Proposal of a Process for selection solar cells Nanosatellite

Asma LARIBI(1)*, Aissa BOUTTE (1),El Yazid BELAIDI(1), AIT AMIRAT Mokhtar(1)
(1) Satellite Development Center (CDS), Algerian space Agency (ASAL)
CDS. Bir El Djir PO.31130, Oran, Algeria;

*alaribi@cds.asal.dz, aboutte@cds.asal.dz/aissa.boutte@gmail.com

Abstract: By the PEDAGOSAT project we aim to democratize all educational activities related to CubeSat-class: nanosatellite, from physics through engineering, technical achievements, integration, to testing and operations to the greatest number of students. The key idea is to eventually have our academic nanosatellite training platform offering an open source opportunity to Algerians universities, and having the capacity to cover all engineer training areas relating to "small satellites". As part of this project, some satellite subsystems, test and emulation facilities will be realized, processes and procedures for testing and integration related to space technology will be addressed, implemented and even mastered. The presented work is part of the development of the on-board power system, and covers the selection of solar cells for the manufacture of solar panels of this satellite. The main source of energy present in space is solar energy, it a continuous and inexhaustible source that a satellite can. In satellite we use a solar panel to ensure its operation. In the dimensioning of a satellite, it is essential to identify these electrical power requirements named “power budget analysis”. Indeed, this makes it possible to determine the number of cells and/solar panels to be installed to guarantee the power continuity of the satellite in sunlight phase of its orbit by recharging its batteries and feeding equipment’s. During all the mission duration; from the beginning of life (BOL) after the launch to it deorbits (EOL) to disintegrate in the atmosphere. For the PEDAGO-SAT as for other satellites, it will be necessary to verify the parameters and physical characteristics of the solar cells/panels according to certified procedures and methodologies in order to be able to pronounce on their qualification for aerospace use. In this context, we propose a low-cost process revision to be able to carry out qualification tests with an accessible facility in the university labs. This revision will also concern the development of homemade means and software that fit the investments that may be made by the Algerian research and academic facilities. As illustrated in this paper a performance evaluation of low-cost solar cells was done using the developed solution and the selected cells will be integrated in the solar panels of PEDAGOSAT.

Keywords: PEDAGO-SAT, solar cell, procedures, qualification for aerospace, low-cost.

1. INTRODUCTION

Due to the limited size of nanosatellite, the choice of photovoltaic cell technology has an important value, knowing that the solar panels are the only source of energy to supply a nanosatellite [1].
Solar power system is the most important subsystem of power generation on small spacecraft
In 2021 around 85% of nanosatellites use solar panels to generate electrical energy [2].
Solar panels & arrays are realized from individual solar cells connected in series and in parallel mounted on a substrate backing.
The deployed solar arrays for PEDAGOSAT [3] are mounted on rigid substrates an aluminum honeycomb.
The selection of the honeycomb core plays a major role in defining the structural performance of a honeycomb panel [ref].
This begins by researching commercially available options that best fit the needs of EDB Subsystem. By weighing cost with efficiency, voltage, and current outputs.
With a limited financial budget of PEDAGOSAT teams, only standardized cell is used for thefirst prototype.

The low-cost solar cells have been tested in the Instrumentation and metrology laboratory (ITM lab) and the results will be detailed in the second part.

2. THEORETICAL BACKGROUND

A. The solar cells

A photovoltaic (PV) cell is made of P-N type doped semiconductor materials to generate energy by transforming the incident energy of photons from solar radiation. But quantum physics shows that for space applications, such cells have a ηPV efficiency, at best of the order of 30% [2] which implies a limitation of the power that can be obtained. The association of several PV cells in series/parallel gives rise to a PV generator (GPV) whose I-V (current-voltage) and P-V (power-voltage) characteristics are non-linear.

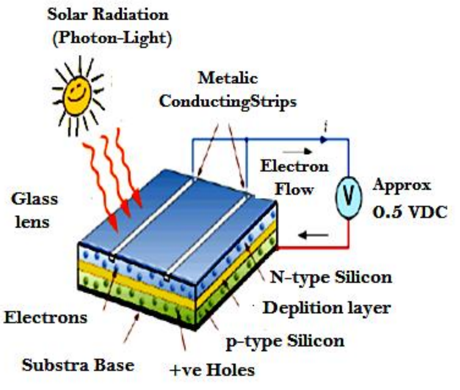


Fig. 1 Structure of a basic Solar cell.[4]

B. Electrical Model of a photovoltaic Cell

A solar cell is a semiconductor PN junction diode as shown in figure 1, solar cells can be produced from various materials, but the most commonly used material is Silicon [5].

