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Compliance Verification of Photovoltaic Solar Components: The Case of the Laboratory for Quality Control of Photovoltaic Solar Components (LCQS) in Senegal

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Africa is a region rich in natural resources but some of its regions are landlocked and the potential exists for significant regional trade. However, integration and trade in the region remains limited despite the efforts of regional institutions to encourage this integration. In general, the quality of goods traded and collected is rather low, import controls are too strict and trade procedures are dexterously cumbersome. Governments create the conditions and rules for the functioning of markets and private enterprises and ensure the well-being of communities and individuals. It is in

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this context of consumer protection that quality assurance is important. In the case of solar photovoltaic components, these checks are carried out by conformity tests carried out in a laboratory. Our compliance tests were carried out at the Laboratory for Quality Control of Solar photovoltaic components (LCQS) of the Centre for Renewable Energy Studies and Research (CERER) at the Cheikh Anta Diop University in Dakar (UCAD). The study of the modules focuses on the electrical performance characteristics in the case of short circuit current, open circuit voltage, form factor, maximum power, current and voltage (I-V) and voltage power (P-V). The study of the controllers concerns the efficiency of charge and discharge, here the average efficiency in charge is 96.45% and that in landfill is 96.11%.

Keywords: Photovoltaic module; compliance control; load regulator; laboratory; Senegal.

1. INTRODUCTION

Taking into account the important needs of Senegal in terms of water and rural electrification, the Centre for Renewable Energy Studies and Research (CERER) has set itself the ambition to participate effectively in the search for solutions in relation to public and private decision-makers [1]. His experience in the field gives him that ability. The CERER houses the Laboratory for Quality Control of Solar Photovoltaic Components in Senegal (LCQS), the Pico-PV Product Compliance Control Laboratory (LCCPV – Lighting Africa) and the National Laboratory on Lighting (LNE). These laboratories make it possible to carry out conformity control tests and propose to respond to the request made by users concerning:

- Design, study, construction, sizing and monitoring of various photovoltaic solar installations (pumping, domestic and public lighting, lighting, centralized and decentralized rural electrification, desalination of brackish water, etc.);
- Opportunities and areas of application of solar photovoltaic energy;
- Study of needs and choice of suitable solutions;
- Expertise and technical support in the installation and maintenance of solar photovoltaic projects;
- Quality control testing of photovoltaic components (LCQS);
- Energy Efficient Lamp (LNE) quality control tests;
- Quality control tests for pico-systems PV (Lighting-Africa);
- Extension of photovoltaic systems;
- Studying and characterizing electrochemical storage (battery) systems;
- Modelling, simulation and experimentation on photovoltaic systems;
- Improved energy efficiency.

The Photovoltaic Solar Energy Department of CERER, whose role is not limited to the control of PV components, but also with the ambition of fulfilling the following missions:

- Advise public or private users;
- Participate in the development of photovoltaic solar energy applications;
- Support local manufacturers to enable them to obtain products that are competitive with imported products;
- Train installation technicians and possibly students interested in photo conversion;
- Collect and disseminate domain information;
- Extension and dissemination of techniques (technology transfer of sustainable systems).
- Design and construction of autonomous solar street lights;
- Performance testing of mills, kilns, dryers, etc.
- Design and sizing of solar systems;
- Implementation and installation of solar systems;
- Monitoring, Energy Audit, Maintenance;
- Training of technicians and project managers.

2. THE LCQS-CERER

2.1 History

The Laboratory for Quality Control of Photovoltaic Solar Components (LCQS) is the structure on which Senegal’s strategy for quality control of photovoltaic equipment components is based [1].

In recent years, Senegal has been developing a policy of massive use of photovoltaic solar energy in several sectors of economic and social activity. Several public and private actors are involved in projects aimed at providing people with photovoltaic solar power for various applications. As Senegal is not a producer of PV equipment components, the State had taken a number of fiscal measures to facilitate the import of PV modules, regulators and some other components.

The number of suppliers is becoming increasingly important. They sourced from large European firms whose product quality was virtually guaranteed. At present, as the sources of supply have become very diversified, the risk of importing poor quality material is also greater.

