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DRAFT TANZANIA STANDARD

(Draft for comments only)

Solar photovoltaic power systems – test procedures for main components – part 3: Test procedures for regulators

TANZANIA BUREAU OF STANDARDS

Second Edition 2017

National Foreword

This draft Tanzania Standard has been prepared by the Solar Power System Technical Committee, under the supervision of the Electrical Engineering Divisional Standards Committee (EEDC)

This draft Tanzania Standard is a revision of TZS 925-3:2006 Solar photovoltaic power systems – test procedures for main components – part 3: Test procedures for Regulator.

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DRAFT TANZANIA STANDARD

Solar photovoltaic power systems — Test procedures for main components —

Part 3: Test procedure for regulators

1 Scope

This Part 3 of DTZS specifies the test procedures for regulators 12 V for use in photovoltaic systems.

2 Referenced documents

The following documents contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards and specifications are subject to revision, and parties to agreements based on this section of the specification are encouraged to investigate the possibility of applying the most recent editions of the documents listed below.

Where there is conflict between the following standards and this section of the specification, the requirements in this section of the specification shall take precedence.

IEC 60068-2-29, *Environmental testing — Part 2: Tests — Section 29: Test Eb and guidance.*

IEC 61000-4-2, *Electromagnetic compatibility (EMC) — Part 4: Testing and measurement techniques — Section 2: Electrostatic discharge immunity test.*

IEC 61000-4-3: *Electromagnetic compatibility (EMC) — Part 4: Testing and measurement techniques — Section 3: Radiated, radio frequency, electromagnetic field immunity test.*

IEC CISPR 22: *Information technology equipment — Radio disturbance characteristics — Limits and method of measurement.*

ISO 3744: *Acoustics — Determination of second power levels of noise sources using pressure — Engineering method in an essentially free field over a reflecting plane.*

3 Definitions and abbreviations

For the purposes of this Tanzania Standard, the definitions and abbreviations given in TZS 876: 2006 apply.

4 Procedures

The test procedures set out in this standard shall be type tests.

4.1 Tests for compliance with electrical parameters

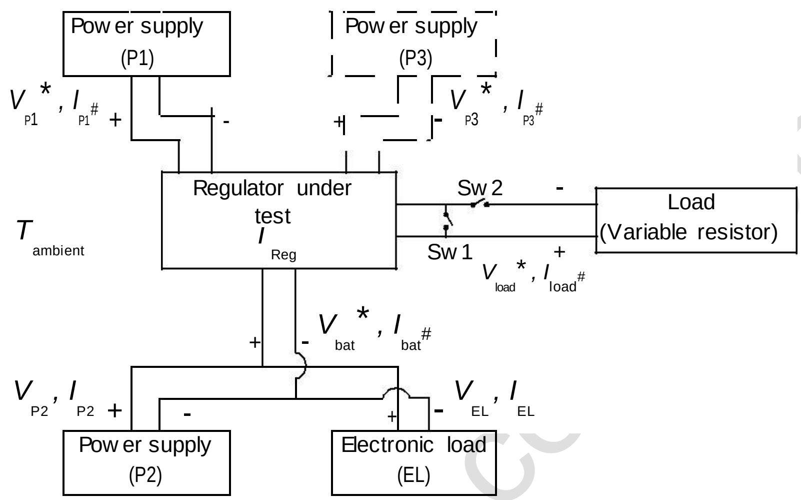
4.1.1 General

These tests are to verify compliance with electrical parameters set out in photovoltaic systems. In all cases the battery manufacturer implies the manufacturer of the battery to be used in a PV system together with the regulator to be tested.

4.1.2 Apparatus

Either the test circuit shown in Figure 1, where a battery simulator is used or the test circuit shown in Figure 2, where an actual lead -acid battery is used, shall be used to provide current flow through the regulator in order to be able to measure voltage drops. Where a lead-acid battery is used, its capacity, in ampere-hours, shall be not less than ten times greater than the battery charge or discharge current, in amperes.

Voltage drops shall be measured using calibrated instruments with an accuracy of 0.5 %.



NOTE 1 Voltages V_{P1}*, V_{P3}*, V_{bat}* and V_{load}* measured at regulator terminals.

NOTE 2 Keep Sw1 in the open position except when the short circuit test on loads is carried out.

Key:

— — Only for certain regulators

* Use DVM

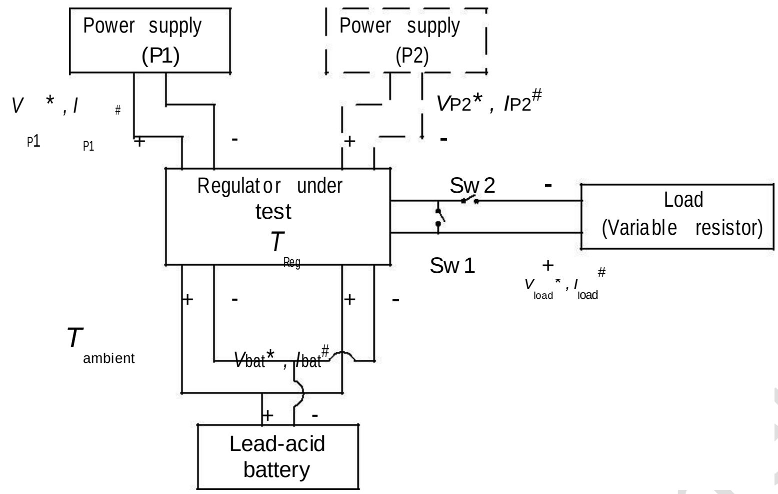
\# Use shunt and DVM

V = Voltage

I = Current

T = Temperature

Figure 1 — Test circuit (rig) for electrical compliance using a simulated battery



V = Voltage in volt
I = Current in Ampere
T = Temperature in degrees Celcius

Key:
— — Only for certain regulators
* Use DVM
\# Use shunt and DVM

Figure 2 — Test circuit using a lead-acid battery

NOTE A battery simulator will make it much easier to get the regulator into different modes. It will also maintain steady state battery voltages during tests. Furthermore, one does not require a very sophisticated battery simulator as the tests are all steady state tests. If an actual battery is used the capacity should be large enough such that the rate of change of voltage during measurement processes is less than 0.05 V/min.

During the tests the battery voltage shall be held constant at 12.5 V (± 0.4 V). The battery voltage shall be steady and shall be measured accurately for each charge and discharge current value. Characteristics of the battery simulator required in the tests are specified in **4.8.3**.

