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DRAFT TANZANIA STANDARD

(Draft for comments only)

Solar photovoltaic power systems – test procedures for main components – part 1: Test procedures for photovoltaic modules

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 925-1:2006 Solar photovoltaic power systems – test procedures for main components – part 1: Test procedures for Photovoltaic Modules.

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Solar photovoltaic power systems — Test procedures for main components —

Part 1:

Test procedures for photovoltaic modules

1 Scope

This Part 1 of Draft Tanzania standard specifies test procedures for photovoltaic modules for use in photovoltaic systems.

2 Referenced documents

The following documents contain provisions which, through reference in this text, constitute provisions of this section of the specification. 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 take precedence.

TZS 877-1:2006, *Crystalline silicon terrestrial photovoltaic modules — Design qualifications and type approval*

TZS 877-2:2006, *Thin film silicon terrestrial photovoltaic modules — Design qualifications and type approval*

3 Definitions and abbreviations

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

4 Procedure

4.1 Module evaluation (indoors)

Compliance with the requirements specified in installation codes determined by tests set out in **4.1**, **4.2** and **4.3** of this procedure shall be the minimum acceptance criteria for PV modules intended for use in the East African environment.

Carry out the following tests to ensure that the modules comply with the requirements of installation codes.

4.1.1 A visual inspection in accordance with test 10.1 of TZS 877-1:2006/TZS 877-2:2006.

4.1.2 The module performance at STC. This test involves measuring module, current-voltage characteristics using natural sunlight or a Class A simulator conforming to the requirements of IEC 60904-9 STC in accordance with test 10.2 of TZS 877-1:2006/TZS 877-2:2006.

4.1.3 An insulation test. This test includes high potential and insulation resistance testing, and earth continuity testing. Carry out the tests in accordance with test 10.3 of TZS 877-1:2006/TZS 877-2:2006.

4.1.4 Measurement of temperature coefficients. Measure the following as a function of temperature:

a) the open-circuit voltage;

b) the short-circuit current;

c) the maximum power;

d) the voltage at maximum power; and

e) the current at maximum power,

all in accordance with test **10.4** of TZS 877-1:2006/TZS 877-2:2006.

4.1.5 The robustness of terminations test in accordance with test **10.14** of TZS 877-1:2006/TZS 877-2:2006.

4.1.6 The twist test in accordance with test **10.15** of TZS 877-1:2006/TZS 877-2:2006.

4.1.7 The mechanical load test in accordance with test **10.16** of TZS 877-1:2006/TZS 877-2:2006.

4.2 Outdoor exposure and monitoring tests

The following tests can only be carried out once the tests specified in 4.1 have been carried out. The tests require a minimum of two modules — one for the outdoor evaluation and the other as a control unit:

a) an outdoor exposure test in accordance with test 10.8 of TZS 877-1:2006/TZS 877-2:2006; and

b) an outdoor performance monitoring test in accordance with test 10.8 of TZS 877-1:2006/TZS 877-2:2006.

4.3 Hail test

The ability of the modules to withstand hail shall be determined in accordance with test **10.17** of TZS 877-1:2006/TZS 877-2:2006.

4.4 Light-soaking

To stabilise the electrical characteristics of thin-film modules by means of simulated solar irradiation in accordance with **10.18** of TZS 877-2:2006.

4.5 Annealing

To anneal thin-film modules before subjecting them to the qualification tests in accordance with **10.19** of TZS 877-2:2006. Without such annealing, the heating during the subsequent test could possibly mask degradation from other causes.

4.6 Wet Leakage current test

To evaluate, in accordance with **10.20** of TZS 877-2:2006, the insulation of the module under wet operating conditions and verify that moisture from rain, fog, dew or melted snow does not enter the active parts of the module circuitry, where it might cause corrosion, a ground fault or a safety hazard.

4.7 Optional tests

Carry out any other tests to determine the actual performance of modules in respect of additional requirements identified in schedule B in accordance with the procedures set out in TZS 877-1:2006/TZS 877-2:2006.

Annex A (Normative) — Photovoltaic module tests

A.1 General

The following method is recommended where references to TZS 877-1:2006 may be found to be inadequate. It is considered normative in that the content represents the requirements of this standard. Where the tests in this annex are deficient, the previous procedures are to be followed.