It is in this context that the State, in order to avoid the risks of failure of its policy of development of photovoltaic solar energy, has created a standards Committee called CT13, a National Standards Management Unit and the Laboratory for Quality Control of Solar Photovoltaic Components (LCQS).

2.2 Organization

The quality control laboratory under the supervision of the Ministry of Oil and Energy is housed by the Centre for Research and Studies on Renewable Energies (CERER) [2].

The permanent technical staff for the tests is composed of one engineer, three senior technicians and two technicians, all from CERER. These staff may be assisted by the following institutions:

- Ecole Supérieur Polytechnique (ESP)/UCAD;
- Société Nationale d'Electricité (SENELEC);
- Faculty of Science and Technology / UCAD;
- Centre for Renewable Energy Studies and Research;
- And any other qualified person.

The Laboratory has already tested a number of photovoltaic equipment:

- Development of the National Rural Electrification Plan, led by the Ministry of Energy, Mines and Industry under the funding of JICA.
- Minibatnet (Spanish product), DC – DC conversion system (12V input- 300V output)
- FOPEN SOLAIRE Electronic Ballasts (Low Voltage Fluorescent Strip Mounting Unit)
- TENESOL solar batteries
- Solar photovoltaic mills (MATFORCE and TENESOL)
- Industrial and Solar Electricity Inverter (EIS)
- Etc.

2.3 Tests Performed

The State had made a provision to oblige any tenderer to public contracts to have their equipment tested beforehand by the LCQS. The certification document shall form part of the tender documents. By this measure, the State would also like to encourage individual users to turn to the LCQS for advice before acquiring any PV equipment [2].

The Laboratory for Quality Control of Solar Photovoltaic Components is equipped to carry out tests and controls on [3]:

2.4 Photovoltaic Modules

The characteristics (short circuit current, open circuit voltage, maximum power point, load current measured for a specified load voltage) are recorded through the module characterization test. In addition to this, there are also tests of electroluminescence, test of resistance to localized heating, test of electrical safety and visual inspection Using these measurements, the performances of the modules are then determined.

2.5 The Load Regulators

The measured parameters are threshold voltages, maximum operating load, vacuum current, load and discharge efficiency. The tests also covered the temperature dependence of these quantities, the overload protection system, the polarity inversion protection system, endurance and the Fail/Self behaviour.

2.6 Electrochemical Storage Batteries

Charge/discharge cycles are performed and analysed to determine battery capacity. Tests relating to the loading/unloading speed and the gassing phenomenon are also carried out.

3. SHARP POLYCRYSTALLINE MODULE ND-E230A2 TEST

The performance declines observed in PV systems are all the more alarming in regions with severe climatic conditions such as sub-Saharan regions. When these irregularities in the system are found, performance tests are performed individually on different panels taken. Our approach is to make a comparison between the data provided in the data sheet and the actual panel data at the time the tests were performed. This will allow to highlight possible irregularities such as the decrease of certain parameters (voltage, current, power etc.) [4]. These tests could explain, among other things, the decrease in performance of a PV system.

3.1 Equipment Used

The tests are divided into two parts:

- Pre-test or visual inspection: This is the first PV module degradation detection technique to detect abnormalities with the naked eye.
- Functional tests that measure the performance of PV modules.

The materials used to perform the tests are:

- SL-Solar5000
- Dominos
- Screw driver
- Connection cables

For the tests, the panels were exposed to natural radiation with a 15° angle of tilt. Then they were connected to the ESL-Solar5000 suitcase following the following assembly:

- The mirror cell that captures solar radiation is connected to the ESL-Solar5000 by a cable and then placed parallel to the panels.
- The characteristics (Pmax, Vmax, Imax, Icc, Vco etc.) of the panel to be tested are inserted
- On the module tab of the ESL-Solar5000 Solar ET software.

NB: In the case of external measurements the control of light and temperature remain difficult to achieve.