The solar cell is presented in Figure 2 by a current generator shunted by a diode to model respectively the illumination and the junction, the resistive effects interference due to manufacturing are presented by two resistors: A series resistance R_s, varies from 1 to 3 Ω and which presents the various contact and connection resistances. A resistance in parallel R_{sh}, varies from 1000 to 10000 Ω and which characterizes the various leakage contacts

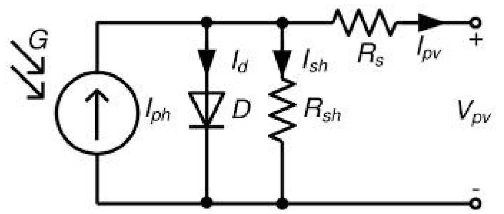


Fig. 2Equivalent circuit of a solar cell [6]

$$I = I_{ph} - I_D - I_{sh} \quad (1)$$

$$I_D = I_s\left(e^{\frac{q(v+IR_S}{AKT}} - 1\right) \quad (2)$$

$$I_{ph} = \left(I_{cc} + K_i(T - 298)\right)\frac{G}{1000} \quad (3)$$

$$I_{sh} = \frac{V+1Rs}{Rsh} \quad (4)$$

$$\frac{KT}{q} = 26mV\ a\ 300K\ pour\ le\ silicium$$

$$I_s = I_{rs}\left(\frac{T}{T_{ref}}\right)^3 exp^{\left[\frac{qEg}{AK}\left(\frac{1}{T_{ref}}\right)-\frac{1}{T}\right]} \quad (5)$$

$$I_{rs} = \frac{I_{cc}}{exp^{\left(\frac{qV_{co}}{AKT}\right)}-1} \quad (6)$$

$$I = I_{ph} - I_s\left[\exp\left(\frac{v+IRs}{AKT}\right) - 1\right] - I_{sh} \quad (7)$$

I_D: diode saturation current [Ampere]. q:electron charge (1.602 10^{-19} C) [Coulomb]. R_s:seriesresistance [Ohm]. R_{sh}:parallelresistance [Ohm]. T:absolutetemperature [°K]. K: Boltzmann constant [1.38 10^{-23}J/K]. α: Duality factor.

The I(V) characteristic of a solar generator can be considered as the result of an association of ns*np cells in series/parallel (fig3)

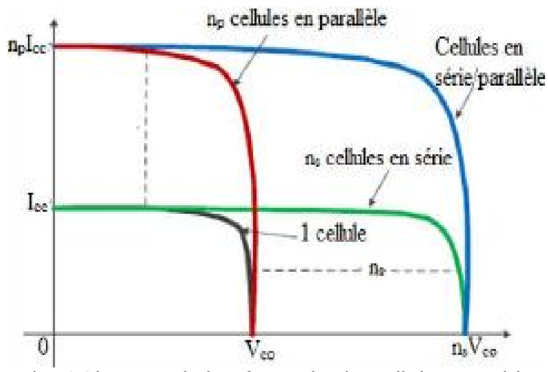


Fig. 3Characteristic of a series/parallel assembly of ns and np PV cells

A. The Electrical power subsystem EPS

The complete power system of a spacecraft consists of the energy source, in this section solar cells – batteries, a power control system and the wiring. In order to generate the required electric currents and voltages solar cells are connected in series and in parallel. Voltage requirements are met by series connections, while current requirements make use of parallel circuits [7].

The primary purpose of an EPSsubsystem is to generate enough power to deploy the space segment's antennas and power its various subsystems.

It is generally made up of three main blocks:

Energy production block via solar cells mounted on the structure of the space segment.

Power conditioning and distribution block to the various subsystems, via DC-DC power converters and voltage regulators.

Energy storage block via batteries that will power the space segment during the LEOP phase and eclipse periods.

