Validating the PV Extended Model against Field Measurements

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Abstract. A practical set up is erected to generate the photovoltaic-I/V characteristics through practical measurements under various operating conditions. The field-test results were correlated with the ones computed from the extended PV single diode model with parameters adapted to perform under various operating conditions published in a companion paper,[1]. The correlation of the I/V characteristics obtained from theoretical and practical approaches came in good agreement, yet minor discrepancies were observed around the zone of maximum power, with a more pronounced effect at low irradiation levels.

Key words: PV model assumptions, PV model, parameter identification, maximum power point.

I- INTRODUCTION

As the photovoltaic cell is basically a diode junction, its mathematical representation involves mathematical relations of exponential nature. The most reliable approach to reach sound relation is the practical one with the field measurements. To this end a thorough approach to the precautions to be taken and the procedure to be followed in recording the I/V cell/module characteristic is suggested in this paper.

The difficulty in providing a reliable general model resides in the sensitivity of its parameters to the environmental operating conditions. Therefore the availability of a solid reference to the PV performance becomes a vital reference.

A set-up rig is erected to provide a practical, accurate and reliable measurement routine to construct the I/V characteristics of the selected PV module under actual operating conditions. Attention is also focused on the precautions to be taken and procedure to be best followed in carrying out the measured values.

II. SYSTEM SET UP

The Siemens mono-crystalline PV solar module, SM50-H was selected for the practical measurement of the I/V characteristics. The detailed manufacturer data at STC [2] are given in appendix A. Measurements were conducted in the month of June 2019 at a ground level elevated about 300 m over sea level.

The circuit diagram of the experimental set-up used in measuring the I/V characteristics of the PV module is shown in fig.(1) and a photo of the set-up is reproduced in fig.(2).

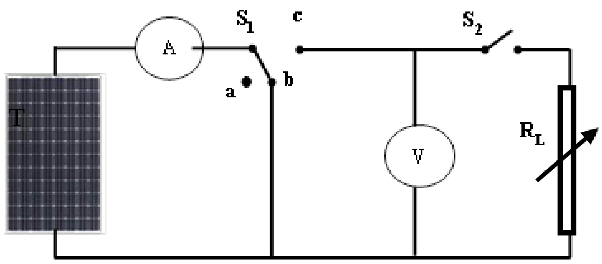

FIGURE (1). Circuit diagram for measuring the PV-I/V, characteristics

Two programmable Metrix AVO meters bearing model number MX 58HD, are used to measure the PV module output voltage and load current.

The EKO Instruments Co Ltd, model MS-602 (second class) pyranometer, was selected to measure the actual irradiance level in W/m^2 [3] as well as the temperature sensor circuit LM016L for measuring the temperature in °C.

A carefully selected set of taped 100 high power resistors are connected in series; thus providing a switchable load resistance with values ranging between $0.5 \le R_L \le 11.330\Omega$

From the results of the analytical solution performed on the extended PV single diode model [1], the calculated range of load resistances at the point of maximum power point is:
R_L= 5Ω at G=1000 W/m^2, T= 25°C and P_{max}= 50.6W
R_L= 15Ω at G=200 W/m^2, T= 65°C and P_{max}= 9.55W

The resistance module comprises 6 switchable ranges as given in table I.

Table I

Selector	No. of resistors	Nominal resistor rating in Ω	Resistor power rating in W
1	20	0.5	10.0
2	20	1.0	3.0
3	20	5.0	2.0
4	20	10.0	1.0
5	10	100.0	1.0
6	10	1000.0	1.0

The bank of resistors is designed to withstand the absolute maximum power with no risk of overheating even under prolonged solar exposure.
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FIGURE (2). A photo of the set-up rig used in measuring the PV I/V, characteristics.

