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A simple and low cost measurement technology for solar PV modules

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Abstract. The appropriate measurement of solar power output plays a critical role in the performance analysis of any solar power plant or a photovoltaic array. The performance under standard test conditions (STC), as mentioned by the manufacturers, is seldom attained as measurements of a PV module/array are done in outdoor terms. To evaluate the efficiency of performance, a photovoltaic module/array accurately, an on-line characterization of such photovoltaic (PV) set-ups at non-standard test conditions (NSTC) is always necessary. In the backdrop of the absence of reliable and competitively priced PV module characterization systems, a smart, digital and portable test set-up seem to be highly significant, and such a model has been developed and analyzed in this work. This system uses supercapacitors as the load to the PV module under test. At present, such characterizations are carried out using imported devices, which cost around INR 200-300 thousand. The system so developed will cost around INR 30 thousand and is aimed at import substitutions of such measurement devices. This is very important with regard to field installations testing and will also be of extreme help to researchers in the laboratories, who require all cannot use extensive testing and costly imported instruments. Proper attention has been paid in this work to determine the suitability of the method concerning I-V plotting time and accuracy. Thus it becomes imperative that the quality of the new PV metrology be verified experimentally and duly validated to instill confidence among the users. A detailed investigation regarding the quality of measurements has been carried out, taking into consideration the effect of a wide range of climatic variations. It has been found that these values are consistently in good agreement with the results obtained at the standard Electronics Regional Test Laboratory (ERTL Govt. Of India) test set-up. Statistical analysis of the PV measurements is ensured by regression analysis (RA) of the respective electrical parameters and the standard deviation (SD) of fill factor (FF) values. Experimental evaluation of quality parameters like Fill-Factor (FF) has yielded satisfactory ranges of 70% to 79% for FF. Elaborate regression analysis (RA) of principal PV parameters has yielded consistently high values exceeding 99%. At this time, when India is planning to install large-scale PV plants, there is a significant need to measure the electrical parameters of PV modules of different technologies and, after that, choose the appropriate one for optimum performance in a specific region.

Keywords. Solar photovoltaic system; I-V characterization; supercapacitor; PV metrology; regression analysis; standard deviation.

1. Introduction

The rapid penetration of the solar photovoltaic systems (SPS) into the electrical networks at different voltage levels is now an accepted global phenomenon. The penetration of renewable energy sources (RES) into the average European grid is expected to cross 30% by the end of 2022, where 12% of such shares being specifically contributed from Photovoltaic [1]. India has already embarked on a policy [2] of delivering at least 20% of grid-power through Renewable Energy Sources (RES) by 2020. Accordingly, massive efforts are currently being undertaken in India for large-scale installations of PV power plants of megawatts capacity. Characterization of photovoltaic (PV) generators provides a visual representation and a quantitative measure of PV electrical parameters. In the photovoltaic field, manufacturers offer ratings to PV modules for conditions referred to as standard test conditions (STC). However,

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these STC conditions rarely occur outdoors. So, to carry out photovoltaic engineering reliably, a proper characterization of PV modules, panels, or arrays of electrical behavior (I-V curves) is necessary [3]. But in India, every PV users or researchers only have the STC datasheet, which is provided by the manufacturers. In order to fulfill this ambitious target, a reliable and intelligent metrological approach relating to the testing of basic building blocks (PV Modules) in a PV array has become indispensable for engineers and technocrats employed in the design, configuration, and performance analysis of upcoming PV power plants.

Since the deployment of large size PV arrays currently on the rise in urban areas, the role of on-line simple and inexpensive I-V curve plotter is expanding outside the academic laboratories also. Supercapacitors (SC) have been used for the first time as the load to the PV cell/modules for characterizing their behavior. The particular advantages of SC over capacitors (constituting a few varieties of commercial I-V plotters) have been reviewed thoroughly and also experimented vis-à-vis the capacitor loading. Appropriate theoretical modeling and validation of the time of I-V plotting has been attempted to establish the precise control over plotting time offered by the SC banks. This is specially reinforced by modeling the role of effective series resistance (ESR) of the supercapacitor. Thus the next section is essentially devoted to a review of the existing metrological approaches practiced in PV Engineering in order to establish the specific merits of the supercapacitor (SC) based method practiced by the authors. Supercapacitors have been used in this metrology for the first time as the load to the PV generators [4, 5].