4.1.3 Voltage drop across the regulator in charging mode

The purpose of this test is to determine the voltage drop V_{drop}, across the regulator between the input of the PV array and the output of the regulator to the battery.
Do the following:

a) set the PV array simulator (d.c. power supply, P1) such that no current is supplied;

b) measure the voltage across the output terminals of the regulator to the battery, V_{bat};

c) measure the voltage across the PV array input terminals of the regulator, V_{charge}; and

d) repeat steps a), b) and c) for a PV simulator charging current equal to 25 %, 50 %, 75 % and 100 % of the rated regulator charging current.

The voltage drop shall be determined for each charging current by the difference between the values of V_{charge} and V_{bat} i.e.:

$$V_{drop} = V_{charge} - V_{bat}$$

The results can be recorded in a table similar to Table 1(a). The voltage drop shall not exceed 2.5 % of nominal (12 V) battery voltage (0.3 V).

Table 1(a) — Table to record voltage drop results for regulator in charge mode

1	2	3	4
I_{charge}	V_{bat}	V_{charge}	V_{drop}
0			
25 % of $I_{charge\ rated}$			
50 % of $I_{charge\ rated}$			
75 % of $I_{charge\ rated}$			
100 % of $I_{charge\ rated}$			

4.1.4 Voltage drop across the regulator in discharge mode

This test is to determine the voltage drop, V_{drop}, across the regulator between the input of the battery and the output of the regulator to the d.c. loads.

Do the following:

a) open switch Sw2 or set the load resistor to draw the current required in accordance with table 1(b);

b) measure V_{bat} as in 4.1.3(b);

c) measure the voltage across the output terminals of the regulator to the load, V_{load}; and

d) repeat steps a), b) and c), adjusting the load resistor to simulate load currents equal to 25 %, 50 %, 75 % and 100 % of the rated load current.

The voltage drop for each discharge current shall be determined by the difference between values of
V_{bat} and V_{load} i.e.

$$V_{drop} = V_{bat} - V_{load}$$

Results may be recorded in a table similar to table 1(b).

This requires that the voltage drop in all cases shall not exceed 2.5 % of the input supply voltage battery.

Table 1(b) — Table to record voltage drop results for regulator in discharge mode

1	2	3	4
$I_{battery}$	V_{bat}	V_{load}	V_{drop}
0			
25 % of $I_{load\ rated}$			
50 % of $I_{load\ rated}$			
75 % of $I_{load\ rated}$			
100 % of $I_{load\ rated}$			

4.1.5 Determining the quiescent operating current consumption

4.1.5.1 The quiescent consumption tests determine the current required to operate the regulators (parasitic power consumption).

NOTE These tests are not intended to determine the total power dissipated by the regulator, which will be a combination of both the self-consumption losses, and the I^2R losses on current flowing through the regulator.

Quiescent consumption tests shall be carried out using either the test circuit shown in Figure 1 or that shown in Figure 2.

The regulator shall be tested for quiescent current consumption under all possible operating states. 4

Two digital multimeters shall be used to accurately measure the current into and out of the regulator. One meter shall be in series with the positive battery lead, while the other shall be in series with the load or array as appropriate. Multimeters shall be calibrated to an accuracy of ± 0.5 % when measuring a current of the order of 500 mA.

The system components shall be set to supply, in the case of a PV simulator, or draw, in the case of the variable load resistor, currents of the order of 300 mA in order to utilize the higher sensitivity of the instruments at low currents for these measurements.

4.1.5.2 Night-time standby state (no load, no charging, load shed not activated)

Do the following:

a) Isolate the PV array simulator and loads from the regulator.

b) Apply a voltage of 12.5 V at the battery simulator terminal.

c) Measure the current flowing through the positive battery lead, I_{bat}.

I_{bat} represents current consumption for the night-time standby state. A 10 mA is acceptable (see Annex A).

4.1.5.3 Night-time load-shed activated, state (no load, no charging, load-shed activated)

Do the following:

a) Isolate the PV array simulator and loads from the regulator.

b) Set the battery simulator or discharge the battery to a voltage such that load-shed is activated.

c) Measure the current flowing through the positive battery lead, I_{bat}.

   I_{bat} represents the current consumption for the nighttime, load-shed activated state.

   A value of 15 mA is acceptable.

4.1.5.4 Night time system-in-use state (loads on, no charging)

Do the following:

a) Isolate the PV array simulator from the regulator.

b) Apply a voltage of 12.5 V at the battery or battery simulator terminals.

c) Set the variable load resistor so that a current of approximately 350 mA is drawn.

d) Measure the current flowing through the positive battery terminal, I_{bat}, and the actual current flowing through the positive regulator output to the loads, I_{load}.

   I_{bat} minus I_{load} represents current consumption for the nighttime, system-in-use state. A value of 20 mA is acceptable.

4.1.5.5 Day time charging, load-shed activated, system-not-in-use, state (no loads, charging on, load-shed activated)

Do the following:

a) Isolate the load from the regulator.

b) Set the battery simulator or discharge the battery to a voltage that will activate the load-shed mode.

c) Set the PV array simulator to supply a charge current of approximately 300 mA.

d) Measure the current flow through the positive battery simulator lead, I_{bat}, and through the positive PV array input terminal, I_{charge}.

I_{charge} minus I_{bat} represents the current consumption for the day-time charging, load-shed activated and system-not-in use state. A value of 15 mA shall be considered acceptable.

4.1.5.6 Daytime charging, above load-shed, system-not-in use, state (no loads, charging on, load shed not activated)

The test procedure shall be as in 4.1.5.5 except that the voltage of 13 V shall be applied at the battery simulator terminal. A value of 15 mA shall be considered acceptable.

4.1.5.7 Daytime boost charging active, system-not-in-use, state (no loads, load-shed not activated and boost charging active)

The test procedure shall be as in 4.1.5.5 except that a voltage of 14 V shall be applied across the battery simulator terminals. For the test, the regulator shall be in the boost charge mode. A value of 20 mA shall be considered acceptable.

4.1.5.8 Results

Results may be recorded in a table similar to table 2.

Table 2 — Table to record quiescent current consumption results

1	2	3	4	5	6
Status description	**Battery voltage** V	I_{charge} mA	I_{bat} mA	I_{load} mA	**Self cons.** mA
No load, no charging, load shed not activated (night-time standby condition)	12.5	0		0	I_{bat}
No load, no charging, load shed activated (night-time, load-shed activated state)	< $V_{load\text{-}shed}$	0		0	I_{bat}
Load of approximately 350 mA, no charging, (night-time system being used)	12.5	0			$I_{bat} - I_{load}$
No load, charge current approximately, 300 mA, load shed active, (daytime, charging condition after load-shed)	12.5			0	$I_{charge} - I_{bat}$
No load, charge current approximately 300 mA, load shed not active, (daytime charging condition)	13			0	$I_{charge} - I_{bat}$
No load, charge current approximately 300 mA, load-shed not active, regulator in boost charge mode (daytime charging condition)	14			0	$I_{charge} - I_{bat}$

NOTE 1 The limitation to low charging or load currents is for the following reason: Self consumption is the difference between the input current and the output current. If these currents are of the order of 10 A it will be very difficult to measure accurately the small self consumption current (which should be of the order of 20 mA) . Self consumption is not expected to vary significantly as the charge or load current varies. If the testing authority has equipment capable of achieving the necessary accuracy and resolution while higher currents are flowing then it is recommended that rated currents be used.