A2.1 Nomenclature and definitions

Symbol	Units	Parameter
β_T	$V.^{o}C^{-1}$	Open-circuit voltage temperature coefficient
φ	^{o}	Local latitude
$D(0)$	$W.m^{-2}$	Diffuse irradiance incident on a horizontal surface
FF	---	Fill factor of a PV module
FF_{cal}	---	Calibration value of the fill factor parameter
FF_0	---	Ideal fill factor of a PV module
G	$W.m^{-2}$	Global irradiance incident on the surface of a PV module
$G(0)$	$W.m^{-2}$	Global irradiance incident on a horizontal surface
I	A	Current given by a PV module
I_M	A	Current given by a PV module at its maximum power point
I_{SC}	A	Short-circuit current of a PV module
$I_{SC,S}$	A	Short-circuit current of a sensor PV module
I_{est}	A	Current (measured and) selected for a first estimate of Rs^* parameter
I_{sel}	A	Current (measured and) selected for Rs^* parameter determination
m	---	Diode ideality factor (1-exponential model of a PV module)
N_S	---	Number of series-connected cells in a PV module
R_S	Ω	Series resistance parameter (1-exponential model of a PV module)
$R_{S,est}$	Ω	First estimate of the series resistance parameter
r_S	---	Normalized series resistance parameter
T_a	ºC	Ambient temperature
T_C	ºC	Operation cell temperature of a PV module
$T_{C,S}$	ºC	Operation cell temperature of a sensor-PV module
V	V	Voltage given by a PV module
V_M	V	Voltage given by a PV module at its maximum power point
V_{OC}	V	Open-circuit voltage of a PV module
$V_{OC,S}$	V	Open-circuit voltage of a sensor-PV module
V_{est}	V	Voltage (measured and) selected for a first estimate of Rs^* parameter
V_{sel}	V	Voltage (measured and) selected for Rs^* parameter determination
V_t	V	Thermal voltage
w_S	$m.s^{-1}$	Wind speed
P_M	W	Maximum power given by a PV module
$P_{M,cal}$	W	Calibration value of the maximum power parameter
P_{MT}	W	Calculated maximum power of a tested PV module
P_{MTA}	W	Acceptation value of the maximum power of a tested PV module
P_{MR}	W	Calculated maximum power of a reference PV module
P_{MRC}	W	Calibration value of the maximum power of a reference PV module
[**Note**: The appearance of any of the following parameters together with the superscript '*' denote its reference to the Standard Test Conditions"]		

A2.2 Reception

Once the module is received, the physical characteristics and the information supplied from manufacturer are registered in the data forms.

Procedure 0: PV modules physical inspection

The PV modules under test should be submitted to a visual inspection in order to detect visual damage. Table 1 lists the different aspects to be inspected, as well as defects leading to a PV module rejection.

Table 1 — Defects leading to PV module rejection (detection by visual inspection)

DEFECT	REJECTION CRITERION
Broken or cracked cells	Breaking or spreading of a crack, causing a piece of more than
	10% of a cell area to be separated
Cells out of line	Cells touching each other
Front surface of cells	Very noticeable metal stains
Inclusions in lamination	Coverage of more than 1% of a cell area
Bubbles in the encapsulant	If they allow a path between the cells and the frame or edge of the
	module
Front glass	Broken
Connecting tape	Torn apart
Labels	Indelible labels missing
Dirty modules	Extraneous silicone or encapsulant
Tedlar	Damaged or holed
Connection box	Broken or worked loose
Aluminium flame	Loose or weak

A2.3 General measurement conditions

The following conditions are, some of them, necessary for outdoor characterization of PV modules and, others, specifically recommended for the proposed method:
Irradiance:

- Global irradiance on the plane of incidence, $G > 600$ W.m^{-2}
- Diffuse fraction of global horizontal irradiance, $D(0)/G(0) < 0.2$ 2) (clear day).
- Direct irradiance on the plane of incidence,

Wind speed higher than 1 m.s^{-1} (this is equivalent to a gentle breeze).

