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New PV Metrology for performance appraisal of Poly-Silicon PV Modules in Eastern Indian climatic Zone

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Abstract. An appropriate number of series-connected supercapacitors (SC) forming an SC bank has been used for the first time as the load to PV generators in course of their electrical characterization. Exhaustive estimates of standard PV parameters along with figures of merits like Fill-factor(FF) and performance ratio(PR) have yielded consistent results under naturally varying levels of insolation and ambient temperature prevalent in West Bengal of India. Regression analysis of selected PV parameters has indicated values above 0.997 for poly-Si PV modules which currently constitute the only essential building blocks for PV arrays in the Indian sub-continent. Work is in progress for the adoption of this simple, user-friendly, and easily scalable I-V plotter in PV Indian industries and field trials.

Keywords. Clearness Index, Performance Ratio, PV Array, Global Solar Radiation, PV Metrology, RES;

1. Introduction

The first Practical Use[1] of Photovoltaic(PV) was initiated by the US Signal Corps powering the Vanguard 1 Satellite in 1958. After a lapse of five decades, the Solar photovoltaic system(SPS) today constitutes the most reliable Renewable Energy Source (RES), that can be configured and deployed for generating electrical power. The current European commitment [2] states that at least 33% of electrical power will be produced from RES, where 12% of this shares being specifically related to photovoltaic. It is well known that the PV modules constitute the basic building block in a typical SPS (electrical power generating unit). As the size of an SPS continues to grow in a line with recent energy policies [3], the issue of configuration and monitoring of an SPS will be largely dependent on the reliability of the PV metrology in question for the field trial of PV Modules [4].
Further, the principal share (about 90%) of a terrestrial PV module market constitutes conventional mono and poly-crystalline silicon modules. In the Indian continent, the lion's share in upcoming PV arrays is constituted from polycrystalline PV modules in the recent past [5]. Accordingly, the authors have initiated the testing of various wattage poly-Si modules with their novel and user-friendly measurement set-up [6, 7,8,9].
In the aforesaid background, authors have carried out extensive measurements and subsequent analysis on poly-Si PV modules of assorted wattages during monsoon seasons [10].In continuation of such studies, further investigations are elaborated in this paper during winter and early summer of 2019 in this part of the sub-continent. Accordingly, the next section is devoted to a realistic estimate of hourly varying levels of clearness index. Finally, the results section analyses the dependences of PV figures of merit on the varying levels of clearness index about two different seasons.

2. Clearness Index (K_T)

The performance of PV modules is also affected by the clearness index directly. The clearness Index (K_T) is defined as the ratio of the global solar radiation (G) measured at the earth's surface to the total solar radiation (G_0) at the top of the atmosphere received on a horizontal surface [11]. The clearness index has a high value under clear, sunny conditions, and a low value under cloudy conditions. This parameter depends on contents such as water vapor, clouds, rain, fog, or dust particles and plays an important role in PV applications whenever PV output power or efficiency is measured in outdoor conditions.
K_T is best estimated using the well-known equations below…..

K_T = G/G_0………………………(1)

Where G_0 is the extraterrestrial irradiance in higher layers of the atmosphere in the horizontal plane for a particular day in a year. Clearness Index impacts are described more accurately by Tadeusz Rodziewicz et al [12] by introducing,

$G_0 = E_c^0 * \varepsilon$ …………………….. (2)

Where,

$\varepsilon = 1+0.033*\cos\left(\frac{360*dn}{365}\right)$………………… (3)

Here, E_c^0 in equation (2) represents the solar constant having a value of 1367 watt/m^2 and 'dn' denotes the specific day in that particular year.

Using equations (1)-(3), the authors have estimated hourly varying levels of clearness index (K_T) for several selected days. Below, sample tables of clearness index estimation are shown in table 1 for 10th, January and table 2 for 15th, March 2019.

Table1: Clearness Index Calculation Chart For 10th-January, 2019

Insolation (W/m^2)	G=Insolation*cos(22.5^o) (W/m^2)	€=1+0.033*cos(360*dn/365)	G_0=E*€(watt/m2)	Clearness Index K_T=G/G_0
200	184.76	0.970118443	1326.151912	0.1393
300	277.14			0.2090
400	369.52			0.2786
450	415.71			0.3135
600	554.28			0.4180
620	572.756			0.4319
680	628.184			0.4737
700	646.66			0.4876
800	739.04			0.5573
890	822.182			0.6200