NOTE 2 If a regulator uses high frequency switching during any of the regulator states listed above (as in some maximum power point tracking devices) the above measurements will need to be carried out using more sophisticated instruments. This is not expected to occur for the type of regulators for which this test procedure is intended.

NOTE 3 It is possible to measure quiescent consumption as the difference in power flow into and out of the charge regulator. Provided that steady state d.c. currents are flowing (as is to be expected for all the operational modes) power consumption measurement can be achieved by measuring the respective terminal voltages and currents at the same time, or by using a wattmeter.

4.2 Testing for electrical protection features

4.2.1 General

These tests are to determine compliance with the electrical protection requirements for PV power systems.

The regulator shall, before all electrical protection tests are carried out, be subjected to the functional performance test set out in 4.8 in order to verify proper operation. Only functional performance test procedures at STC shall be carried out for this purpose.

For the purposes of the tests the regulator shall be mounted in the test circuit (rig) as indicated in Figure 2.

In all cases connections shall, except where the test procedure requires otherwise, be made in the order specified by the regulator manufacturer.

Where protection devices operate during the tests they shall be either reset in the case of a manually operated circuit-breaker or replaced in the case of a fuse before continuing with the next test. The replacement fuse shall be of equal rating to that removed.

The regulator shall, after being subjected to all electrical protection tests, again be subjected to the functional performance test specified in 4.8 to verify that proper operation of the regulator has not been impaired by application of the tests. Only a functional performance tests at STC shall be carried out for this purpose. Where the manufacturer requires fault diagnostic information for each electrical protection feature, functionality tests shall be carried out after each protection test. Where applicable, regulator sensing leads shall be inspected for isolation from power cables.

The requirements of 10.1 of TZS 925-2:2007 for the accuracy of measuring instruments shall apply.

4.2.2 Apparatus

4.2.2.1 Battery

A solar/PV type lead-acid battery that complies with the requirement of IEC 61427 shall be used.

At the start of each test, the terminal voltage of the battery shall be between 12.2 V and 12.7 V. The battery and battery cables shall be protected with a d.c. circuit-breaker rated at 10 times the rated charging current of the regulator.

4.2.2.2 Loads

Loads shall be simulated by appropriately sized current shunt variable resistors.

4.2.2.3 PV array simulator

The PV array shall be simulated by d.c. power supply units shown as P1 in Figure 1 and, where necessary, as P3 in Figure 1. The power supply units shall be current power sources with rapid dynamic voltage control. Each power supply unit shall be able to simulate current-voltage (IV) supply characteristic curves of all sizes of PV arrays.

The r.m.s. current ripple of the power supply units shall not exceed 0.2 %.

The PV array simulator shall be set to supply a maximum voltage of 25 V and the current limit control shall be set at the required array input current (in the regulators).

The power supply will thus operate to deliver either no current (array disconnected) at 25 V or operate in a constant current mode at a voltage determined by the battery.

For some of the tests, a higher open-circuit voltage will be required and the PV array simulator shall provide these higher voltages.

4.2.2.4 PV array

As an alternative to the PV array simulator an actual PV array may be used. Where used, the PV array shall be capable of supplying the high open-circuit voltages and charging currents required to carry out these tests.

NOTE Selection of the PV array option implies that ability to carry out tests will be dependent on weather conditions.

4.2.3 Test for regulator protection and load protection against high PV voltages

This test is to verify that the regulator and loads are protected from high PV array voltages when the battery is disconnected.

Connect the regulator to the d.c. power supply, loads and battery as shown in figure 2.

Set the d.c. power supply (PV simulator) to supply the rated regulator current.

Set the maximum voltage limit of the array simulator to 25 V.

Set the variable load resistor to draw a current equal to 10 % of the rated current or design load current at 12.5 V.

Disconnect (isolate) the battery from the regulator for 1 min.

Measure the voltage across the load terminals. This shall not exceed 14.6 V to indicate that the loads are protected from high array voltages.

4.2.4 Test for polarity reversal protection at the battery terminals

Isolate (disconnect) the PV array simulator unit from the regulator.

Set the variable resistor (load simulator) to a value of resistance that is such that the measured output current equals the current drawn by the designed (rated) system load at 12.5 V.

Disconnect and reconnect the regulator battery terminals to the battery with polarity reversed for 1 min. When the regulator is connected with reversed polarity, in addition to withstanding the reversed polarity, there shall be no current flow in the d.c. load circuit.

4.2.5 Protection against polarity reversal at the PV array input

Connect the regulator to the test circuit as shown in Figure 2. Set the PV array simulator to supply the rated charging current. Set the variable load resistor so that it draws the rated load current.

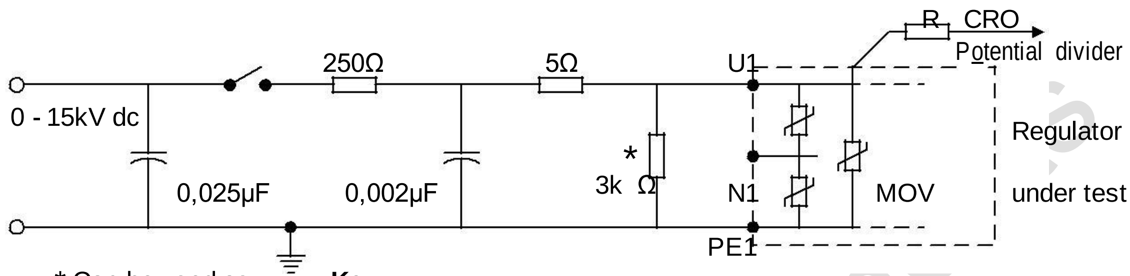
Disconnect the d.c. power supply and reconnect it to the regulator with reversed polarity for 1 min. When the regulator is connected with reversed polarity to the array, in addition to withstanding the reversed polarity, there shall be no current flow in the d.c. load circuit.

In some cases regulators will have more than one array input. Where this is the case all possible combinations of reversed polarity connection shall be tested.