2. Review of existing PV metrology

Different researchers and scientists have been using different methodologies to characterize Photovoltaic (PV) generators [6–8] in order to estimate the essential electrical parameters. The conventional analog method of determination of the I-V characteristic of a solar module involves a variable resistance used as the load. A I-V characteristic has two extremities - the short circuit current point (I_{sc}, 0) and open circuit voltage point (0, V_{oc}). By varying the resistive load the above co-ordinates can be approached but not reached. Further, this manual process consumes sufficient time leading to undesired heating of all the p-n junctions of a PV module.

To minimize human intervention and to characterize the PV module faster and accurately, researchers started to use electronic loads instead of resistive loads. The electronic load is an instrument, which permits an electronic control of the current or voltage load. The linear MOSFET can be used as an electronic load to test the PV panel [9]. The potential advantage of the electronic load is the fast variation (scanning) of the equivalent load resistance. Commercial systems for testing PV panels under field conditions are available, but they are computer-controlled and are very expensive. A MOSFET based electronic load circuit was introduced by Kuai *et al* [10], where a fast scanning monitoring system was achieved. A useful se-tup of an outdoor test facility capable of measuring a broad spectrum of different PV technologies without time-consuming adaptation of the measurement equipment has been described in the work of Daniel Koster *et al* [11]. Recently Sahbel *et al* designed a simple electronic circuit for testing the photovoltaic (PV) modules by tracing their I-V characteristics [12]. However, all such methods are constrained by a requirement of an expensive test set-up or the total set-up suited to the laboratory measurement conditions only. A new technique using the LABVIEW software suffering from an inappropriate matching with the System Management Unit (SMU) based hardware has been developed by different researchers [13, 14].

In the next phase of development, researchers developed capacitor charging with the aid of open-circuit voltage. Such an effort by Mahmoud [15] has used capacitors as the load to PV Generators. But, such reports contain a detailed transient analysis, which leads to the dependence of I-V plotting time on open circuit voltage (V_{oc}) and short circuit current (I_{sc}) only. Also, such reports do not contain real traces of I-V characteristics of PV Generators. Further, this method calls for a high precision DAS, making the plotter higher in capital cost, although other researchers like Yunus Erkaya *et al* and Flippo Spertino *et al* [16, 17] have in the recent past used capacitive load. But neither of these curve tracers provide the assessment of the I-V plotting time and effective means to control the same.

In view of the above points, authors of this paper have introduced a new technique employing supercapacitors as the load for plotting the I-V characteristics of PV modules, where the plotting time is controllable at around 10-12 seconds. Advantages conceived by the use of SC's are outlined in the next section.

3. Advantages of SUPERCAPACITORS (SC) over CAPACITORS

In this work, supercapacitors have been used as a measuring element rather than as a storage device. The advantages perceived are:

a) A High coulombic efficiency exceeding 99%.
b) The thermal management of the SC bank is possible without the use of any kind of heat sink, as the heat dissipation is not expected to cross the level of a few watts, which prevails for only 5 to 10 seconds.
c) An adequate range of capacities of SCs are commercially available with low effective series resistance (ESR) values (within a few milliohms). A range of commercial capacitors are also available with low values

of ESR, however such capacitors are costlier and bulkier than the corresponding supercapacitors

d) A Wide voltage range of available SCs are available compatible with the open circuit voltages of standard PV modules and panels.

e) With the use of SC as the load, control over the plotting time is much better established.

This is evident from the mathematical modeling as envisaged in section 3.6 [18].

