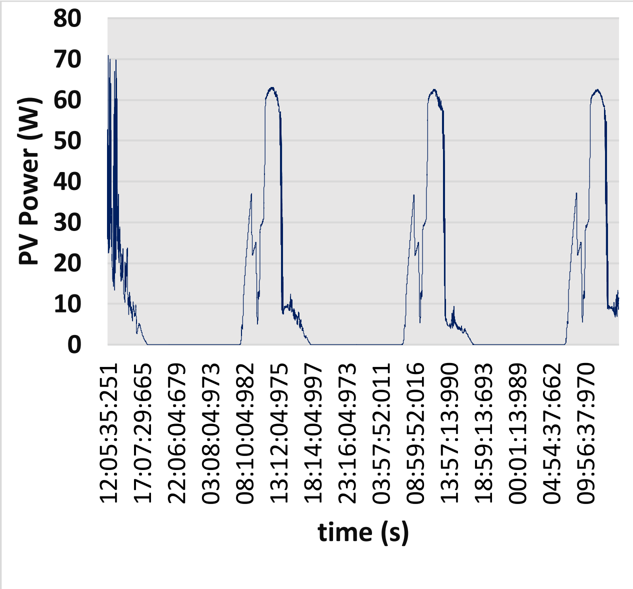


Fig. 22. PV panel power profile (W)

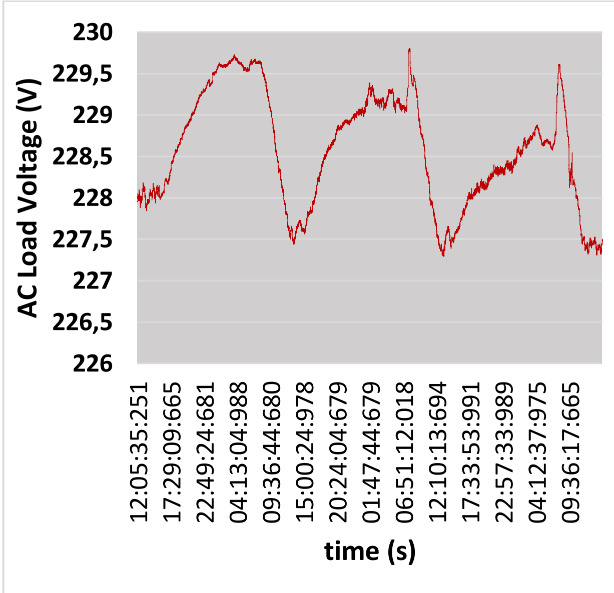


Fig. 24. AC load voltage profile (V)

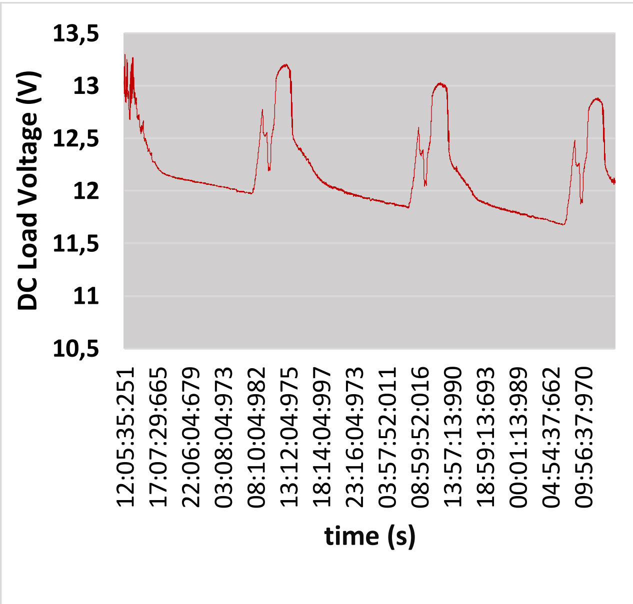


Fig. 23. DC load voltage profile (V)

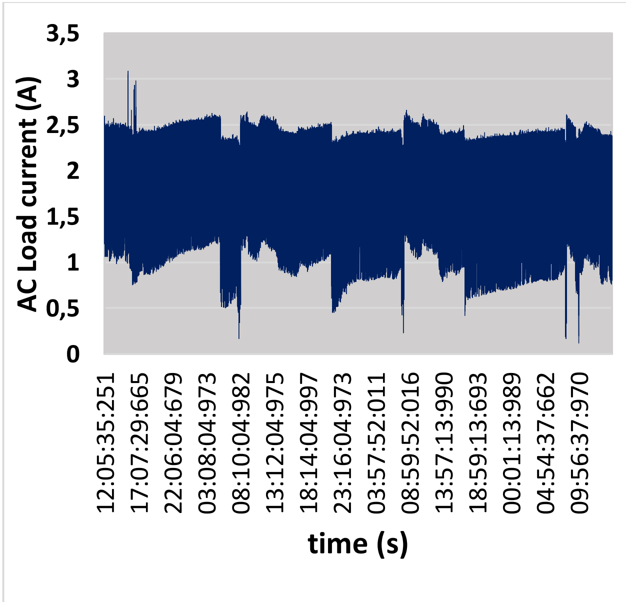


Fig. 25. AC load current profile (A)