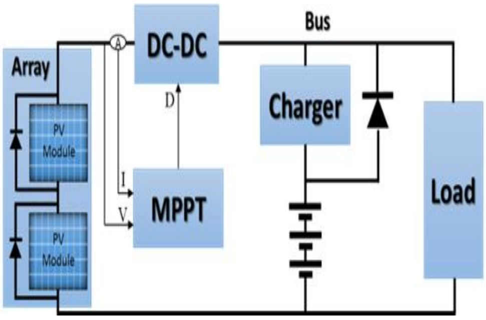


Fig. 4 Satellite EPS schematic [8]

3. MEASUREMENT TESTING FOR LOW COST SOLAR CELL

The objective of this Lab activity is to study and measure the output voltage and current characteristics of a solar cell and power calculation.

A. Technological choice of photovoltaic cells

Our choice is for a first prototype on the solar cell sourcing map 110mm x 60mm 1 Watt 6 Volt, this solar cell will fit perfectly into small projects.

The cell produces a DC voltage of 6V in direct exposure for a maximum power of 1W (i.e. a current of 167mA). Multiple panels can be arranged in series and/or parallel to increase voltage and current.

Fig. 5 Technological choice of photovoltaic cells [9]

Measure the efficiency of solar cells as they convert sunlight to power, we did the experiment indoors in the laboratory under a light source.

B. Testing means for solar cells:

for the characterization test (I-V) of solar cells, we needed specific means to ensure the temporary fixations and connections of each cell; as well as a piloting instrumentation, for the scanning in electric current. In this context, a system is realized to answer the need of repetitive tests on a group of solar cells or a temporary assembly of a solar panel. The objective of the tests is to select the cells having a similar behavior and in conformity with the standards, to be integrated in series/parallel on the GS panels of PEDAGO-SAT. In the following figures 6,7 and 8you can see the realized part of means, which includes: the softwareautomatizing thecharacterization test, see figure6, developed in python de conducted the setup of test, the fastening and temporary connection mechanism (encapsulation system) illustrated in figure8. All are covered by a user manual and a test procedure to include the aerospace test standards and de prepare the setup of test figure 7.

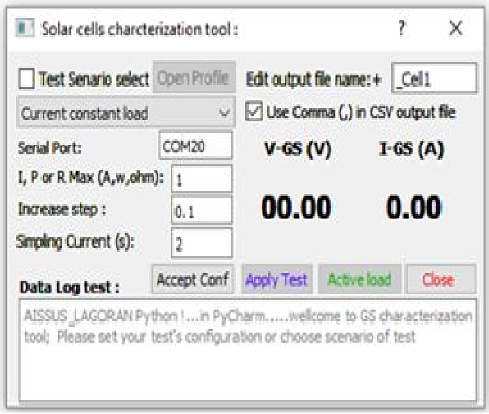


Fig. 6 Characterization Tool

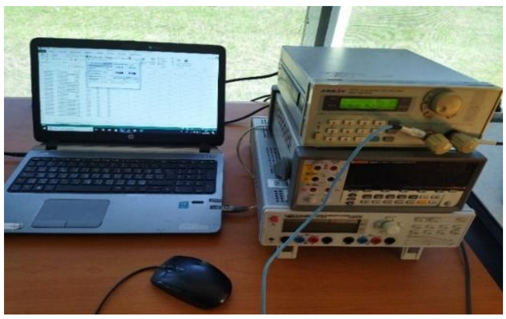


Fig. 7 Setup test

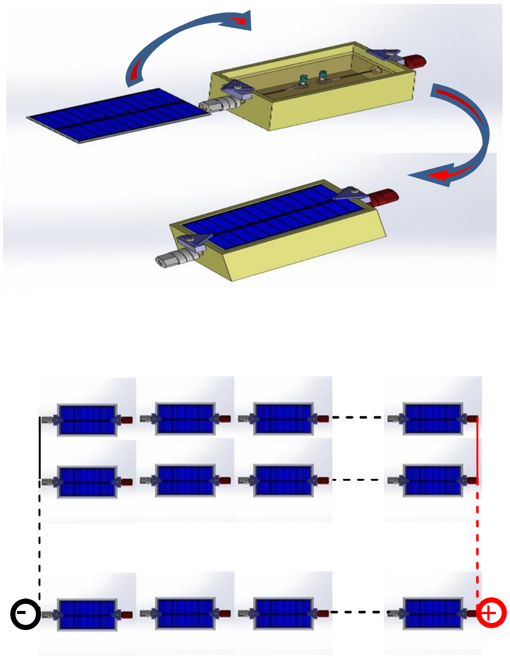


Fig. 8 The realized Solar cells encapsulation system.