The ESL-Solar5000 records the different voltage, current and power values for different irradiation values every 20s. The results show us here the electrical parameters of the panel that was inserted upstream in the software, that is to say the manufacturer's data (all the parameters preceded by the word specified), then they give us the values of the electrical parameters corrected to the standard test conditions (E=1000W/m² and T=25°C). These corrected parameters are MPP voltage, MPP current and MPP power. The tests were performed at two light indices: 600 W/m² and 900 W/m².

3.2 Results Obtained

Table 1 shows the results obtained after the visual inspection. The results of the functional tests are recorded in Table 2. The characteristic curves (Figs. 4, 5, 6 and 7) were obtained from the various current, voltage and power values given by ESL-Solar5000 (Table 3 et 4).

Fig. 1. PV module

Fig. 2. ESL-Solar5000

Fig. 3. Polycrystalline Module ND-E230A2

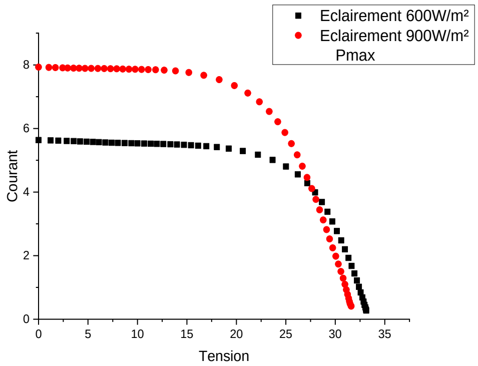

Fig. 4. IV curve

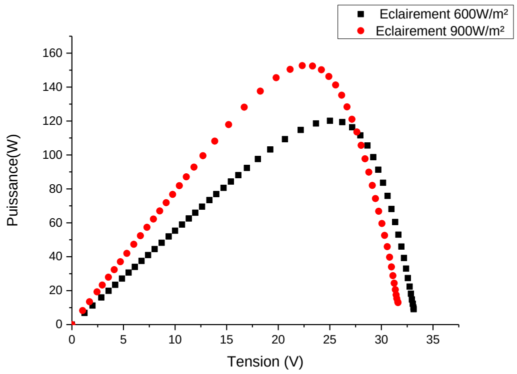

Fig. 5. Power curve

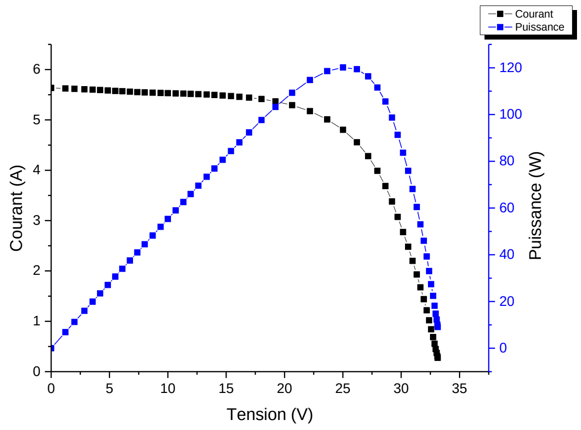

Fig. 6. IV and Power curve: E=600W/m²

Table 1. Visual inspection of the polycrystalline module

Product	
Cell type	Polycristalline
Manufacturer	Sharp
Country of origin	Germany
Serial number	ND-E230A2
Mechanical and physical parameters	
Length (cm)	165
Width (cm)	99
Area (cm²)	16335
Number of cells	60
Rating plate	Yes
Junction box	Yes
Tightness	Yes
Front protection	Glass
Back protection	Glass
Framing of the module	Aluminium
Yield	14
Module mounting type	Serie
Electrical characteristic	
Cells association	Serie
Maximum power W)	230
Open circuit voltage (V)	37
Short circuit current (A)	8.24
MPP current (A)	7.60
MPP voltage (V)	30.3
FF (calculated)	0.75
Current temperature coefficient	0.053 %/°C
Voltage temperature coefficient	- 130 mV/°C
Power temperature coefficient	-0485 %/°C
Polarity (+) (-)	Yes
Diode	Yes