PV modules (sensors and tested):

- Co-planar position, without obstacles hindering thermal dissipation.
- Orientation: towards the equator.
- Tilt: an angle leading to incident angles direct solar irradiance below 40º. [For example: solar zenith angle at noon or, generally speaking, tilt angle equal to |φ| (local latitude) in autumn-winter, and equal to max {|φ|-20º, 0} in spring-summer.]
- Previously cleaned with water, soap and smooth cloths.
- Previous exposition of modules for, at least, 1 hour to outdoor conditions, in order to assure modules are at thermal equilibrium.

(V, I) Measurements:

- Performed within ±1 hour from solar noon.

2) This condition is very often achieved, for example, in cloudless skies. Other sky conditions, for example, days with dust floating in the air (*i.e.*, high atmospheric turbidity), would require the use of a pyranometer in order to decide about the measurements viability.

• Total duration for the three (V, I) points and their corresponding operation conditions must be less than 5 minutes. In this way, no major variations of operation conditions can be achieved. (For this same reason, no measurements should be done in days with strong wind or passing clouds).

A2.4 Operating conditions test

To characterise the electrical parameters of the PV module specimen requires the measurement of the irradiance and temperature conditions. The sensor for this test is the reference module.

Procedure 1: Irradiance measurement

The method is based on the following basic relation between I_{SC} and G:

$$I_{SC} = C_1 \cdot G = I_{SC}' \cdot \frac{G(W\,m^{-2})}{1000} \quad (1)$$

According with the figure 1 and eq. (1), the voltage measurement in the calibrated shunt (precision resistance) allows calculate the irradiance value.

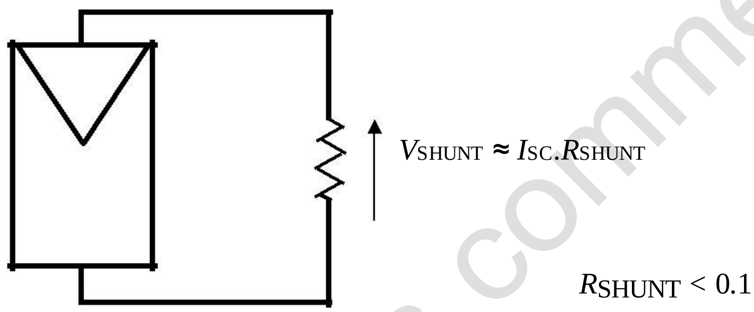

Figure 1 — Assembly for the irradiance measurements method

Procedure 2: Cell temperature measurement

The method is based on the relationship between V_{OC} and T_C, without considering other influences of the operation conditions. It leads to:

$$T_C = \frac{1}{N_S \cdot \beta_T} \cdot (V_{OC} - V_{OC}') + 25 \quad (2)$$

where β_T = 2.3 mV/°C and N_S the number of solar cells in the reference module.

This expression involves a slight overestimation. Nevertheless, as it is the case with irradiance measurements, the use of the proposed expression in extrapolations of V_{OC} parameters will have the effect of cancelling such errors. Figure 2 shows the assembly required for the use of the proposed method.

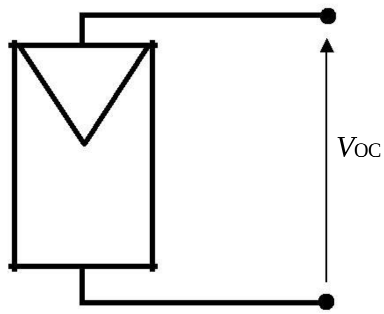

Figure 2 — Assembly for the cell temperature measurements method

A2.5 Electrical parameters test

Procedure 3: Extrapolation of the short-circuit current parameter at STC

$$G\,(\mathrm{Wm}^{-2}) = 1000 \cdot \frac{I_{SC,S}}{I_{SC,S}^{*}} \qquad (3)$$

where subscript "S" denotes the sensor-module.

Measure during one day I_{SC} values of the module under test, together with the G value given by procedure 1.

Experimental values are then to be statistically fitted by means of a simple linear regression, $y = a.x$ ($x = G$; $y = I_{SC}$), the significance level of which (R^2) should be higher than 0.99. The desired parameter, I_{SC}^* , is then obtained by making $x = 1000\ \mathrm{W.m^{-2}}$ in the regression.