III-EXPERIMENTAL PRECAUTIONS

Although the set-up for the measurement of the I-V characteristics of the photovoltaic cell is relatively straight forward and simple, yet some practical precautions must be observed to achieve accurate and reliable results [4].

i- All system wiring connections must be made and secured prior to attempting any recording of results.

ii- The solar panel must be left exposed to the solar radiation long enough prior to recording any results to ensure PV module reaching a thermal steady state condition.

iii- The front and back surfaces of the solar panel are to be kept well ventilated such that no thermal build-up of heat underneath or on top of the module surfaces occurs and that temperature could be maintained constant at the ambient level during the testing period.

iv- The load resistors must be linear with almost negligible temperature coefficient.

v- The thermal effect of the output current flowing from the PV solar panel on the resistance of the connecting cables especially near the short circuit current condition must be negligible.

vi- The resistance of the leads connecting the module to the measuring equipment must be kept to a minimum, since their value will add to the load resistance, which exhibit a relatively low value. Some manufacturers suggest the cable length to be used during test conditions to be in the vicinity of one meter.

vii- The possible shading effect caused by the personnel carrying out the switching in load resistance or during the recording stage must be totally avoided.

viii- The duration of performing the experiment (taking reading) must be kept as short as can reliably and consistently be, to minimize the effect of any changes in solar irradiance or temperature.

ix- Results must be taken in ascending order of load resistance to avoid being trapped in a hysteresis sequence.

IV-EXPERIMENTAL PROCEDURE

Initially the actual value of solar irradiation intensity G_{act} and the ambient temperature T_{amb} level is recorded, the experimental procedure will follows the order of the given sequence:

i-Switch S_1 is moved from position S_{1a} to position S_{1b}, while switch S_2 remains open. The ammeter reading refers to the short circuit current I_{sc}.

ii- Switch S_1 is moved afterwards to position S_{1c} and the voltmeter reading refers to the open circuit voltage V_{oc}.

iii- Switch S_2 is now closed while switch S_1 remains in position S_{1c} to connect the load resistance bank that is primarily set to its minimum value (0.5Ω), and accordingly values of current I_L and voltage V_L are recorded.

iv-This procedure is repeated for all switched values of the resistive load.

v- According to the recorded readings the relation between I_L and V_L is plotted at the prerecorded values of irradiation G_{act} and ambient temperature T_{amb}.

vi-This sequence is repeated at different values of irradiation G_{act} and ambient temperature T_{amb} as listed hereafter:

a- Irradiance G=735W/m^2 and ambient temperature $T_{amb} = 31°C$

b- Irradiance G=562W/m^2 and ambient temperature $T_{amb} = 36°C$

c- Irradiance G=352 W/m^2 and ambient temperature $T_{amb} = 38°C$

V- RESULTS AND OBSERVATIONS

As mentioned in sec.(iv) the field measurements were carried out three times under the surrounding conditions mentioned above thus generating the I/V, P/V characteristics and deducing the equivalent load resistance R_L. The same data was introduced to the extended PV model derived in [1] and the results obtained are plotted in conjunction with the ones taken from practical measurements are shown in fig (3), fig.(4) and fig.(5).

It can be noticed that the value of load resistance producing maximum power transfer fall between 5 and 15 Ω depending on the surrounding conditions.

The voltage at which maximum power transfer occurs falls in the range of $15.39 \le V_L \le 16.53V$

The overall maximum power under all practical operating conditions varies between $9.560.5 \le P_{max} \le 50.62$

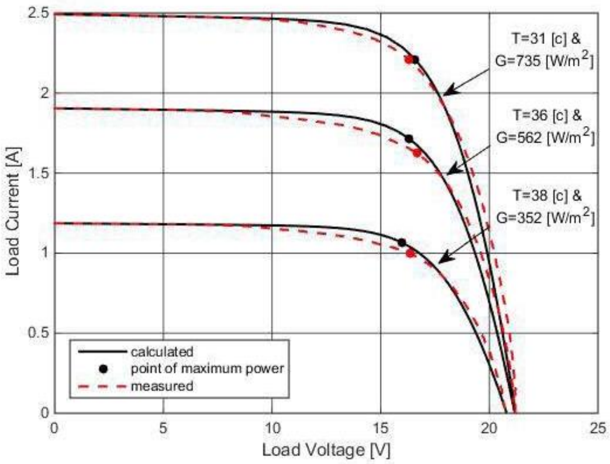

Figure (3) Comparison of I/V characteristics between practical and analytical results