Table2: Clearness Index Calculation Chart For 15th-March, 2019

Insolation (W/m^2)	G=Insolation*cos(22.5^o) (W/m^2)	€=1+0.033*cos(360*dn/365)	G_0=E*€(watt/m^2)	Clearness Index K_T=G/G_0
160	147.808	0.975401991	1333.374522	0.1109
210	193.998			0.1455
400	369.52			0.2771
580	535.804			0.4018
675	623.565			0.4677
820	757.516			0.5681
900	831.42			0.6235
970	896.086			0.6720

3. Measurement Procedure and Method

A) Fig 1. Depicts two poly-si PV modules of 100Wp and 320Wp placed on a roof-top steel structure with a small 3.0Wp PV module placed in the same plane in between the two types of Devices under Test (DUT). The short circuit current recorded by the 3W PV module is converted to actual insolation on the plane of DUT. One remote IR sensor (TESTO-830T1) is used to collect the module back surface temperature of the PV module just before recording the V-I data. Then this data is translated to module cell temperature using the standard Sandia model [13]. Data from aforesaid insolation and temperature sensor are used for input to Data Acquisition System (DAS). A graphical user interface (GUI) named Agilent Bench link Datalogger has been used to control the DAS from a personal computer.

Further, in this novel approach, a series string of supercapacitor (Supercapacitor Bank) has for the first time used as the load to the PV modules, where the open-circuit voltage (V_{OC}) of the module charges the supercapacitor(SC) bank. Principles of charging and discharging of SC's have been described in detail with relevant block diagrams in earlier publications [6,7,8,9]. However, careful configuration of SC banks are to be worked out depending on Device under Test (DUT) specifications and this is detailed in the next sub-section.

B) *Configuration of Supercapacitor Bank*

The task of choosing the elements of the SC bank was performed with initial priority on low ESR values.

a) In the 1st phase, the PV Modules wattage range is considered between 10 watts to 100 watts. Six numbers of series-connected 1F, 5.5V Supercapacitors were chosen since the V_{oc} of the 10Wp to 100Wp PV modules lies between 21Volts to 25Volt levels. For the first case, the 6 pc of KAMCAP supercapacitors have been used with low ESR values around 0.022 ohms. This resulted in an equivalent capacitance of the SC Bank = 1/6=0.166F

b) In the second phase, 320Wp PV modules were the DUT. Here, the lowest ESR values (.022 ohm) capacitors came out with specifications of 7F, 5.5Volts. Since the V_{OC} of a 320Wp module (the largest capacity building block in Indian PV arrays) is 48 Volt, a series connection of 9 identical supercapacitors is required.

The rooftop test bench is clearly shown in below figure 1.

Figure 1: Rooftop set-up

4. Experimental Evaluation of Figures of Merit

To evaluate to figures of merit of the PV metrology at varying climatic conditions mainly three checks conducted by the authors:

i) Evaluation of Regression Co-Efficient(R^2) of essential electrical parameters with varying insolation

ii) Fill factor variation with different Clearness Index values

iii) Performance Ratio of Maximum Power variation with Clearness Index Values

i) Regression Analysis of PV Parameters

A Regression Analysis is performed on short circuit current (I_{sc}), peak power current (I_m), and peak-power (P_m) variations against insolation for the 100Wp and 320Wp PV modules. Table-3 depicts regression coefficient (R^2) values of the selected PV parameters to be in the range of 0.993-0.999.

Table3: Regression Analysis Results For 100Wp and 320Wp PV Modules

PV Module Wattage And Test Date	PV-Characterization Parameter	Regression Coefficient (R^2)
100Wp 10th-January,2018	Isc	0.99
	Im	0.975
	Pm	0.997
320Wp 10th-January,2018	Isc	1
	Im	0.999
	Pm	0.996
100Wp 15th-March,2018	Isc	0.999
	Im	0.99
	Pm	0.993
320Wp 15th-March,2018	Isc	0.999
	Im	0.996
	Pm	0.995

ii) Fill factor (FF) Variation with Clearness Index

Fill Factor (FF) has been extracted from each of the V-I characteristics. Below in figures 2 and 3, the plot of Fill Factor Vs CI is demonstrated for the same set of PV modules.