Moreover, an experimental estimation of heat dissipation for 100.0 Wp PV modules using supercapacitors as load is shown in table 2 vis-à-vis capacitor loading as in table 1. The heat dissipation values in the last column have been estimated by considering individual ESR value of the supercapacitors to be 0.02 Ω and the total ESR value of the supercapacitor bank to be 0.12 Ω (optimum combination of six SC's in series).

3.1 *Supercapacitors as the load to PV generators*

In this technique, tracing the I-V curve of a photovoltaic cell or module is done using the supercapacitors as load. Tracing V-I curve of a Photo-Voltaic (PV) cell or module from the transient analysis of charging a capacitor has been already established [3]. The supercapacitor method for tracing V-I curve also works on the same principle. Considering the circuit arrangement in figure 1, where the variable resistance used in erstwhile analog metrology is replaced by a supercapacitor.

Also, the voltmeter and ammeter in figure 1 can be replaced by a single Data Acquisition System (DAS). The technical fitness of this method over the resistive method can be observed by comparing figure 2 with figure 3. The data points are continuous in the case of the supercapacitive method (figure 3). This yields an accurate determination of module electrical parameters. It is also a cost-effective proposition compared to the capacitive method as a supercapacitor sweeps the I-V trace at a moderate scanning speed. As a result, a cost-effective and compatible Data Acquisition System (DAS) is likely to be compatible.

In the capacitive method described by Mahamod [6], the author has given an expression of characterization time involving C, I_{sc} and V_{oc}only. It is obviously in adequate as open and short circuit point cannot define the I-V characteristics of a PV Generator. It is necessary to add another important data point, i.e., the peak power point constitutes a complete I-V curve. In different approaches, it has been observed that second degree polynomial like parabola or hyperbola cannot be fitted with these points to match the curve. So, the author has followed a simple piece-wise linear break-up of the characteristic to define an approximate I-V curve. A detailed analysis of characterization time using piece-wise linear break-up has been attempted in the next section.

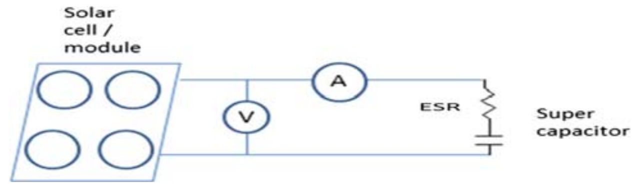

Figure 1. I-V characterization using supercapacitor loading.

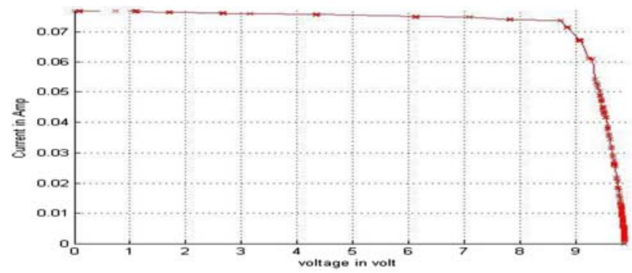

Figure 2. I-V characteristics of a solar module at 500 W/m^2 by using a variable resistor.

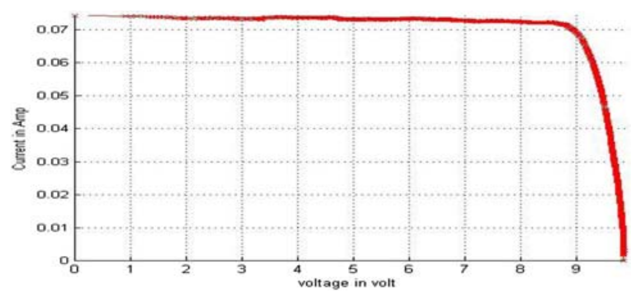

Figure 3. I-V characteristics of a solar module at 500 W/m^2 by using a supercapacitor.

Table 1. Heat dissipation for 100 Wp PV modules using capacitor having ESR of 0.95 ohm.