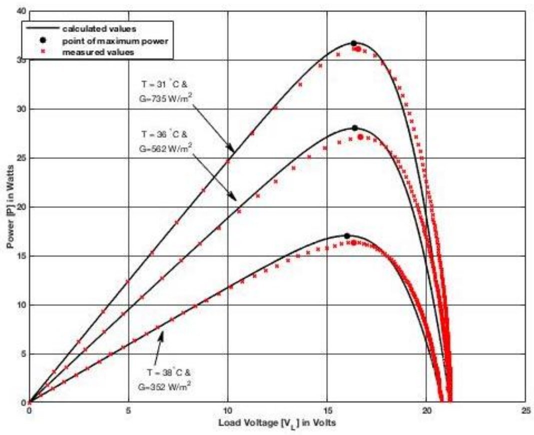

Figure (4) Comparison of P/V characteristics between practical and analytical results

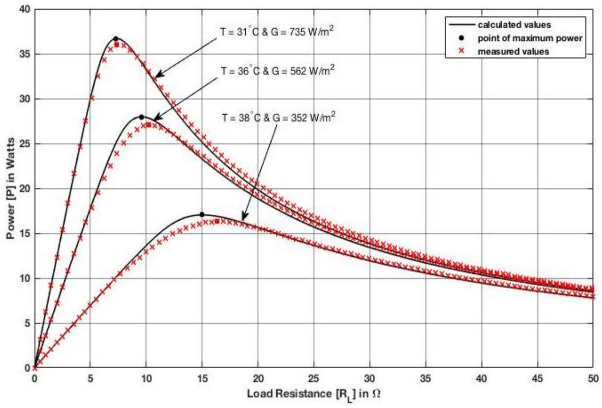

Figure (4) Comparison of P/R_L characteristics between practical and analytical results

VI. CONCLUSION

In this work a thorough approach to the precautions and experimental procedure that must be followed to reach concrete results for the identification of the PV module I/V and P/V characteristics. All measuring equipment were carefully selected and calibrated to ensure reliable results.

The design of a load simulator is presented to ensure thermal stability of the resistive load irrespective of the experiment time exposure with a small incremental step of 0.5 Ω near the short circuit zone, and large steps near the open circuit zone.

The field measurements were effected to encompass various surrounding conditions of irradiance and temperature as mentioned in sec. (IV). Comparing these results with the ones derived from the analytical approach of the extended single diode model derived earlier in a companion paper are presented and came in good agreement, [1], [5], yet minor discrepancies were observed around the zone of maximum power, with a more pronounced effect at low irradiation levels.

VII- REFERENCES

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Appendix A

Manufacturer name	Siemens
Model number	SM-50
Electrical Parameters	
Type of Cells	Monocrystalline
Nominal Voltage	12V
Maximum power	50W
Voltage at maximum power	16.6V
Current at maximum power	3.05A
Open-circuit voltage	21.4V
Short- circuit current	3.4A
Maximum system voltage	600V (UL1703) 1000 V (ISPRA)
Thermal Parameters	
Temperature coefficient of short circuit current $\alpha_{I_{sc}}$	1.2 mA/°C
Temperature coefficient of open circuit voltage $\alpha_{V_{oc}}$	-.077 V/°C
NOCT	45± 2 /°C
Temperature range	-40°C to +85°C
Mechanical Parameters	
Weight	5.5Kg
Dimensions	1293 x 329 x 34 mm
Number of series cells	36
Maximum pressure on surface	2400N/m^2
Maximum Distortion	1.2 degrees
Ice ball resistance (ϕ=25mm)	23m/s
Type of Aluminum Frame	Torsion and Corrosion-resistant anodized aluminum
Warranty Condition	
Limit Warranty on power output	25 years
Accessories to be provided as an optional extra	
Load cable	4mm^2