4.2.6 Protection from lightning induced current and voltage surges

4.2.6.1 Current and voltage transients and surges

For the purposes of this test, the regulator shall be tested using the voltage impulse generator shown in Figure 3. Other test circuits capable of generating the specified waveform may be used, with the provision that the impulse energy does not exceed 0.5 J at 6 kV.



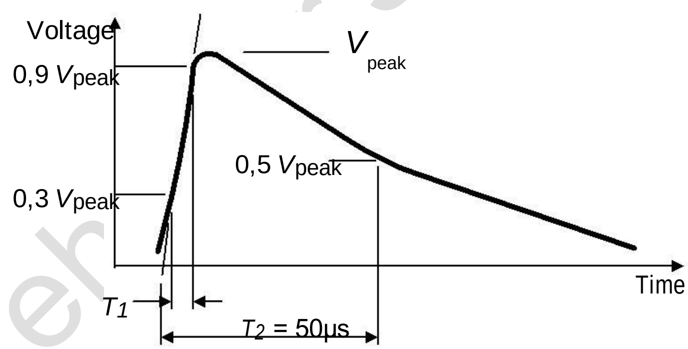
* Can be used as voltage divider

Key:
See figure 5

Figure 3 — Voltage impulse generator

4.2.6.2 Waveform of a voltage impulse

The voltage impulse generator shall produce an open-circuit voltage impulse waveform as shown in figure 4.

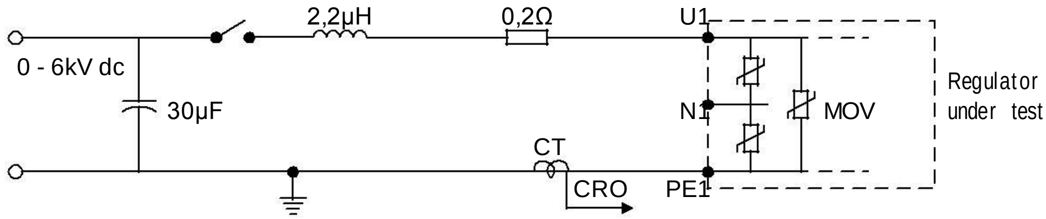


$T_1 \times 1,67 = 1,2\mu s$

Figure 4 — Open-circuit voltage impulse waveform

4.2.6.3 Test circuit of current impulse generator

The regulator shall be tested for protection against current transients and surges using the current impulse generator shown in Figure 5. Other test circuits that are able to generate the specified waveform may be used.



Key:
U1 is the live input to the regulator under test.
N1 is the neutral input to the egulator under test.
PE1 is the potential earth.
CT is a current transformer.
CRO is a cathode ray tube oscilloscope.

Figure 5 — Current impulse generator

4.2.6.4 Waveform of the current impulse

The current impulse generator shall produce the current impulse waveform as shown in Figure 6 below.

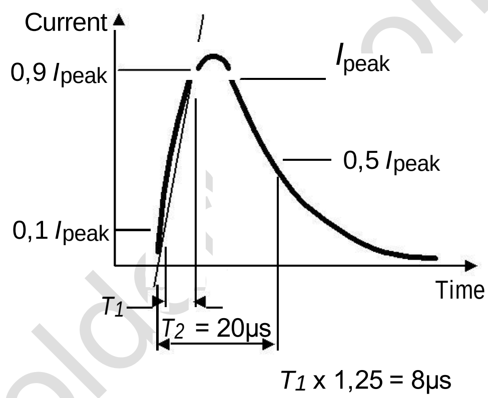


Figure 6 – Current impulse discharge waveform

4.2.6.5 Voltage impulse test procedure

Connect the voltage impulse generator to the input of the regulator.

Set the voltage impulse generator to generate an open-circuit voltage impulse waveform as shown in Figure 4.

Apply 10 successive voltage impulses, at approximately 10 s intervals between the input terminals. Use an oscilloscope to record the clamping voltage of each impulse and take the average value as the clamping voltage recorded.

4.2.6.6 Current impulse test procedure

Connect the current impulse generator to the input of the regulator.

Supply a calibrating 8/20 µs current impulse with a peak current not exceeding 1500 A, by appropriately adjusting and noting the values of the d.c. voltage to the capacitor.

Preferably do not apply more than three current impulses to the regulator during calibration.

After establishing the d.c. voltage necessary to achieve the specified amplitude of the peak current impulse, apply 10 successive current impulses at approximately 30 s intervals. Use an oscilloscope to record the peak current impulse and the resulting clamping voltage during each impulse.

Calculate the energy absorbed by the surge arresting device of the regulator as follows:

$$E = V_c I_p \tau$$

where

E is the energy absorbed, in joules;

V_c is the average clamping voltage, in volts;

I_p is the peak current impulse, in amperes; and

τ is the pulse width, in seconds.

The charge regulator shall be capable to absorb the induced voltages and currents without damage and not pass the effects to the load circuit.

4.2.7 Test for protection against short-circuits in the load circuits

Mount the regulator in the test circuit (rig) as shown in figure 1 or figure 2.

Set the array simulator to provide the rated charge current.

Set the variable load resistor to draw a current equal to the rated load current at the nominal battery voltage. Short the load output by closing switch Sw1 for a period of 1 min. Protection mechanism should be activated.

4.2.8 Test for protection against over-current at the PV array input

This test shall be carried out with the regulator exposed to an ambient temperature of 40 °C, which is the worst case condition that the regulator is required to withstand in PV systems.

Connect the regulator to the test circuit as shown in Figure 2. Set the variable load resistor to draw a current equal to the regulator rated load current.

Increase the d.c. power supply current to the over-current level specified by the regulator manufacturer. Continue to increase the array input current at a rate of approximately 0.05 A/s until the regulator protection mechanism operates.

The current at which the regulator protection mechanism operates shall not be less than 1.3 times the PV array short-circuit current at STC.

4.2.9 Test for protection against over-current at the load circuit

Connect the regulator to the test circuit as shown in Figure 2. Set the array simulator (d.c. power supply unit) to supply the rated charging current.

Gradually, increase the current drawn by the variable load resistor at a rate of approximately 0.05 A/s until the regulator protection mechanism operates.

4.2.10 Test for protection against reverse current

This test is to verify that the regulator is provided with protection against reverse currents in order to prevent loss of charge from battery to the PV array.

Connect the regulator to the test circuit as shown in Figure 1. Replace the d.c. power supply with a resistor sized to equal the PV array resistance under zero irradiance conditions. Apply a voltage of 15 V at the battery simulator terminal. Verify that there is no current flow through this resistor.

4.3 Acoustic emissions

This emission test is to verify compliance with the requirements for acoustic noise specified in IEC 61000.