Insolation (W/m^2)	ESR value (Ω)	Charging-current (I) (A)	Heat dissipation (W) =(ESR*I*I)
200	0.95	1.535	2.2384
450	0.95	4.31	17.6473
650	0.95	4.8	21.8880
780	0.95	5.616	29.9625

3.2 *Curve-tracing-time of PV Characterization*

An equation for curve tracing using supercapacitive load had been developed as a part of this work [18], where,

T_{ESR} = Curve Tracing Time with considering ESR ESR = Effective Series Resistance of supercapacitor, where the other symbols have usual meanings and pertain to PV modules

$$T_{ESR} = C \times \left(\frac{V_m}{I_{sc} - I_m} ln \left(\frac{V_m}{V_m + (I_{sc} - I_m)ESR} \left(\frac{I_{sc}}{I_m} \right) \right) + \frac{(V_{oc} - V_m)}{I_m} ln \left(\frac{100(V_{oc} - V_m)}{(100 - K)V_{oc}} \right) + ESR.ln \left(\frac{100 I_{sc} V_m (V_{oc} - V_m)}{I_m V_{oc} (100 - K)(V_m + (I_{sc} - I_m)ESR)} \right) \right) \quad (1)$$

The equation thereafter helps to,

- The analysis has been extended to consider the effect of Equivalent Series Resistance (ESR) wherein an original expression for charging time of a supercapacitor and its ESR value has been developed
- This is a significant contribution to the metrology of photovoltaic engineering, where the role of ESR has been identified to the right extent.

3.3 *Choice of supercapacitor values*

Mahmoud[15] showed the effort, for enabling the proper choice of a capacitance value as the load. Such practices are seen to be confronted by

(a) Use of X-Y Recorders or Compatible Data Acquisition systems (DAS) and
(b) Lack of suitable analysis controlling the plotting time.

In this backdrop, the author uses supercapacitor for the first time as the load to the PV generators. It is observed that an ordinary DAS performs suitably and also the curve plotting time can be controlled accurately by using the right value of supercapacitors.The task of choosing the elements of the SC bank was performed with initial priority on low ESR values. The SC banks are configured in two steps:

a) In the 1st phase, the PV Module's capacity is considered between 10 Wp and 100 Wp. Since the V_{oc} of the 10 Wp to 100Wp PV modules lie between 21 V to 25 V levels, six numbers of series connected 1 F, 5.5 V supercapacitors with ESR values (0.022 ohms) were chosen. For the first case, the simple Kamcap supercapacitors have been used, where the equivalent capacitance of the SC Bank = 1/6=0.166F
b) In the second stage, the largest capacity building block in PV arrays is considered. Since the V_{OC} of a 300 W PV module is 48 V, lowest ESR values (.022 Ω) supercapacitors came out with the specification of 7.5 F, 5.4 V [19]. Here, nine numbers of 7.5 F, 5.5 V supercapacitors in series have been configured to constitute an equivalent capacitance value, 0.83 F (7.5/ 9).

4. Description of the characterization set-up

Figure 4 represents typically a block diagram of the testing scheme used by the authors.

Experimental set-up required for measuring different electrical parameters are as follows:

(a) Data Acquisition System (DAS): The DAS (AGILENT 34970A) is used for data acquisition purpose. DAS records the voltage and current values and sends to the computer where it is stored in an Excel file. A simple MATLAB program accesses these data from the Excel file to plot the desired I-V characteristics.
(b) Supercapacitor Load: Supercapacitor Bank according to wattage of PV modules is used. Authors have used a Supercapacitor load method to measure different electrical parameters. In fact, the principle of operating with a Supercapacitor load is illustrated in publication of the concerned research group [4,5 and 18].
(c) Computer/ GLCD display .
(d) PV modules of different wattages according to experimental requirement.
(e) Insolation Sensor: A 3Wp panel is used to measure insolation. 3Wp panel supply short circuit current to DAS and DAS convert this short circuit current proportional to insolation.
(f) Temperature Sensor: Resistance temperature Detector (RTD) is used to measure module back surface temperature and back-surface is converted to cell temperature using well-known Sandia equations [20].