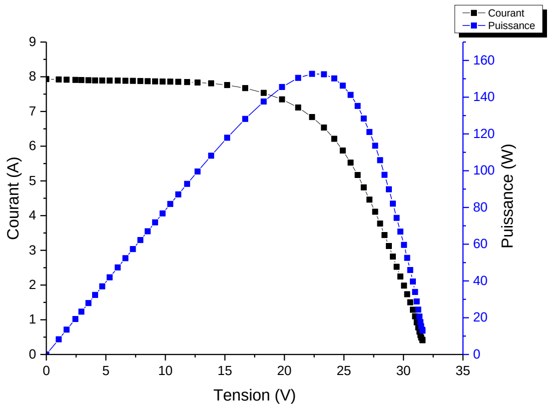

Fig. 7. IV and Power curve: E=900W/m²

Table 2. Test results for an illumination of 900W/m²

Voltage(V)	Current(A)	Power(W)	Irradiation (W/m²)
31.609	0.409	12.928	952
31.583	0.425	13.412	952
31.492	0.488	15.368	951
31.430	0.558	17.531	951
31.352	0.657	20.598	951
31.242	0.781	24.394	950
31.117	0.927	28.858	951
30.976	1.098	34.006	950
30.797	1.289	39.709	947
30.570	1.502	45.922	949
30.312	1.734	52.567	949
30.054	1.983	59.603	950
29.742	2.246	66.812	949
29.429	2.525	74.314	950
29.117	2.818	82.045	951
28.781	3.123	89.876	951
28.413	3.440	97.742	951
28.038	3.769	105.687	951
27.624	4.111	113.551	950
27.147	4.459	121.055	951
26.670	4.813	128.375	951
26.155	5.170	135.230	950
25.561	5.525	141.234	952
24.904	5.873	146.269	951
24.186	6.211	150.212	954
23.326	6.535	152.435	952
22.326	6.839	152.677	953
21.154	7.114	150.482	952
19.802	7.349	145.531	952
18.262	7.536	137.631	951
16.707	7.672	128.171	953
15.191	7.761	117.893	953
13.847	7.811	108.156	952
12.706	7.834	99.541	953
11.831	7.846	92.822	952
11.092	7.853	87.106	952
10.420	7.858	81.881	955

Voltage(V)	Current(A)	Power(W)	Irradiation (W/m²)
9.764	7.862	76.761	952
9.139	7.866	71.891	952
8.514	7.871	67.014	954
7.901	7.877	62.231	952
7.275	7.881	57.339	954
6.643	7.885	52.376	953
6.002	7.888	47.343	952
5.322	7.890	41.990	952
4.697	7.891	37.061	951
4.103	7.894	32.386	954
3.540	7.898	27.958	955
2.946	7.903	23.282	953
2.438	7.908	19.282	953
1.704	7.915	13.485	954
1.042	7.921	8.254	954
0.000	7.931	0.000	954

Table 3. Test results for an illumination of 600W/m²²

Voltage(V)	Current(A)	Power(W)	Irradiation (W/m²)
33.133	0.274	9.078	641
33.107	0.304	10.053	641
33.047	0.371	12.267	641
32.961	0.449	14.786	641
32.860	0.553	18.171	641
32.742	0.685	22.415	642
32.563	0.841	27.398	641
32.391	1.019	33.006	641
32.187	1.219	39.243	642
31.937	1.439	45.964	641
31.648	1.675	53.017	642
31.336	1.929	60.440	641
30.976	2.199	68.129	641
30.601	2.480	75.897	642
30.164	2.773	83.638	642
29.703	3.074	91.300	642
29.210	3.379	98.696	642
28.648	3.685	105.561	641
27.960	3.989	111.528	641
27.171	4.281	116.330	641
26.204	4.556	119.396	641
25.016	4.803	120.148	642
23.664	5.010	118.567	642
22.179	5.174	114.765	642
20.655	5.292	109.308	641
19.231	5.368	103.241	641
18.028	5.415	97.617	641
16.965	5.443	92.334	641
16.137	5.459	88.090	641
15.410	5.473	84.336	641
14.699	5.485	80.623	642
13.995	5.495	76.910	642
13.331	5.504	73.375	641
12.620	5.511	69.547	641
11.956	5.517	65.959	642
11.331	5.522	62.570	641