C. Experimental Setup

The test procedure is straightforward in theory a load is applied and then the voltage across the cell and the current through it need to be measured to calculate the power being supplied to the load, and this test needs to be repeated at different load settings.

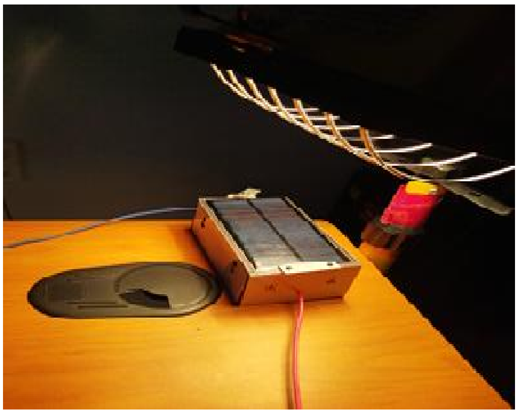


Fig. 9 Measure the efficiency of solar cells as they convert sunlight to power.

The light source for the solar cell used in this research is 500 watts, we used an electronic load for testing cells.
Using the red clip lead, connect the positive terminal of the meter to the positive terminal of the solar cell. Then use the black clip lead to connect the common (COM) terminal of the meter to the negative terminal of the solar cell (see photos below).
The test procedure was implemented in a file called sell 1.html and it was run with a solar cell (Polycrystalline Silicon) shown in the photo above) as the device-under-test.
With the software it was just set the min/max voltage range and click the 'Start Test' button. The value of current and voltage is shown in real-time as the test runs, the results are then imported into excel.

D. Results and discussion

To investigate the performance of the best cell we tested the 40 cells available in the laboratory to make the final choice in relation to the maximum power supplied by each cell.
The amount of power generated by the solar panel depends on using the most efficient solar cells, so we tested several cells to determine the best ones.
the following table summarizes the test of all the cells available in the laboratory, then we will present the test results of the cell which provides the best maximum power as well as the cell which gives the minimum power.

The following flowchart shows the method used in the selection of solar cells

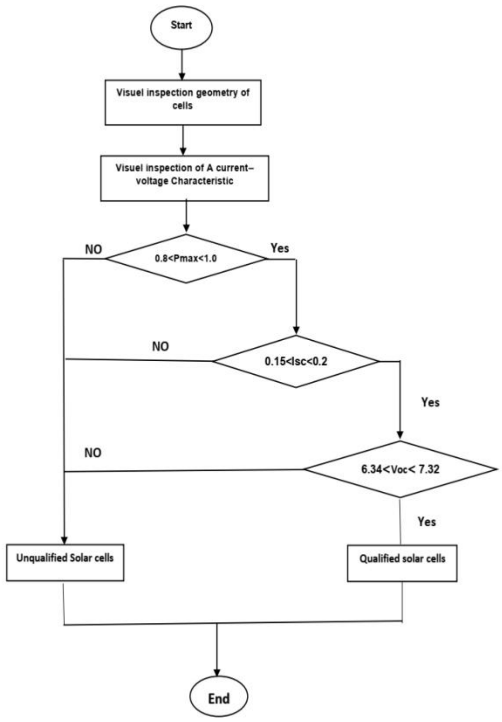


Fig.10 Flowchart of the proposed method for selection of solar cells

Table 1 The basic characteristics of the tesedsolar cells (quantity = 40) are summarized in table