Now, figure 5 shows PV modules of 74 Wp and 100 Wp which are kept on steel frame structure and this steel structure placed on roof-top of EE department of IIEST, Shibpur, India. Three output channels i.e., voltage channel (VC), current channel (CC), Temperature coming from PV module are connected to input channel of data acquition system (DAS). The DAS record the values of current, voltage, temperature at fixed interval of time.

The data acquisition system (DAS) is being made operational on an embedded platform (dsPIC30F4013) making the instrument light-weight and portable.

5. Results and discussions

In India currently, the local PV market is dominated by assorted poly-Si PV Modules. As such authors have experimented with the characterization of poly-Si PV modules only. According to the current PV market scenario

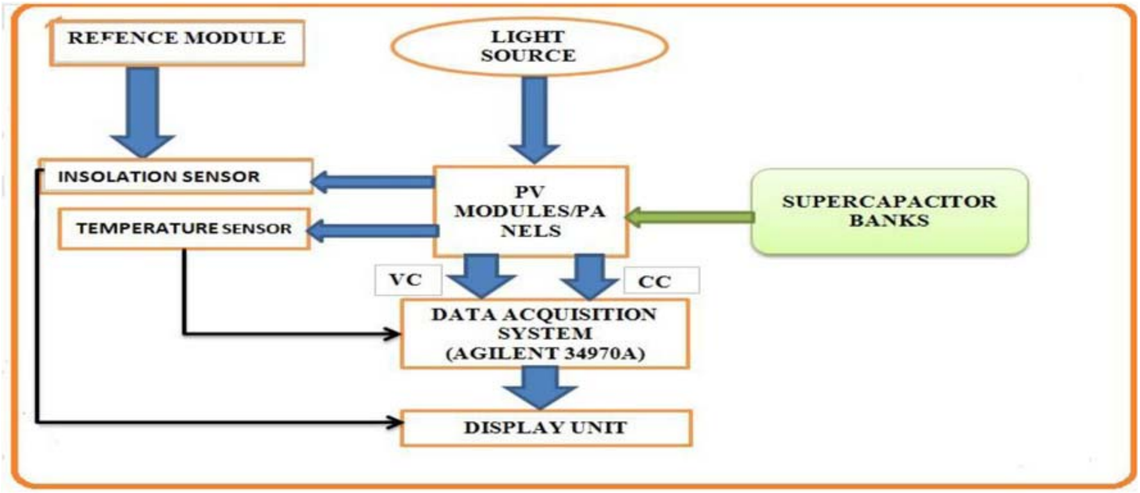

Figure 4. Functional blocks of the testing set-up.

Figure 5. Rooftop test set-up.

in India, VIKRAM SOLAR LTD. (VSL) is one of the foremost PV manufacturing companies in India. Modules manufactured by the aforesaid company have been used in this study. In order to confirm the accuracy of the newly developed supercapacitor based I-V tracing method, author has conducted two types of validation.

1) A few comparative measurements with a standard test set-up of Electronics Regional Test Laboratory-East (ERTL), Govt. of India [21] were done for validation of the new metrological procedure.
2) Determination of quality through reliability analysis of the new metrology.

5.1 *Maximum power point comparison with standard test set-up*

The I-V characterization of poly-Si modules of different wattages from 10Wp to 100Wp using different test conditions have been recorded with the newly developed I-V tracer set-up. After that the total results also compared with the data of ERTL test data.The tables 3, 4, 5 and 6 show all the basic electrical PV Parameters for a 50 Wp and 100 Wp poly-Si PV module tested by the authors method vis-à-vis the ERTL test data.

5.2 *Consistency of the results*

The following checks have been exercised by the authors to ascertain the reliability of new metrology:

A) Regression Analysis [22] of selected PV Parameters (Pm) of different levels of insolation and have been computed and found to be above 95%.
B) Estimation of Standard deviation [23] of Fill Factor has been done for all conditions. The value is 0.02.
C) Using the Anderson's translation equation [24], the peak wattage of the PV module is translated from each of the NON-STC to the STC condition.