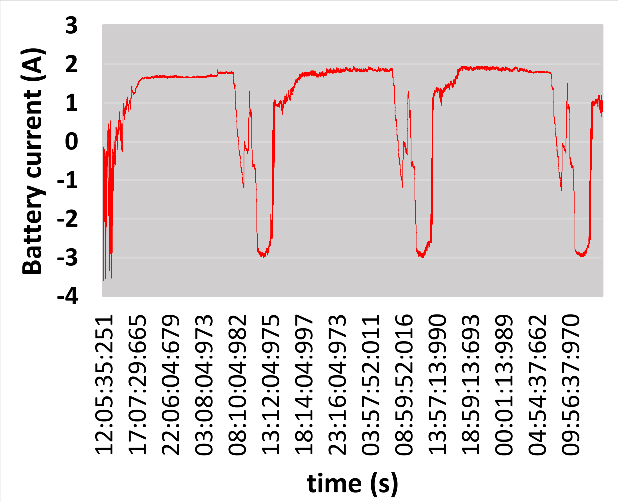


Fig. 26. Battery current profile (A)

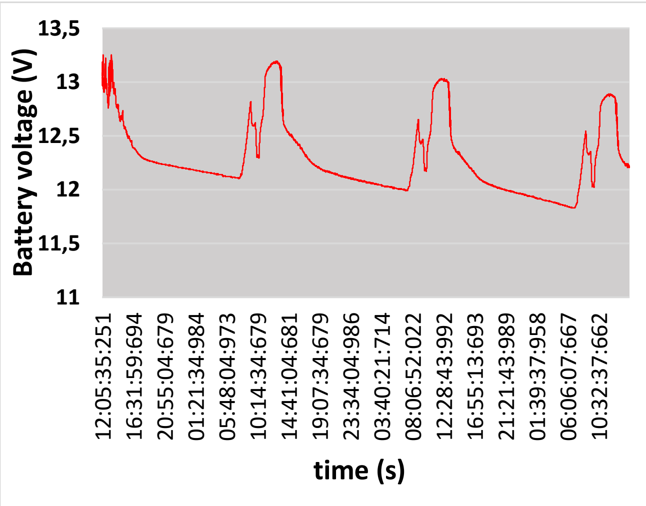


Fig. 27. Battery voltage profile (V)

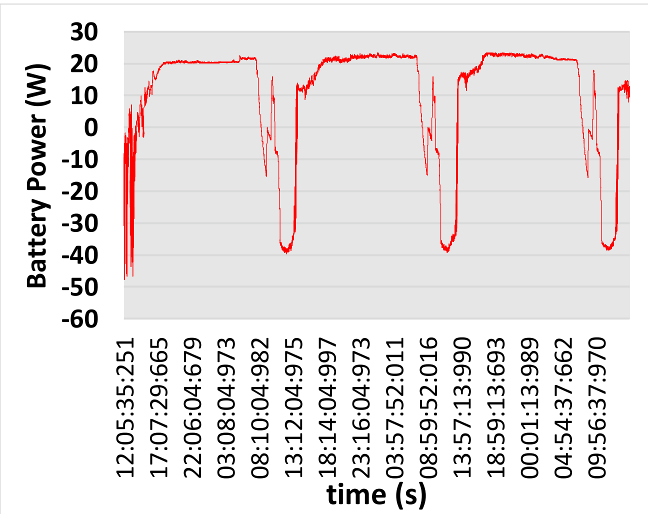


Fig. 28. Battery power profile (W)

CONCLUSION

The photovoltaic (PV) systems provide a reliable solution to the problems of access to electricity in isolated area. The storage of electrical energy, provided by batteries, is the critical part of these systems. Good management of the charge and discharge of the batteries is necessary to prolong their life while ensuring optimum operating conditions. It is important to test the strategy of this administration and to observe the behavior of the system simulation prior to implementation. The work presented in this paper focuses on the study, implementation and management of a PV / battery / charge to visualize the electrical parameters of the system including current, voltage and state of charge of the battery, the voltage and current of the PV generator.

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