Procedure 4: Extrapolation of the open-circuit voltage parameter at STC

Take one or several measurements of V_{OC} of the module under test, together with T_C estimates from the procedure 2. Individual points are then to be extrapolated to STC by means of the following expression:

$$V_{OC}^{*} = V_{OC} - \frac{N_S}{N_{S,S}} \cdot (V_{OC,S} - V_{OC,S}^{*}) \qquad (4)$$

The desired parameter V_{OC}^* is the average value of the extrapolations.

Procedure 5: Determination of the Maximum Power at STC

It is based on the measurement of three individual points of the module I-V curve, which are to be extrapolated and used for the determination of the maximum power (STC), P_M^*, using eq. 5, once the fill factor, FF^* , has been calculated.

$$P_M^{*} = I_{SC}^{*} \cdot V_{OC}^{*} \cdot FF^{*} \qquad (5)$$

Fill Factor determination

For the practical determination of FF in a PV module, the following equations are proposed:

$$FF = FF_O\ .\ (1-r_S) \qquad (6)$$

where FF_O is the ideal fill factor (no resistive effects):

$$FF_o = \frac{v_{oc} - \ln(v_{oc} + 0.72)}{v_{oc} + 1} \qquad (7)$$

v_{OC} is the normalized open-circuit voltage of each solar cell (average):

$$v_{oc} = \frac{V_{oc}}{N_S \cdot V_t} \qquad (8)$$

where V_t is the thermal voltage.

r_S is the normalized series resistance of each solar cell (average):

$$r_S = R_S \cdot \frac{I_{sc}}{V_{oc}} \qquad (9)$$

These parameters enable to calculate directly the maximum power point (V_M, I_M):

$$V_M = V_{oc} \cdot \left[1 - \frac{b}{v_{oc}} \cdot \ln a - r_S \cdot (1 - a^{-b})\right] \qquad (10)$$

$$I_M = I_{SC} \cdot \left[1 - a^{-b}\right] \qquad (11)$$

being a and b two intermediate parameters:

$$a = v_{OC} + 1 - 2 v_{OC} \cdot r_S \qquad (12)$$

$$b = \frac{a}{1 + a} \qquad (13)$$

All these equations can be used for any operation conditions, given the following compliance: $v_{OC} > 15$ and $r_S < 0.4$. This covers real operation for most Si solar cells. Accuracy in the calculation of the maximum power using equations (10) and (11) is better than 1%.

The series resistance, assumed independent of operation conditions, can be calculated using equation (14) and three (V,I) points:

$$R_S = R_S^* = \frac{N_S \cdot V_t\,(25\,^{\circ}C) \ln\left(1 - \frac{I^*}{I^*_{sc}}\right) + V^*_{OC} - V^*}{I^*} \qquad (14)$$

Apparatus

Figure 3 shows schematically the equipment and assembly recommended.

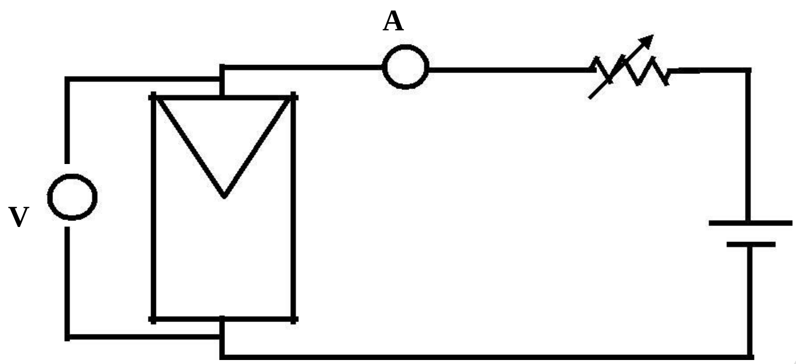

Figure 3 — Instrumentation and assembly recommended

Instrumentation comprises the following elements:

- Voltmeter, for the PV module voltage measurements.

- Ammeter for the module current measurements or, alternatively, a combination shunt + voltmeter.

- Battery, for fixing a certain operation voltage at the PV module. If it is a conventional (36 series-connected) module, a 12-Volts battery will be used. For other types of modules (e.g., low-voltage, based on 12 series-connected assemblies), combination of 2-Volts battery vases can be used (or even the battery can be disregarded).