The acoustic noise generated by the regulator shall be determined in accordance with the procedure set out in ISO 3744.

4.4 Electromagnetic and electrostatic emissions

4.4.1 General

These emission tests are to verify compliance with the requirements for electromagnetic interference and electrostatic discharge specified in IEC 61000.

4.4.2 Electromagnetic interference

The regulator shall be tested for electromagnetic emissions in accordance with the procedures set out in IEC CISPR 22.

4.4.3 Radiated susceptibility

The regulator shall be subjected to the test procedure specified in IEC 61000-4-3 and shall be fully functional thereafter.

4.4.4 Electrostatic discharge

The regulator shall be subjected to the test procedure specified in IEC 61000-4-2 and shall be fully functional thereafter.

4.5 Mechanical test

The regulator shall be tested for mechanical robustness in accordance with test Eb in IEC 60068-2-29.

The regulator shall be packed, as for transportation, in a casing/packaging box provided by the regulator manufacturer.

1000 bumps with a peak acceleration of 100 m/s^2 and a pulse duration of 10 ms shall be applied on each of the three principal axes of the regulator.

The regulator shall be subjected to the functional performance test after the application of the 3000 bumps to verify that its normal operation has not been impaired by this bumping.

4.6 Visual inspection

Visual inspection shall be carried out to verify that the regulator complies with requirements of this standard for system status indicators and labelling.

4.7 Documentation inspection

The documentation supplied with the regulator shall be inspected to confirm compliance with the requirements for documentation specified in this standard.

4.8 Functional performance tests for voltage set-point based regulators

4.8.1 General

4.8.1.1 This set of tests is to characterize and verify the functional performance of the regulator with respect to compliance of the charge regulation process with specified set-points.

4.8.1.2 The test procedures are for regulators that measure battery voltage and operate at specified battery voltage thresholds. A test procedure for new technologies such as regulators that measure current and operate on ampere-hour based algorithms is set-out in **4.9** of this procedure.

The test shall verify compliance with requirements of this standard and in particular to verify that:

a) the regulator charge control process is in accordance with either set-points specified by the battery manufacturer or those specified for PV systems, at STC and rated charge and discharge currents,

b) any changes in set-points that may occur as a result of different charge, or load currents are either minimal, or in line with the optional current compensation adjustment specified for specific PV systems,

c) any changes in set-points that may occur as a result of changes in ambient temperatures are either minimal or correctly compensated for.

4.8.1.3 The regulator shall be tested for functional performance by:

a) Testing for compliance with set-points at rated charge/discharge currents over a range of temperatures.

b) Testing for compliance with set-points at a constant temperature over a range of charge/discharge currents.

NOTE Since the test procedures require that regulator set-points be measured over a range of currents and temperatures, to ensure accuracy, a number of measurements for each condition is required. Further since a number of regulators incorporate time delays as part of the algorithm, it may be appropriate to use an automated (computer controlled) testing system in order to reduce intervention by testing personnel.

4.8.1.4 Two alternative testing methods are specified. The testing facility may choose either method depending on the available equipment. Other methods may be used provided they enable the requisite conditions to be effected.

4.8.1.5 In all cases care shall be taken to ensure that the rate of voltage increase or decrease at voltages close to set-point values is sufficiently low to avoid errors due to time delay features integral to certain regulator algorithms.

4.8.1.6 The set-point test equipment shall be able to allow specified charge or load currents to flow through the regulator during the test procedure.

4.8.1.7 Where it is necessary to temperature condition a regulator and battery, they shall, before measurements are taken, be allowed to stabilize at each test temperature for a minimum of 1 h with the charge and load currents set at the required values. This stabilization period shall be at a battery voltage that is such that switching of loads or charge currents by the regulator does not occur.

4.8.1.8 The set points shall be measured at least three times for each test condition, i.e. for each set of charge and/or load currents and temperature.

4.8.1.9 Tests for the proper operation or functioning of battery SOC/System status indicators shall be carried out simultaneously with the charge regulation tests.

4.8.2 Testing for set-points using a battery

4.8.2.1 Apparatus

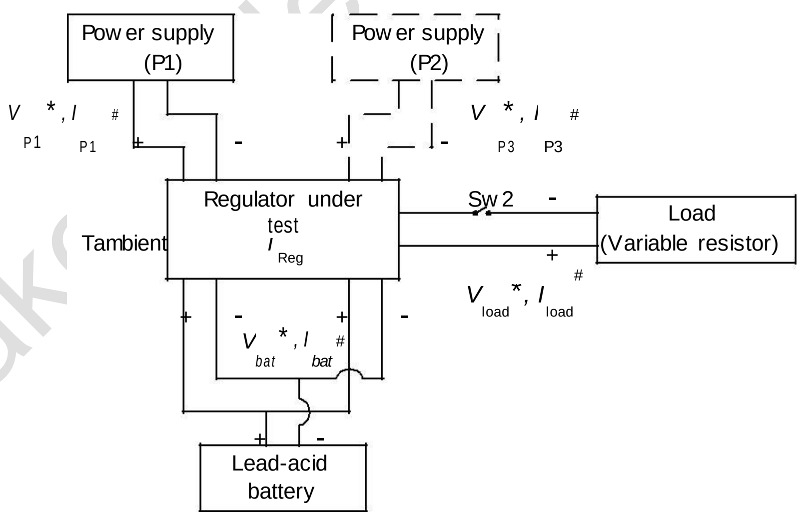
The test circuit shown in Figure 7 shall be used. In order to facilitate speedy progression of the testing process it might be necessary to change the battery after each test.

The capacity of the battery, in ampere-hours, shall be not less than ten times the greater of the maximum charge or discharge current in amperes. The battery voltage shall be measured at the regulator terminals (with an accuracy of 0.4 %), or, in the case of a regulator with sensing leads, at the sensing lead terminals. A continuous recording device, for example, a chart recorder, shall be used to make all measurements. Where automated control is used, a computer based analogue to digital (A/D) converter system shall be used. Selection of the system shall ensure a high sampling rate (> 0.5 Hz) at or near the set-point voltages while, if necessary, limiting the sampling of excessive data at voltages not in the neighbourhood of set-points during the charging and discharging cycles.

The regulator and battery shall be temperature conditioned in an environmental chamber. The regulator and battery shall be mounted in the environmental chamber in accordance with applicable mounting instructions. All surfaces in the environmental chamber, except that on which the regulator or battery is mounted, shall be at least 200 mm away from the regulator or battery. The environmental chamber shall be able to operate over the temperature range of 0 °C to 40 °C and shall be able to hold temperatures constant with an accuracy of ±2 °C.