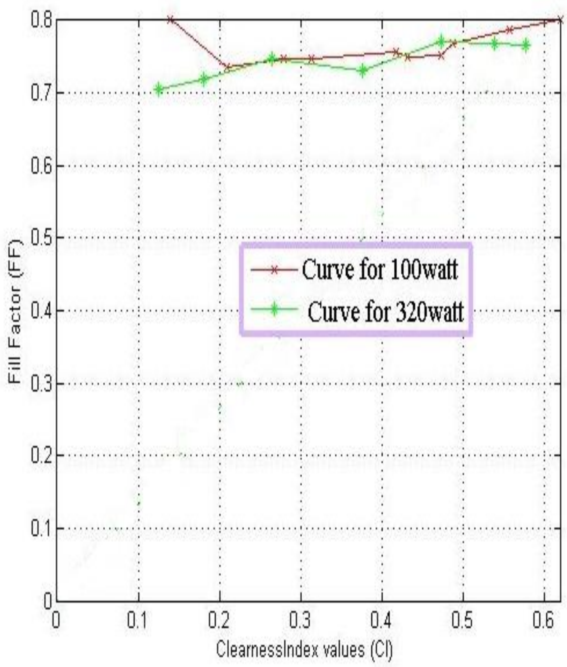

Figure2: FF Vs. Clearness Index graph of 10th, January 2019

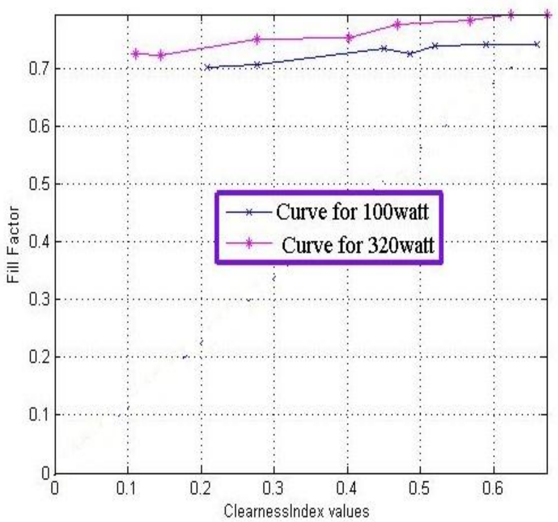

Figure3: FF Vs. Clearness Index graph of 15th March 2019

iii) Performance Ratio (PR)

The Performance of a PV generator at any site is best judged by this important parameter [14], where the PR for different climatic conditions have been estimated using

$$PR = (mP_{MPP}/P_{STC}).(1000\ W/m^2/G_{POA}) \quad (4)$$

Where mP_{MPP} = measured power in NON-STC condition

P_{STC} = Rated Maximum power in STC

G_{POA} = Insolation actually incident on the plane of Array

The operating climatic conditions of the modules are naturally occurring non-standard test (NSTC) conditions. The authors of this paper have tried to investigate the effect of the clearness index on PR of the PV modules. Figure 4 and 5 below represents PR vs Clearness Index for the two different DUT's, on selected dates of 10th January and 15th March respectively.

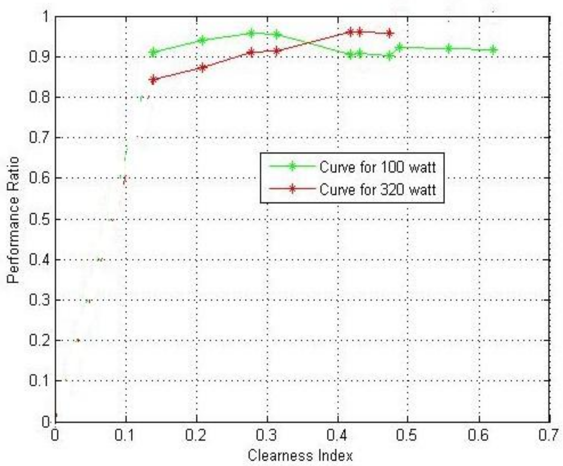

Figure 4: PR vs. Clearness Index graph(10th January 2019)

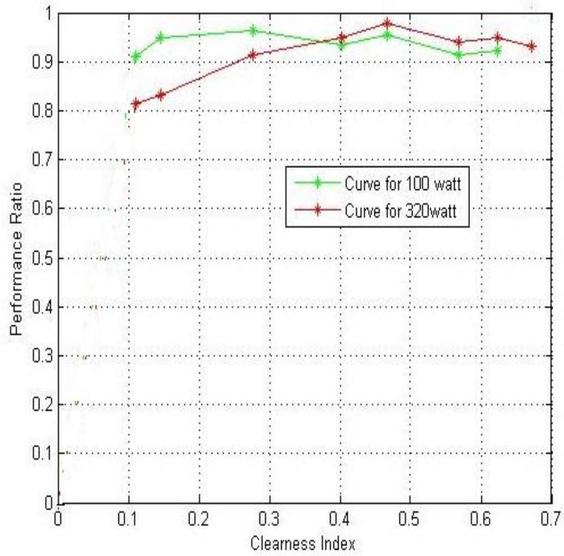

Figure 5: PR Vs .clearness Index graph on 15th March,2019

V. Conclusion

To determine the reliability of the building block PV array i.e Certain Figures of Merits (FOM), commonly encountered in practice are

(i) Regression analysis (of Isc, Im, Pm)

(ii) Fill Factor variation concerning insolation and temperature.