Cell	Isc	Voc	P max	Status
Cell n°01	0.21	7.04	1.02	OK
Cell n°02	0.20	6.65	0.94	OK
Cell n°03	0.20	6.97	0.77	NOK
Cell n°04	0.22	6.48	0.89	Ok
Cell n°05	0.18	6.78	0.68	NOK
Cell n°06	0.18	7.26	0.92	Ok
Cell n°07	0.21	6.74	0.95	OK
Cell n°08	0.18	6.78	0.68	NOK
Cell n°09	0.20	7.02	0.70	NOK
Cell n°10	0.20	7.07	0.82	OK
Cell n°11	0.20	7.11	0.98	OK
Cell n°12	0.20	7.14	1.02	OK
Cell n°13	0.18	7.13	0.91	OK
Cell n°14	0.19	7.08	1	OK
Cell n°15	0.18	7.03	0.92	OK
Cell n°16	0.21	7.02	1.01	OK
Cell n°17	0.19	7.27	0.98	OK
Cell n°18	0.19	7.24	1.03	OK
Cell n°19	0.17	6.74	0.82	NOK
Cell n°20	0.20	7.27	1.03	OK
Cell n°21	0.21	7.06	1.01	OK
Cell n°22	0.17	7.18	0.91	Ok
Cell n°23	0.15	7.18	0.85	NOK
Cell n°24	**0.17**	**6.82**	**0.56**	**NOK**
Cell n°25	0.17	6.91	0.84	NOK
Cell n°26	**0.21**	**7.32**	**1.04**	**OK**
Cell n°27	0.17	7.00	0.84	OK
Cell n°28	0.18	7.11	0.91	Ok
Cell n°29	0.21	7.06	0.98	Ok
Cell n°30	0.21	6.96	0.99	OK
Cell n°31	0.17	6.98	0.87	OK
Cell n°32	0.2	7.18	1.00	Ok
Cell n°33	0.2	6.34	0.53	NOK
Cell n°34	0.16	6.92	0.80	OK
Cell n°35	0.19	7.04	0.78	NOK
Cell n°36	0.19	7.12	0.99	OK
Cell n°37	0.19	7.08	0.96	NOK
Cell n°38	0.17	7.07	0.91	OK
Cell n°39	0.18	7.25	0.98	OK
Cell n°40	0.22	7.08	1.05	OK

I_{SC}: short-circuit current

V_{OC}: open-circuit voltage

P_{max}: The Maximum Power Point

The Solar Cell Current-Voltage (I-V)characteristic Curves shows the current and voltage (**I**-V) characteristics of a particular photovoltaic (PV) cell, module or array. It gives a detailed description of its solar energy conversion ability and efficiency [4]. Knowing the electrical **I**-V characteristics (more importantly P_{max}) of a solar cell, or panel is critical in determining the device's output performance and solar efficiency.

The key points of the **I**-V Characteristic curve used to select cells is the open circuit voltage (V_{OC}), the short circuit current (I_{SC}), and the maximum power point (MPP or Pmax), defined by its voltage V_{Pmax}, and I_{Pmax}).

the followed table illustrates the I-V Characteristic of a typical cell accepted to be part of our solar panel.

Table 2 The Characteristics from theaccepted Solar Cell (cell Number 26th)

I command	Voltage	Curent	Power
0	7,32	0	0
0,01	7,38	0	0
0,02	7,33	0,01	0,07
0,03	7,27	0,02	0,14
0,04	7,19	0,03	0,21
0,05	7,14	0,04	0,28
0,06	7,06	0,05	0,35
0,07	7,00	0,06	0,41
0,08	6,91	0,07	0,48
0,09	6,86	0,08	0,54
0,10	6,78	0,09	0,60
0,11	6,70	0,10	0,66
0,12	6,62	0,11	0,73
0,13	6,51	0,12	0,77
0,14	6,43	0,13	0,83
0,15	6,32	0,14	0,88
0,16	6,21	0,15	0,92
0,17	6,06	0,16	0,96
0,18	5,90	0,17	1,00
0,19	5,73	0,18	1,03
0,20	5,49 (V_{pm})	0,19 (I_{PM})	1,04 P_{max}
0,21	5,13	0,20	1,02
0,22	2,03	0,21	0,43
0,23	0,06	0,21	0,01
0,24	0,06	0,21	0,01
0,25	0,06	0,21	0,01

Fig 11,12,13,14 shows the current-voltage (I-V) and (P-V) Characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by a single solar cell is the product of its output current and voltage (I x V).
Solar cell experimental I-V curves are determined through measurements ofthe output voltage and output current variations [9] and the information needed for us to configure a solar power array so that it can operate as
close as possible to its maximum peak power point. [11]