All measurements of set points shall be taken immediately before the regulator switching occurs. The set-point voltage is that recorded immediately before switching occurs, and not that recorded after switching.

Since the test procedures require repeated charge and discharging cycles at specific currents and temperatures, the use of programmable logic controllers (PLCs) or other control devices is recommended. The PLCs shall switch the charge or load current on or off in response to logic signals based on current flow in the circuit.



NOTE Power supplies 1 and 2 have on-board voltage and current measurement

Key:

— – Only for certain regulators

* Use DVM

\# Use shunt and DVM

Figure 7 — Set-point test circuit, using a battery

4.8.2.2 Test for top-of-charge regulation (boost and float charging)

The testing process may be started at any point in the charge and discharge cycle. The sequence of the procedure adopted in this standard assumes that the regulator is in the charge mode with the boost charge function activated.

Condition the battery and regulator to the required temperature for the test concerned (see table 3) for a period of 1 h. For tests that are conducted at 25 ºC, if the ambient temperature in the test laboratory is between 20 °C and 27 °C it shall not be necessary to condition the regulator and battery.

Set the PV array simulator to supply a charge current equal to 25 % of the rated charging current.

Set the variable load resistor so that it draws a current of approximately I_{l20} (exact value not critical). (I_{120} implies that current which will fully discharge the battery in 120 h).

Apply 12.5 V at the battery terminals.

Isolate the loads. In the case of manual operation this will be achieved by opening switch Sw2.

The boost charging will now start and the battery voltage will increase until the boost voltage cut-off is reached. Prior to reaching this point SOC/System status indicators showing either 30 % DOD or battery fully charged shall be active.

When the voltage cut-off is reached the regulator shall disconnect the battery from the PV array simulator; the battery current will instantaneously drop to zero. At this point, the SOC/system status indicator should show “Battery fully charged”.

NOTE Some regulators will maintain the boost charge mode for a few minutes. Where this is the case the PLC or other controller should allow for this delay and ‘wait’ for the regulator to disconnect the battery from the PV array simulator before reconnecting the loads.

The boost-charge voltage set-point at STC is the highest voltage reached.

Switch the load on. In the case of manual operation this will be achieved by closing switch Sw2.

The battery voltage will gradually decrease until the regulator automatically reconnects the charging i.e. it reconnects the battery to the PV array simulator. The battery charging current will step up to the rated charging current. Disconnect the load immediately after the regulator reconnects the charging.

The voltage value at which the charging is reconnected is the float-reconnect voltage set-point.

The battery voltage will gradually increase until the regulator automatically disconnects the battery from the PV array simulator, at which point the battery charging current will drop down to zero.

The voltage value at which the charging is disconnected is the float-charge-disconnect voltage set-point.

Reconnect the load immediately when the regulator disconnects the charging. Where PLCs or other control devices are used they shall automatically reconnect the loads at this point.

The battery voltage will decrease again until the float charge reconnect activates. The float-connect-disconnect cycle may be repeated as many times as it is necessary to ensure thorough testing of this operation.

During the float-charging cycle the SOC/System status indicator will show a fully charged battery.

Regulators that utilize linear or pulse width modulation (PWM) charge control will not disconnect the array completely when float-charging or boost-charging the battery. The regulator will hold the short-term, average battery voltage at the float voltage level while gradually reducing the recharging current.

To cycle these regulators, monitor the average battery charging current. When the charge current decreases to a value of approximately 30 % of the full charging current, isolate the PV array simulator and connect the loads for a minimum period of 2 min in order to discharge the battery. The loads can then be disconnected and the PV array simulator reconnected in order to restart the cycle.

The float voltage shall be that voltage at which the battery voltage stops increasing and remains constant.

When it is deemed necessary to verify the boost voltage more than once, the mode shall be re-activated. Procedures to do this will depend on the regulator algorithm. For those that are re-activated by a deep discharge, the battery voltage shall be decreased. Boost mode can often be reset either manually or by disconnecting the regulator from the battery, with array inputs disconnected first.

The deep discharge method (i.e. not using any manual reset function) of reactivating boost mode shall be tested at least once during the test to ensure proper operation thereof. In the case of regulators which only activate boost mode using a time based algorithm, e.g. once every ten days, the clock shall be set forward to simulate the elapsing of the activation period.

4.8.2.3 Determining the load-shed and load-reconnect set-points

This test uses a principle similar to that in **4.8.2.2** however, the PLC or other system controller shall be used to connect and disconnect the PV array simulator.

To facilitate speedy progression of the test process, the cycle can be started with a battery that has been discharged to a voltage approximately 0.2 V less than the load-reconnect voltage.

Condition the regulator to the required temperature for the test concerned (see table 3) for a period of 1 h.

Set the PV array simulator to supply the rated current at STC and disconnect it from the regulator.

Set the variable load resistor to draw the required discharge current for the test concerned (see table 3). Maintain connection of the load and discharge the battery.

The test assumes a cycle that starts during night-time with the system in use.

The battery will be discharged until the regulator disconnects the loads at which point the load current will instantaneously drop to zero. At this point the SOC or System Status indicator showing load shed shall be active.

The voltage at which the loads are disconnected is the load-shed voltage.

Reconnect the PV array simulator.
The battery charging current will instantaneously increase to the set charging level.

The battery will now recharge and its voltage will increase until the load-reconnect voltage is reached. The regulator will automatically reconnect the loads, at which point the load currents will instantaneously step up to the rated system current. The load- shed SOC indicator shall deactivate and one of the indicators showing fractional SOC shall be active.

The voltage at which the regulator reconnects the loads is the load-reconnect set-point.

Disconnect the PV array simulator from the regulator. The battery voltage will gradually decrease to the load-shed level again. The cycle shall be repeated as often as it is deemed necessary.

4.8.3 Testing for set points using a battery simulator and an automated control system

An alternative test that uses a battery simulator may be carried out to determine the regulator set-points. In this case the testing process can be carried out quicker than the method specified in 4.8.2.

The test circuit shown in figure 8 shall be used.