Voltage(V)	Current(A)	Power(W)	Irradiation (W/m²)
10.675	5.527	58.996	642
10.003	5.531	55.324	641
9.383	5.536	51.944	641
8.703	5.541	48.224	642
8.023	5.546	44.500	642
7.382	5.552	40.990	642
6.749	5.560	37.528	641
6.103	5.569	33.984	641
5.501	5.576	30.676	641
4.853	5.585	27.101	641
4.196	5.593	23.470	642
3.555	5.601	19.915	642
2.852	5.608	15.995	641
2.000	5.617	11.235	641
1.224	5.625	6.887	641
0.000	5.636	0.000	641

Table 4. Data comparison

Manufacturer's data					Measured data				
Pmax(W)	**Vmax(V)**	**Imax(A)**	**FF**	η	**Pmax(W)**	**Vmax(V)**	**Imax(A)**	**FF**	η
230	30.3	7.60	0.75	14	152.677	22.326	6.839	0.60	9.5

Table 5. Acceptability results

	Acceptability				Remark
Module number	**Pmax**	**Vmax**	**Visual compliance**	**Acceptability**	**Power drop**
ND-E230A2	No	Yes	Yes	Yes	

Module junction temperature: 87.2°C
Open circuit voltage: 31.824V
Short circuit current: 7.931A
MPP power: 152.677W

Tables 4 and 5 show the comparison between the manufacturer's data and the measured data.

The fill factor FF is obtained from the equation [5]:

$$FF = \frac{V_{max} * I_{max}}{V_{co} * I_{cc}}$$

The yield is given by the equation [6,7]:

$$\eta = \frac{V_{max} * I_{max}}{\phi * S}$$

ϕ (W/m²): incident light power
S (m²): surface of the module

The photovoltaic module is still usable because after several years of operation, its power is more than 66% of its initial power and its efficiency is more than 67% of its initial efficiency. So, the conditions of use are still acceptable.

3.3 Discussion

As shown in the graphs above, illumination has a considerable influence on cell performance. The maximum power delivered by the latter increases with irradiation. Indeed, we notice that the short-circuit current increases with the light intensity while the voltage varies little. This phenomenon is explained by the fact that the illuminance leads the module to generate more load carrier which results in the birth of significant current. To illustrate this, the tests were carried out with different irradiation deviations to see the behaviour of the maximum power bridge of the different panels (300W/m² for the Sharp polycrystalline panel ND-E230A2). For polycrystalline there is a considerable increase in Pmax.

For the different module technologies, we notice that after the tests the power decreases. This decrease may be due to: [8]

- Too high temperatures: Senegal is located in the sub-Saharan area with temperatures ranging from 16°C to 38°C. An increase in temperature leads to a significant drop in the open circuit voltage while the short current circuit varies little. The characteristics given by the manufacturer indicate degradation values in the order of 0.4% per degree of elevation.
- Humidity: Studies have shown that the increase in humidity leads to an increase in the serial resistance of the modules and therefore a decrease in maximum power.
- Seniority: after several years of operation the modules become less and less productive.

3.4 Recommendation for Panel Maintenance

For optimal operation of solar panels, it is important to perform regular maintenance. There are two levels of maintenance: [9]

- Small maintenance that is performed by the owner on a regular basis. This level of maintenance consists of cleaning the panels with water early in the morning or late at night, making sure there is no shading near the PV modules.
- Heavy maintenance by qualified personnel.

4. REGULATOR WHC2410CC TEST

Also known as a charge controller, it is an electronic system or device that operates completely automatically to which the generator (solar panels, wind turbines, etc.) is connected, as well as any equipment or components of the installation [10].

The charge controller is used primarily to check the battery condition. It ensures the full charge of the battery and prevents any risk of overloading the battery by stopping the power when necessary. This regulation mechanism consists in constantly monitoring the state of charge of the battery.

- The regulator shuts off the generator power when the state of charge of the battery reaches the limit value (Vfc). It reconnects the generator when the voltage goes down sufficiently (Vrp).
- The regulator shuts off the charge when the battery state reaches the discharge limit (Vfd). It reconnects the load when the voltage rises sufficiently (Vrc).
- The regulator is protected against short circuit, reverse polarity, power surge, etc.