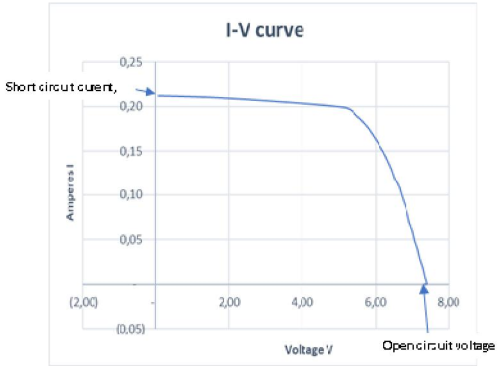


Fig .11Characteristic I-V curves of a solar cell number 26

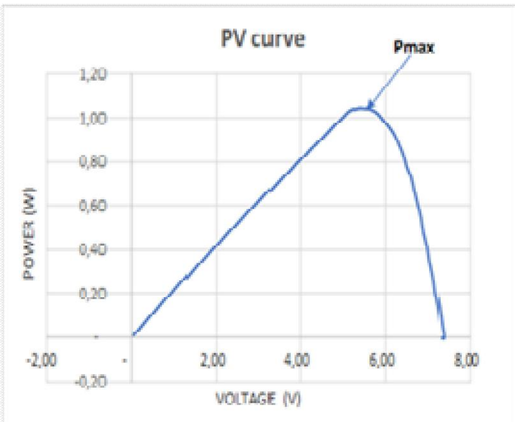


Fig .12 Characteristic P-V curves of a solar cell number 26

The I(V) and P(V) characteristics of cell number 26 are correct, we observe that in Figure 11 and 12, under short-circuit conditions, the current generated is at its maximum(Isc), while when the generated circuit is open, the voltage is at its maximum (Voc).
In both conditions, the electrical energy produced in the cell is zero, sothat under all other conditions, when the voltage increases, the energy produced
also increases. It first reaches its maximum (Pmax) then it drops until it approaches the open circuit voltage value.

Tab 3 The Electrical Characteristics of Solar Cell to be rejected, (cell Number 24th)

I command	Voltage	Curent	Power
0	6.82	0	0
0,01	7,22	0	0
0,02	6.25	0,01	0,06
0,03	5.99	0,02	0,11
0,04	5.93	0,03	0,17
0,05	5.80	0,04	0,23
0,06	6,03	0,05	0,30
0,07	5.83	0,06	0,34
0,08	5.62	0,07	0,39
0,09	5.46	0,08	0,44
0,10	5.42	0,09	0,48
0,11	5.19	0,10	0,51
0,12	4.97	0,11	0,55
0,13	4.67	0,12	0,56
0,14	4.06	0,13	0,53
0,15	3.49	0,14	0,49
0,16	2.22	0,15	0,44
0,17	0.04	0,16	0,36
0,18	0.04	0,17	0.01
0,19	0.04	0,18	0,01
0,20	0.04	0,19	0,01
0,21	0.04	0,20	0,01
0,22	0.04	0,21	0,01
0,23	0,04	0,21	0,01
0,24	0,04	0,17	0,01
0,25	0,04	0,17	0,01

the prior table illustrates the I-V Characteristic of a cell that could not be part of our mission solar panel.

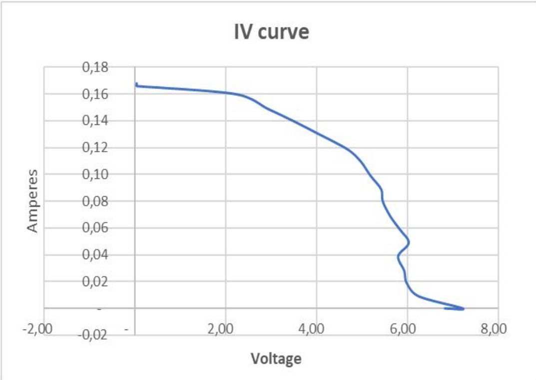


Fig .13 Characteristic I-V curves of a solar cell number 24

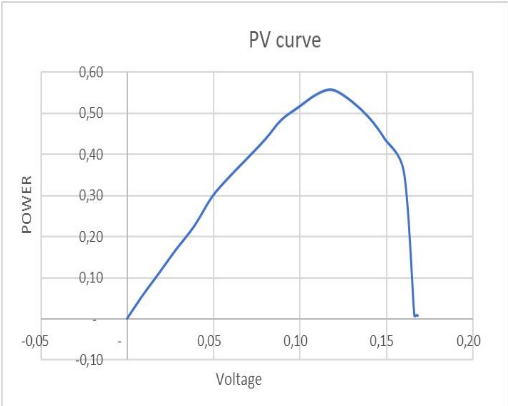


Fig.14 Characteristic P-V curves of a solar cell number 24

Figures 13 and 14 show the I(v) and P(V) characteristic of cell number 24, given the shape of the curves, it is clearly seen that the cell is defective so it will be rejected