5.2a Regression analysis of PV parameters: Regression analysis on essential electrical PV parameters (Isc, Im, Pm) is conducted for 10 Wp to 100 Wp poly-Si PV modules. The study is done to find out the effect of varying supercapacitor on a set of PV modules. Figure 6 depicts only the regression co-efficient (R^2) values of Pm using different supercapacitor values for 100 Wp, 50 Wp and 320 Wp of poly-Si modules where it can be seen that the level of R^2 values is consistently above 0.98.

5.2b Estimation of standard deviation of FILL FACTOR (FF): Fill factor is an essential and intrinsic parameter of any kind of PV module. To ascertain the quality of measurements, the standard deviation (SD) of the Fill Factor is calculated for the solar PV modules using the relation [22]. The variation of FF Vs. Different supercapacitor values in figure 7 is plotted for 50 Wp, 100 Wp, and 320 Wp poly-Si modules under varying levels of climatic condition.

For smaller module sizes, SCs of rating 0.166 offers the best characterization results, as evident from figures 6 and 7. A close inspection of figures 6 and 7 reveal that the most suited supercapacitor rating for testing 320 Wp modules is 0.1 F, having a minimum standard deviation of .002, whereas the same value also allows a regression coefficient of 0.985.

5.2c Estimation of peak power values at Standard Test Condition (STC): To ascertain the performance behavior of the PV modules at outdoor Non-Standard Test Conditions (NSTC) as compared to their manufacturer's ratings at Standard Test Conditions (STC), the measured Pm is translated from NSTC to STC. This check is performed on a number of different wattage PV modules so as to ascertain their peak wattage values. Results obtained from the author's experimental set-up were compared with the data from a standard test set-up of the Electronics Regional Test Laboratory-East (ERTL), Govt. of India [21]. The operating conditions where the modules were tested obviously did not pertain to Standard Test Conditions (STC). Table 7 shows translated peak power values from non-STC conditions to Standard Test Conditions (STC). As seen in table 1, the non-standard experimental values obtained by the author's method and results of the ERTL test se-tup method are converted to Pm values at STC by using the well-known Anderson's approach [24].

6. Conclusion

It can be easily seen that table 7 has used supercapacitor values ranging from 0.1F to 0.2F as this range has restricted the plotting time of I-V characterization in the range of 6 to 9 seconds [4, 18] typically. Further, the new PV metrology has been tested under variable climatic conditions and different values of selected PV modules to establish the "robustness" of the method. Not only that, the accuracy and precision of the measurement technique have been developed from the results. Inferences drawn from various sections of the presented results are:

1. Tables 1 and 2 clearly present the reasons why supercapacitors have an edge over capacitors with respect to thermal management.
2. It is seen from figure 6 that, consistently high values of R^2 (above 0.98) are found with respect to Regression Analysis of P_m of the chosen modules.
3. From figure 7 it is clearly seen that, the range of FF for poly-Si PV modules is constantly in the range of 77% - 82% .Actually; figure 5 also suggests a suitable range of compatible Supercapacitor values for use in this measurement technique.
4. Precision means the reproducibility of the measurement system. The precision of the supercapacitor based metrology has been also established from table 7, because at the same insolation using different SC values the value of P_m is almost the same.
5. The measurement procedure operates over a wide range of insolations i.e., 100 W/m^2 to 1000 W/m^2 enabling this computation of accurate P_m at varying climatic conditions.
6. Accuracy means the amount of uncertainty in measurement with respect to an absolute standard