Thanks to this monitoring and permanent protection, the battery's performance and life can be significantly extended.

Most controllers are equipped with LEDs to provide a set of indications such as:

- The state of charge of the battery,
- The operating status of the generator,
- The current mode of operation,
- The state of the various protections, etc.

4.1 The Equipment Used

The equipment used to perform the tests is:

- Two amperemeters
- Two voltmeters
- A voltage generator
- A rheostat
- Wire connections.

The tests performed on the WHC2410CC controller are intended to test the operation of the controller, to know the regulatory thresholds and to calculate the load and discharge efficiency. The controller is of the Pulse With Modulation (PWM) type.

These controllers use MOSFET or power transistors operating at high frequencies, to generate pulses, to keep the batteries at a constant voltage. Pulse Width Modulation (PWM) is a very fast and efficient method to achieve the full charge state of a solar battery. Unlike older controllers that only acted on the charge current by ON or OFF (which is enough to restore the charge state of a battery to about 70%) [10].

The PWM technical controller constantly checks the state of charge of the battery to adjust the duration and frequency of the current pulses to be delivered.

If the battery is discharged, the current pulses are long and almost uninterrupted. When the battery is almost fully charged, the pulses become shorter and shorter.

These tests were performed according to the following assembly: (Fig. 8).

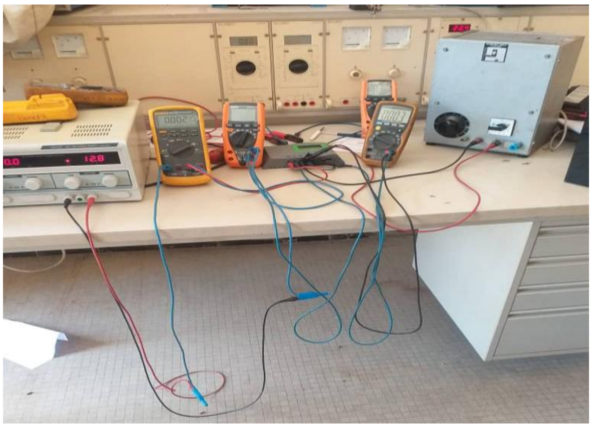

Fig. 8. Test setup

4.2 Results

Our regulator is usually inserted between the photovoltaic field and the battery. It consists of an electronic switch operating in PWM (Pulse Width Modulation) and an anti-feedback device (diode).

The electronic switch is opened and closed at a certain frequency, allowing the charge current to be precisely regulated according to the state of charge [11]. When the battery voltage is below the limiting voltage of the regulator, the switch is closed. The battery then charges with the current corresponding to the sunshine. We are in the "Bulk" phase. When the battery voltage reaches a predetermined regulation threshold, the switch opens and closes at a fixed frequency to maintain an average current injected into the battery. The battery is charged, we are in the "Floating" phase.

The control thresholds obtained are in Table 6.

4.3 Yield Charge

Knowledge of yield charge is of great importance in assessing the quality of the load regulator. The purpose of this manipulation is to determine if the regulator is capable of pulling energy from the PV field and properly charging the battery. In this test the PV field is represented by the voltage generator and the battery by the rheostat. Then we adjust the rheostat for different current values (10%, 50%,80% of the nominal current of the regulator), then we read the voltages and currents on the PV and battery fields. The voltage generator is set to 12.8V. Note that here the maximum current of the regulator is 10A. This test is done as follow [11].

4.4 Yield of Discharge

The purpose of this test is to check if the regulator is capable of pulling energy from the batteries to power the receivers (lamps for example). In this test the voltage generator and the rheostat represent respectively the battery and the charge. As for the charge efficiency, the rheostat is affected and the voltage and current values for the charge and batteries are recorded. This test is done according to the following assembly [11].