E. Selection of the best solar cells for Assembly of Solar Arrays

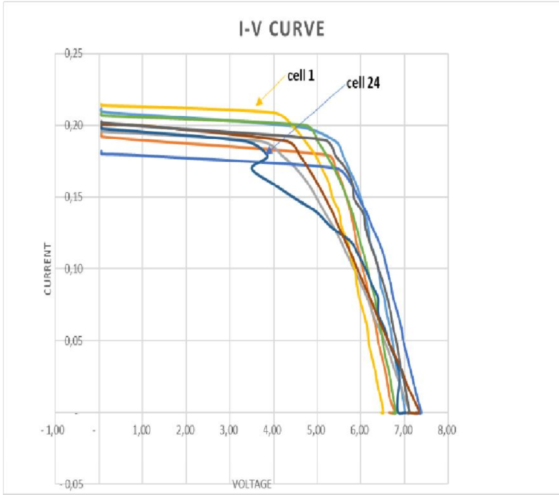
One of the major efforts during a typical spacecraft-oriented solar array design process is concerned with "choosing" the "right" solar cell, for selecting the best solar cells it is based on various groups of criteria (Electrical, mechanical.), in this study our choice is based on electrical and power criteria.

The power range chosen is between 0.8 watt and 1.02 watt.

The fig14, 15 showna sample of (I-V)and (P-V)curves for ten solar cells.

this stage of the test allowed us to choose between the defective solar cells and the one that gives good performance.

we notice that the test results for solar cells number 01,02,11,12,26 are acceptableand



those of the solar cells number 03,09,19,33,37 are rejected.

Fig .15 Characteristic I-V curves of a ten solar cells

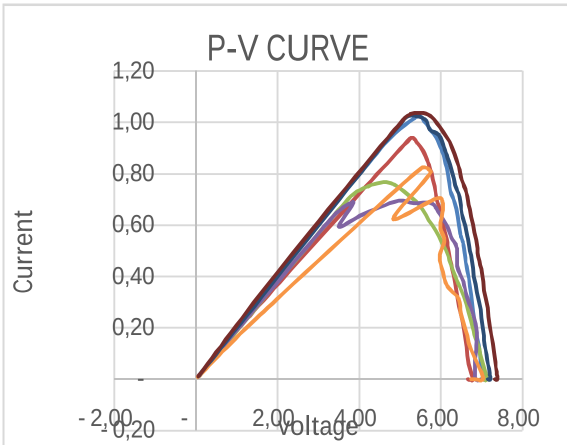


Fig .16 Characteristic P-V curves of ten solar cells.

From Fig. 15 and Fig. 16, it is clear that the importance of the preliminary test of all the solar cells to select the best one in order to begin their assemblies on the panels which will be the subject of the next step.

4. CONCLUSION

The curves of solar panels have an important role in the design of photovoltaic systems. Experimental data showed that the solar cells with highest efficiencies are interesting for our solar panel configurations.

For the next steps, following the results of the tests obtained, we were able to choose the most efficient cells to and to manufacture the PEDAGO-SAT solar panels. After efficiency of cells, operational spectral panel (visible, infrared, ultraviolet) and technology (mono or multijunction) shape, the nominal power is the most important indicator to choose the solar cells to be embedded in satellite.

Generally, the elaborate work has allowed us to set up a Hardware/software tool which makes characterization tests of solar cells systematic, easier and faster. The result obtained allowed us to accept, in the 1st step of procedure qualification, 20 from 40 tested cells. Knowing satellites, they could have more than one solar panel (typically 3 panels); each panel could contain about fifty cells, and knowing that there are other steps also should be included to decide the qualification status to be fly space equipment, it becomes clear that this activity is going to be heavier and more expensive.

In perspective, we plan to continue our efforts to reduce the cost and time and update the proposed tool to automate the diagnosis, decision support and include other automated steps of the test procedure; for example, visual inspection.

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