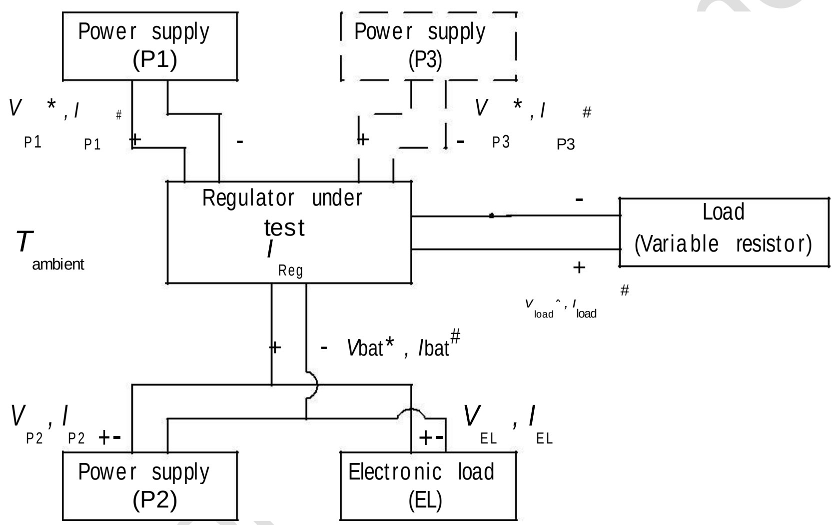
The battery simulator comprises an electronic d.c. power supply system, P2, connected in parallel with an electronic load ,EL.

The electronic load shall have a rapid response rate, and shall be able to accept a current that is three times the maximum battery charging current over a voltage range of 10.5 V to 15 V.

The power supply shall be a current source at voltages determined by the setting on the electronic load.

The system shall operate as a simulated battery, able to supply or accept current at constant voltages determined by the setting of the electronic load. The voltage shall be adjustable manually or automatically where a suitable device is provided.

Instruments used in the test shall measure the battery simulator voltage to an accuracy of 0.4 %, and, PV array simulator current, battery simulator current and load current to an accuracy of 2 %.



NOTE 1 Power supplies, 1, 2 and electronic load have on board voltage and current measurement.

NOTE 2 Voltages V_{P1}*, V_{P3}*, V_{bat}* and V_{load}* measured at regulator terminals.

Key:

- – – Only for certain regulators
- * Use DVM
- # Use shunt and DVM

Figure 8 — Set-point test rig, using a battery simulator

Where values of current flowing in circuits are known, currents in interconnected circuits may be deduced applying Kirchoff's Laws.

The battery simulator voltage shall be measured at the regulator terminals (to an accuracy of 0.4 %), or, in the case of a regulator with sensing leads, at the sensing lead terminals. A continuous recording device, for example, chart recorder, shall be used to make all measurements. Where automated control is used a computer based A/D converter system shall be used. Selection of the system shall ensure a high sampling rate (> 0.5 Hz) at or near the set-point voltages while, if necessary, limiting the sampling of excessive data at voltages not in the neighbourhood of set-points during the charging and discharging cycles.

The battery simulator shall be able to accept currents as high as the maximum rated charge current of the regulator and supply current up to the maximum rated load currents. The capacity of the battery simulator shall be such that voltage fluctuations, which can occur as the regulator switches charge or load currents, are not as large as to initiate oscillating conditions. This capacity shall not compromise a rapid response rate.

The regulator and battery shall be temperature conditioned in an environmental chamber. The regulator and battery shall be mounted in the environmental chamber in accordance with the mounting instructions. All surfaces in the environmental chamber, except that on which the regulator or battery is mounted, shall be at least 200 mm away from the regulator or battery. The environmental chamber shall be able to operate over the temperature range of 0 ºC to 40 ºC and shall be able to hold temperatures constant with an accuracy of ± 2 ºC.

All measurements of set points shall be taken immediately before the regulator switching occurs. The set-point voltage is that recorded immediately before switching occurs, and not that recorded after switching.

4.8.3.1 Algorithms for automatic determining of set-points

A battery simulator may be used in a manual mode to measure set-points fairly rapidly, simply by adjusting the simulated battery voltage appropriately. Care shall be taken to ensure that any delays which the regulator might utilize are properly allowed for.

A range of algorithms can be used to allow automated measurement of set-points, if the test system has programmable measurement and a control interface. The control algorithm shall cycle the regulator in a sequence similar to that described in 4.8.2 when top-of-charge and load-shed set-point voltages are determined

4.8.3.1.2 Possible concept algorithm for adjusting simulated battery voltages

Measure the battery voltage at the regulator terminals and the current flowing into or out of the battery simulator at regular intervals of 10 s or less. After each measurement, change the simulated battery voltage in accordance with the following formula:

$$V_{t+1} = V_t + \frac{I_{bat}}{|I_{bat}|} K$$

where

I_{bat} is the current flowing into or out of the battery (positive for a charging current, and negative for a discharge current); and

K is a constant, say 0.05 V, such that a quotient of K, and the sampling period is less than 0.15 V/min to allow for delays at set-points.

The above model for the simulated battery control will thus approximate an actual lead-acid battery. The set-point voltage is between the battery voltage, V_t, recorded just before the regulator control function operates and the battery voltage specified by the control algorithm which caused the regulator to operate or change modes, V_{t+1}.

The concept can be refined by using estimate of set-point values as follows:

A larger value of K is used when the battery simulator voltage is 10 K volts or more from the set-point to be determined. As the battery simulator voltage approaches the set-point voltage, the value of K shall be gradually reduced so as to approach the set-point slowly.

The estimated set-point value shall be revised each time a new set-point is determined. This revision will require that the computer algorithm keeps track of exactly which set-point is being measured and when. Take care to ensure that it is working properly, as highly erroneous set-point values can be recorded if a set-point is approached too rapidly because of delay functions built into some regulators.

4.8.4 Determining temperature and current compensated set-points

All set-points shall be checked at $25\ ^{+2}_{-5}$ ºC, at charge current corresponding to I_{50}, and discharge current of I_{120} and at selected (unshaded or open blocks) temperature and current conditions specified in table 3.

The set points shall be tested in accordance with procedure set out in either 4.8.2 or 4.8.4.

Table 3 — Table to record temperature compensated top-of-charge set-points

Charge currents	I_{rated}			½I_{rated}	I_{50}		
Discharge currents	I_{rated}			½I_{rated}	I_{120}		
Temperature °C	0	25	40	25	0	25	40
V_{boost}							
$V_{float\text{-}disconnect}$							
$V_{float\ reconnect}$							
$V_{load\text{-}reconnect}$							
$V_{load\text{-}shed}$							

Tests need only be carried out for the open blocks in the above table. The conditions for which the regulator shall be tested have been selected based on the following considerations:

a) the regulator shall be tested for all set-points at the respective charge and discharge currents of I_{50} and I_{120} and at the three temperatures in order to verify

1) all set-points at STC (25 ºC) given the said currents of I_{50} and I_{120}*; and*

2) the response (if any) of the set-points to low (0 ºC) and high temperatures (40 ºC) given the same charge and discharge currents,

b) the regulator shall be tested for V_{boost}, $V_{float\text{-}disconnect}$, $V_{load\text{-}shed}$ at charge and discharge currents of I_{rated} and at 40 ºC in order to verify proper operation under high temperature and the high current conditions. During this test the testing authority shall verify that the temperature at any surface that can be touched does not exceed 60 ºC; and

c) the load-shed set-point shall be tested for discharge currents of I_{rated} and I_{120} at 25 ºC in order to verify response (if any) to changes in discharge current given the STC temperature.