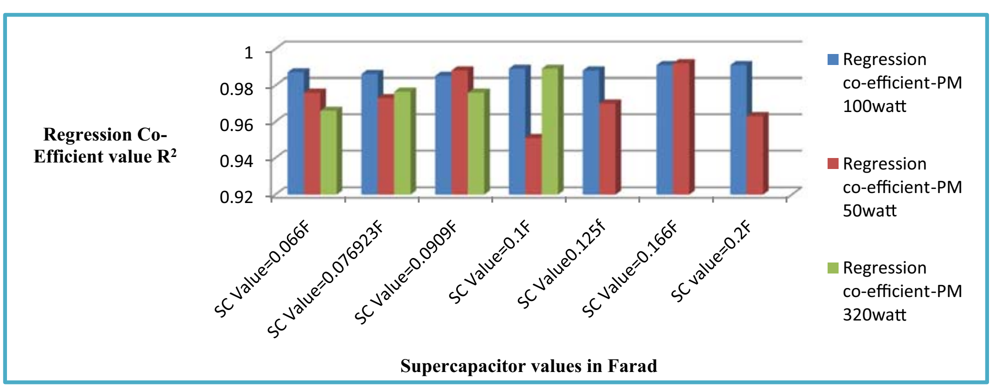

Figure 6. Regression co-efficient of P_m values against different supercapacitor ratings.

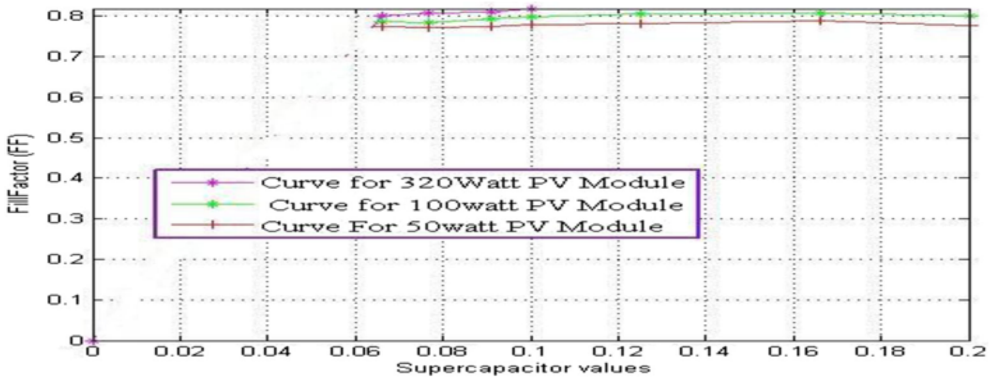

Figure 7. Fill Factor vs. supercapacitor values for different poly-Si PV modules.

Table 2. Heat dissipation 100 Wp PV modules using supercapacitor having ESR 0.12 ohm.

Insolation (W/m^2)	ESR value (Ω)	Charging-current (I) (A)	Heat dissipation (W) =(ESR*I*I)
245	0.12	1.59	0.3033
300	0.12	1.8	0.388
350	0.12	2.14	0.5495
400	0.12	2.44	0.7144
540	0.12	3.31	1.314
800	0.12	4.5	2.43

Table 3. 50 Wp poly-Si module I-V characterization results at insolation 700 W/m^2 (Authors' Method).

50 watt-poly-Si-Results									
Insolation (W/m^2)	Cell-temperature (°C)	Sc-value (F)	I_{sc} (A)	V_{oc} (V)	I_m (A)	V_m (Volt)	P_m (W)	FF	Efficiency (%)
700	25.1	0.2	2.1696	21.1288	2.0289	17.55	35.6237	0.77713	13.9161
700	25	0.166	2.1706	21.2877	2.0389	17.7885	36.2683	0.78916	14.1678
700	25	0.125	2.171	21.0688	2.0389	17.7585	36.2	0.79159	14.1439
700	25	0.1	2.17	21.08	2.0269	17.8085	36.0985	0.78876	14.1
700	25	0.0909	2.1716	21.0688	2.0289	17.7159	35.943	0.78559	14.0408
700	25.1	0.0769	2.173	21.0688	2.0389	17.7585	36.2071	0.79159	14.1439
700	25.2	0.066	2.1699	21.0688	2.0489	17.6085	36.077	0.78492	14.0933

Table 4. 50 Wp poly-Si module I-V characterization results (ERTL Test Set-up).