(iii) Performance Ratio

This FOM will be evaluated under daily/seasonal climatic conditions. This is why the hourly variation in climatic conditions has been estimated theoretically by the authors in terms of various solar geometry which are discussed in this paper. Measurements of FOM under varying climatological parameters i.e clearness index are discussed in this paper very clearly.

REFERENCES

[1] L.A.Lamont, " 12 – Third generation photovoltaic (PV) cells for eco-efficient buildings and other applications", Construction, Materials, Processes and Applications, A volume in Woodhead Publishing Series in Civil and Structural Engineering,2013, Pages 270–296

[2] Angel Hsu, Carlin Rosengarten, Amy Weinfurter, Yihao Xie "Renewable Energy and Energy Efficiency in Developing countries: Contribution to Reducing Global emission", United Nations Environment Programme, 2017, Third Report 2017.

[3] "Development of Solar Parks and Ultra Solar Power Projects", Ministry of New and Renewable Energy, National Solar Mission, Govt. Of India, January 2018.

[4] F. Granck and T. Zdanwich, "Advanced System for characterization and Calibration of Solar Cells,"

Opto-Electronics Review, vol. 12, no. 1, pp. 57-67, 2004.

[5] S. Basu Pal, K. Das (Bhattacharya), D. Mukherjee, D. Paul, “Electrical Characterization of PV Modules employing Supercapacitors – A Scalable Method for Field Metrology”, Renewable Energy & Power Quality Journal, Vol.1, No.15, April 2017, ISSN 2172-038X. https://doi.org/10.24084/repqj15.303.

[6] S. B. Pal, K. Das Bhattacharya, D. Mukherjee, and D. Paul, "A quality assessment of PV Metrological technique ---- A case study with Poly-Si PV Modules at IIEST, Kolkata India," 2020 47th IEEE Photovoltaic Specialists Conference (PVSC), Calgary, AB, Canada, 2020, pp. 0033-0036, DOI: 10.1109/PVSC45281.2020.9300399.

[7] S. Basu Pal, K. Das (Bhattacharya), D. Mukherjee, D. Paul, “A Simple and low-cost Measurement Technology for SOLAR PV Modules”, SADHANA, 45,279, Springer publications, November 2020.

[8] S. Basu Pal, T. Belel, K. Das (Bhattacharya), D.Mukherjee, “A Simple cost Effective method of Characterizing PV Cell/Modules using Supercapacitor”, WCPEC6-November-2014, Kyoto, Japan.

[9] S. Basu Pal, K. Das (Bhattacharya), D. Mukherjee, D. Paul, “Estimating of Curve tracing Time in Supercapacitor based PV Characterization”, Journal of the Institution Engineers (India) Series B, Springer Series, August 2017, pp. 385-391.

[10] S.Basu Pal, R.Kumar, K.Das Bhattacharya, D.Mukherjee, “A Reliability Estimate for a Roof-Top PV during early monsoon in Eastern India”, Universities Power Engineering Conference (AUPEC), Melbourne, Australia,2017.

[11] Sukumar Roy, Snigdha Pal, and Nabajit Chakravarty, “ Global Solar Radiation characteristics at DUMDUM(WEST BENGAL ”, Indian Journal of Radio & Space Physics, Vol 45, December 2016, pp 148-153.

[12] Tadeusz Rodziewicz, Aleksander Zarembaand Maria Wacławek, “USE OF CLEARNESS INDEXES FOR PREDICTION OF THE PERFORMANCE OF PV MODULES”, 24th EUPVSEC, 2009, DOI: 10.4229/24thEUPVSEC2009-4AV.3.66.

[13] D.L King, W.E.Boyson, J.A.Kratochvill, “Photovoltaic Array Performance Model”, Sandia Report, No: SAND2004-3535,2004.

[14] Atse Louwen, Arjen C. de Waal, Ruud E. I. Schropp, André P. C. Faaij, Wilfried G. J. H. M. van Sark, “Comprehensive characterization and analysis of PV module performance under real operating conditions”, Progress In Photovoltaics: Research And Applications, John Wiley & Sons. Publications,Volume 25,Issue 3, March,2017, pages- 218-232.