The temperature compensated top-of-charge set-points shall be derived as shown in equation (1) while the combined temperature and discharge current compensated bottom-of-charge set-points shall be derived as shown in equation (2).

$$V_{charge} = V_{charge:T=25} + \alpha\ (T_{bat} - 25) \qquad (1)$$

where

V_{charge} is the compensated top-of-charge set-point (boost, float-reconnect and float-disconnect);

$V_{charge:T=25}$ is the top-of-charge set-point (boost, float-reconnect and float-disconnect) specified by the battery manufacturer or specified in CD/K/03-1/2003;

α is the temperature compensation coefficient (–36 mV/°C for the 12 V battery); and

T_{bat} is the battery temperature in degrees Celcius measured at one of the battery terminals (0 °C for this specific instance).

The load-shed and load-reconnect voltage set-points shall be different from those specified in CD/K/03-1/2003. For these conditions the set-point shall be given by:

$$V_{discharge} = V_{sp:T=25} + \alpha\ (T_{bat} - 25) + \beta \frac{I_{bat} - I_{100}}{I_{100}} \quad (2)$$

where

$V_{discharge}$ is the compensated discharge set-point (load-shed or load reconnect);

$V_{sp:T=25}$ is the discharge set-point (load-shed or load reconnect) specified by the battery manufacturer or specified in table 1;

α is the temperature compensation coefficient (–36 mV/°C for the 12 V battery);

T_{bat} is the battery temperature in °C measured at one of the battery terminals;

β is the discharge current compensation coefficient; and

I_{bat} is the actual discharging current.

4.9 Functionality tests for new regulator technologies

(Under development).

Annex A (informative) — Charge regulator reception and tests

A.1 Reception

An electrical scheme of the charge controller, with the symbols used in the present report is shown in Figure A.1.

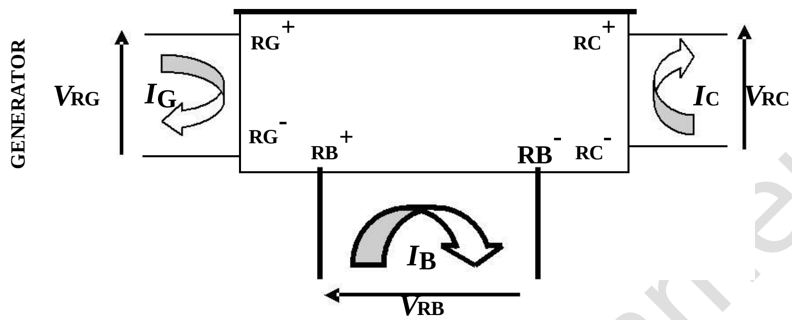


Figure A.1 — electrical scheme of the charge controller

Procedure 0: Visual inspection

The objective of this procedure is to define the main characteristics of the charge controller delivered:

Type: Shunt, Series
Control: On/off, PWM
Switching device: Electro-mechanical relay, Solid State relay MOSFET.

It is also necessary to check if the charge controller fulfils the following requirements and verifications:

-All charge regulator terminals should easily accommodate, at least, 4 mm^2 section cables (norm CR9).

-Warning facilities must be included (norm RR2).

-It will be highly valued the inclusion of an independent battery voltage sensor line (norm SR1).

-Check if there is any manual disconnection or reconnection facility (norm SR3).

-The charge controllers must be properly labelled (norm CS2).

-Check if the protection fuses are of a widely available type (car fuses, for example) (norm RS6).

A.2 Self-consumption

The objective of this test is to determine the energy losses due to the current self-consumption of the device in operation. Its influence on the system energy balance comes from its behaviour as a 24-hour constant load.

Procedure 1 — PV Generator OFF, Loads OFF

Connect a power source, acting as a battery, to the battery terminals of the charge controller, with an ammeter in series. Varying the supply voltage from 5V to 16V in steps of 1V, measure V_{RB} and I_B. The result of the test will be considered as "positive" when the charge controller self-consumption is under 10 mA (norm CR9). However, values under 5 mA are recommended (norm RR11).

Instrumentation

Power source and multimeter.

Procedure 2 — PV Generator ON, Loads ON

Connect a battery to the charge controller, then connect a power source as a 50W PV generator (I_G ≈ 3A), and, finally, a 50W lamp to the load line, including a calibrated shunt resistor in each line. Measure V_{RB}, I_G, I_B and I_C, obtaining the self-consumption current as $I_G - I_B - I_C$ when $I_G > I_C$ or $I_G + I_B - I_C$ when $I_G < I_C$. The result of the test will be considered as "positive" when the charge controller self-consumption is under 15mA (norm CR9). However, values under 5 mA are recommended (norm RR11).

Instrumentation

Power source, three calibrated shunt resistors, multimeter, battery, and 50W lamp.

A.3 Internal voltage drops

The objective of this test is to determine the voltage drops inside the charge controller at different operating conditions. Its importance is not only related to the direct energy loss induced, but also because of its influence in the PV generator working point and in the input voltage of load devices.

Procedure 3: Generator-battery line

Connect a power source, acting as a PV generator and a partially discharged battery (SOC < 80 %) to the charge controller, with loads OFF and a calibrated shunt resistor in each line. Varying the generator current I_G from 0 to I_{max} amps in at least 5 steps, measure the following parameters: V_{RG}, V_{RB}, $V_{RG^+RB^+}$, $V_{RG^-RB^-}$, I_G, I_B. The result of the test will be considered as "positive" when the charge controller internal voltage drops between generator and battery terminals are under 0.5V in a 12V system (norm CR10), under the maximum current.

Instrumentation

Power source, discharged battery (SOC<80 %), two calibrated shunt resistors, and multimeter.

Procedure 4: Battery-load line

Connect a charged battery (SOC > 80%) to the charge controller, with the PV generator OFF. Include a calibrated shunt resistor in the battery and load lines. Varying the load current I_C from 0 to I_{max} amps in at least 5 steps, by connecting an increasing load power, measure the following parameters: V_{RB}, V_{RC}, $V_{RB^+RC^+}$, $V_{RB^-RC^-}$, I_B, I_C. The result of the test will be considered as "positive" when the charge controller internal voltage drops between battery and load terminals are under 0.5V in a 12V system (norm CR11), under the maximum current.