50 W test results (ERTL)								
Insolation (W/m^2)	Cell-temperature (°C)	I_{sc} (A)	V_{oc} (V)	I_m (A)	V_m (Volt)	P_m (Watt)	FF	Efficiency (%)
700	24.4	2.168	22.57	2.052	18.75	38.473	0.7861	15.027

value. Table 1 is used here to compare the STC values of Pm obtained by the author's estimation and the ERTL testing methodologies. It is observed that the predicted STC values from the developed method differ only by 1 to 3 % from those obtained by ERTL test set up. Thus, the new metrology will be expected to continue generating higher popularity amongst the PV manufacturers and users with regard to the process of testing and deployability of PV modules.

Table 5. 100 Wp poly-Si module I-V characterization results at insolation 700 W/m^2 (Authors' Method).

100 watt-Poly-Si-Results									
Insolation (W/m^2)	Cell-temperature (°C)	Sc-value (F)	I_{sc} (A)	V_{oc} (V)	I_m (A)	V_m (V)	P_m (W)	FF	Efficiency (%)
700	25	0.2	4.457	20.4396	4.1605	17.725	73.7449	0.8095	15.078
700	25.1	0.166	4.4595	20.436896	4.1626	17.7448	73.8883	0.810727	15.1057
700	25	0.125	4.4556	20.4388	4.1358	17.7067	73.231	0.804143	14.9729
700	25.1	0.1	4.4586	20.445	4.1485	17.7867	73.7881	0.80947	15.0886
700	25.2	0.0909	4.4592	20.48	4.1585	17.7688	73.8916	0.809111	15.108
700	25.1	0.076923	4.4625	20.4255	4.1685	17.7288	73.9025	0.811584	15.1102
700	25.3	0.066	4.4615	20.45868	4.1665	17.8088	74.2	0.813706	15.1711

Table 6. 100 Wp poly-Si module I-V characterization results (ERTL Test Set).

100 Wp poly-Si results (ERTL test set-up)								
Insolation (W/m^2)	Cell-temperature (°C)	I_{sc} (A)	V_{oc} (V)	I_m (A)	V_m (V)	P_m (W)	FF	Efficiency (%)
700	24.3	4.466	22.467	4.147	18.89	78.338	0.78	16.016

Table 7. Estimation of Peak wattage values using Anderson's approach.

Module-type with metrological condition	SC-value (F)	Experimental Pm at NSTC (Author's) (W)	Estimated Pm at STC (Author's) (W)	Experimental Pm at NSTC (ERTL-East) (W)	Estimated Pm at STC (ERTL-East) (W)
10 Wp Poly-Si module at insolation 700 W/m^2 and 29°C temperature	0.2	6.92	10.49	7.01	10.39
	0.166	7.00	10.61		
	0.125	6.83	10.35		
	0.1	6.74	10.21		
20 Wp Poly-Si module at insolation 700 W/m^2 and 29.5°C temperature	0.2	13.23	20.05	13.65	20.23
	0.166	13.06	19.80		
	0.125	13.25	20.08		
	0.1	12.88	19.52		
40 Wp Poly-Si module at insolation 700 W/m^2 and 29°C temperature	0.2	26.69	40.05	27.21	40.33
	0.166	26.65	40.00		
	0.125	26.76	40.15		
	0.1	26.46	39.72		
50 Wp Poly-Si module at insolation 700 W/m^2 and 29°C temperature	0.2	33.29	50.40	33.87	50.22
	0.166	33.08	50.08		
	0.125	33.20	50.26		
	0.1	32.82	49.69		
100 Wp Poly-Si module at insolation 700 W/m^2 and 29°C temperature	0.2	64.88	99.27	66.17	99.66
	0.166	64.99	99.44		
	0.125	65.43	100.11		
	0.1	65.59	100.35		

In this paper, authors have been made an attempt to quantify the quality of measurement through the figures of merit. Values of the RA, FF, and precision, sensitivity so discussed bring out the reliability of the new technique and also its robustness. In view of conclusions 1 to 5, reliable measurement technology is established wrt. to PV field trials. Currently, Field trials with the new instrumentation technique are in progress at selected PV industry sites and other installations to enhance the confidence level among the various users.

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