Table 6. Regulation thresholds

Ambient temperature	21,3°C	
Nominal voltage	12 V	
Test stand N°	001	
	Manufacturer Data	**Measured Data**
Regulation thresholds	12V	12V
End of the voltage charge	--	15
Maximum voltage		
End of the voltage discharge	11	10.8
Trigger point	12.6	12.5
Load shedding signs	--	11.6

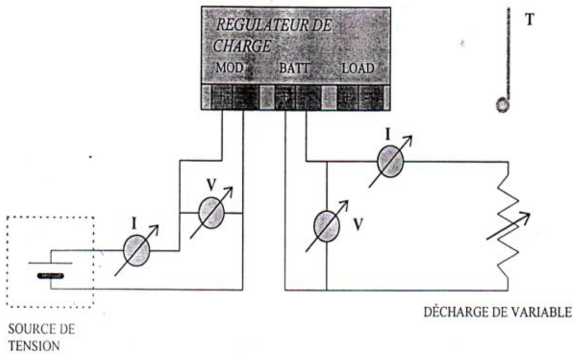

Fig. 9. Yield charge assembly

Table 7. Yield charge of the regulator

Load	PV Module			Battery			η
	Voltage	Current	Power	Voltage	Current	Power	Yield
1	12.89	1.07	13.79	12.43	1.03	12.80	92.82
5	12.38	5.04	62.40	12.08	5.02	60.64	97.17
8	12.28	7.83	96.15	11.93	8.01	95.55	99.37
η average							**96.45**

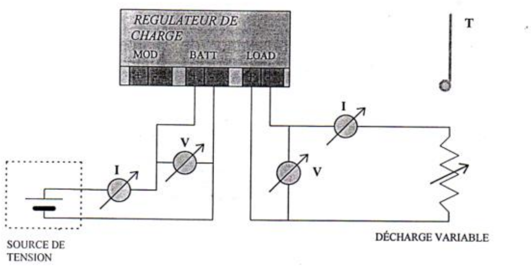

Fig. 10. Yield discharge assembly

Table 8. Yield discharge of the regulator

Load	Load			Battery			η
	Voltage	Current	Power	Voltage	Current	Power	Yield
1	12.57	1.01	12.70	12.75	1.03	13.13	96.72
5	11.97	4.97	59.49	12.31	5.07	62.41	95.32
8	11.48	8.04	92.29	11.79	8.13	95.85	96.28
η average							**96.11**

5. DISCUSSION

With a load and discharge efficiency of 96%, it can be concluded that the regulator performs its role satisfactorily.

To know the load disconnection threshold (during discharge), we consider the voltage generator as the battery. Then the voltage is lowered until the regulator flows a voltage that can no longer supply a charge (a lamp for example).

Note: During the tests we noticed that when there is an overload of the battery (16.3V), the regulator signals the unloading, then cuts the power supply.

When there is a deep discharge of the battery (11.6V), the regulator signals the unloading and then cuts the charge, at this moment the regulator flows a voltage of 11.2 V. If the battery discharges until reaching 5V, the regulator turns off. We used the voltage generator instead of the battery to test low voltage ranges (5V for example). After unloading, the regulator gives the battery time to charge, when the battery voltage is at 12.5V, the regulator then flows a voltage of 12.48V. This tension being sufficient; will allow a reconnection of the receivers: it is the phenomenon of re-engagement. The controller is equipped with LED battery charging status indicators. It provides the user with information such as: the sufficient charge level of the battery, the input voltage of the regulator. It also emits a warning signal indicating a near end of discharge. It bears an indelible marking indicating the + or – polarity of each electrical terminal block. The terminal blocks of the regulator are inaccessible to the user.

In the end, following the various tests carried out on the regulator, we can conclude that the regulator adequately performs its role and complies with technical standards and requirements.

6. CONCLUSION

This work was initially devoted to acceptability tests on module technologies in order to test their performance after several years of operation. Then, in a second step, we conducted conformity tests or quality tests of a regulator that was submitted to us by a customer. The acceptability tests showed that after several years the performance of the PV modules decreased and the conformity tests allowed us to check the quality of the regulator. Thus, it appears that compliance checks are necessary to judge the quality of solar photovoltaic equipment especially for a country like Senegal which does not manufacture these different solar components.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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