- Potentiometer (variable resistance), for a more precise adjustment of the module operation voltage. It should be noted that this adjustment, because of inherent limitations of the potentiometer, cannot be as fine as would be desired. This component must be able to stand the maximum power of the PV module under test.

- Irradiance sensor-module: calibrated module in I_{SC}^* parameter.

- Cell temperature sensor-module: calibrated module in V_{OC}^* parameter.

Method description

Measurement of the operation conditions (irradiance and cell temperature) will be done with procedure 1 and 2. As extrapolation method the following criteria are adopted:
- Current measurements are extrapolated as the short-circuit current:

$$I^* = I + I_{SC} = I^* + (I_{SC}^* - I_{SC}) \qquad (15)$$

Voltage measurements are extrapolated as the open-circuit voltage:

$$V^* = V + V_{OC} = V^* + (V_{OC}^* - V_{OC}) \qquad (16)$$

The series of steps to be taken are the following:

Step 1 Characterisation of I_{SC} at STC using the procedure 1.

Result: I_{SC}^*.

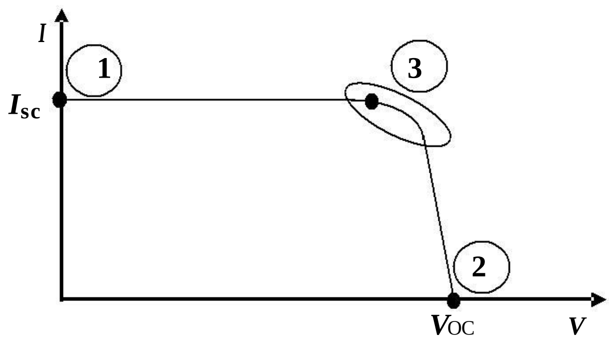

Figure 4 — Graphical representation of the three (V,I) points to be measured

Step 2 Characterisation of V_{OC} at STC using the procedure 2.

Result: V_{OC}^*.

Step 3 Initial selection of point 3 (V_{sel}^*, I_{sel}^*), to be used in subsequent calculation of R_S^*. There are two possibilities, depending on the information available from the PV module under test:

a) An approximate value of V_M^* is known (manufacturer catalogue or calibration of a module of

$V_{sel,0}^*$.

b) No approximate value of V_M^* is known. As initial point, a voltage $V_{est,0} = 0.7V_{OC}$ is estimated (V_{OC} being just previously measured, for example, at Step 2). An iteration calculation is performed, in order to select a better point for later calculation of R_S^*:

Step 3.1 Measurement of a (V,I) point as close as possible to the estimated one (V_{est} $V_{est,0}$, I_{est}), simultaneously with the operation conditions (G and T_C, through $I_{SC,S}$ and $V_{OC,S}$ of the sensor-modules). Extrapolation of measured point to STC using criteria expressed in (15) and (16), together with equations (3) and (4).

Result: (V_{est}^* , I_{est}^*).

Step 3.2 First estimation of the R_S^* parameter, using equation (14) and the results from Steps 1, 2 and 3.1.

Result: $R_{S,est}^*$.

Step 3.3 Estimation of the V_M^* parameter, using equations (6) and (13) together with the results from steps 1, 2 and 3.2. This selected as initial point to be used for subsequent calculation of R_S^* , $V_{sel,0}^*$.

Result from Step 3: $V_{sel,0}^*$.

Step 4 Measurement of cell temperature T_C using the procedure 2. Inverse extrapolation of $V_{sel,0}^*$ to the measured operation conditions by means of equation (2).

Result: $V_{sel,0}$.

Step 5 Measurement of point 3, as close as possible to the initial selected point (V_{sel}, I_{sel}), simultaneously with the operation conditions (G and T_C, through procedures 1 and 2). Extrapolation of point 3 to STC using criteria expressed in (15) and 16), together with procedure 3 value and equation (4)

Result: (V_{sel}^*, I_{sel}^*).

Step 6 Calculation of the R_S * parameter, using equation (14) and the results from Steps 1, 2 and 5.

Result: $R_S^* = R_{S,sel}^*$.

Step 7 Calculation of the FF^* parameter, using equations (6) and (9) and the results from Steps 1, 2 and 6.

Result: FF^* .

Step 8 Determination of the P_M^* ,using eq. 5.

