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Research Article

Performance Analysis of Polycrystalline Silicon PV Modules on the basis of Indoor and Outdoor Conditions

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Abstract

This paper summarizes the electrical characteristics of two Polycrystalline silicon PV Modules. Tests are operated in outdoor exposure and natural sunlight located in Gurgaon Region of Haryana (India) as specific composite climate environment, characterized by high irradiation and temperature levels. PV modules performance evaluation was performed according to International Standard as diagnostic test of data, manufacturer. Data acquired by Environmental Operating Conditions (EOC) was converted into Solar Module Output characteristics at Standard Test Conditions (STC) by using method suggested by A.J. Anderson and G. Blaesser. Then, based on the investigation results of the conversion equations, these methods of translation are distinguished by the type of Solar cell Technology and the application range. A difference between the tests in indoor situation and in natural environment exists, attributed to various factors including effect of spectral changes over time, module temperature, effect of reflection by PV incident angles and also light induced degradation in crystalline silicon.

Keywords: *Polycrystalline – Photovoltaic Module – Performances - Translation - Standard Conditions.*

1. Introduction

More than 83% of Photovoltaic (PV) solar modules produced for terrestrial applications is made from crystalline silicon solar cells. The properties of silicon solar cells are affected on changing the environment. Solar cells, like all other semi-conducting materials are subjected to an electrical degradation. Generally, solar cells are exposed to temperature changing from 10 to 50^{o}C. The output parameters like open-circuit voltage, fill factor, short circuit current and efficiency of the solar cell are temperature dependent (Singh, P *et al* 2008).Solar cell efficiency is an important input parameter in PV powered design often, only limited space is available for the solar cells to be integrated. Cell efficiency can even become a criterion of principal system feasibility. As a basic parameter, cell efficiency serves as an input in calculating the optimal system configuration. Different irradiation condition compared to those outdoor require a more detailed knowledge of solar cell characteristics than is described with the current standard test condition (STC), where in the user of a solar powered device will be satisfied is supposed to be strongly related with the overall energy balance of demand and solar energy supply, which is the overall energy flow. (Castaner, L *et al* (2002). Photovoltaic cells allow the direct conversion of solar energy into electrical energy with maximum efficiency at around 9-12%, depending on the type of solar cells. More than 80% of the solar radiation reaching the photovoltaic cell (PV) is not converted into electricity; it is reflected or transformed into heat energy. The heat generated yields to an increase in cell temperature and consequently to a decrease in conversion efficiency of electricity. According to (Angriest *et al* 1982), (Hu, C *et al*1983), (Graff, K *et al*) the inverse relationship of output power (conversion efficiency) with temperature is mainly due to the dependence of the open - circuit voltage (V_{oc}) with temperature. The cell temperature of PV modules in operation is, after solar irradiance, the second most important time dependent parameter in determining the power output of a PV generator. PV cell temperature is higher than the ambient temperature by an amount depending on the balance between the irradiance on the array plane and the heat dissipation mechanisms, knowledge of the instantaneous solar irradiance, the air temperature and the wind speed at any location allows an estimate of solar cell temperature, which is quite satisfactory as was demonstrated by(King, D.L *et al*1998).In addition to other renewable energy sources, photovoltaic cells (PV) present a prime source of clean energy that utilizes energy from sunlight. Solar energy is converted directly to power without intermediate production of heat. Photovoltaic cells are manufactured from fine films or wafers made from silicon (Moller, H.J *et al* 2005), (Loque, A and Hegedees, S (2003), they are semiconductor devices capable of converting incident solar light to DC current. The series or parallel connection of cells allows the design of solar cells with high currents

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and voltages (reaching up to 1Kilovolt). Solar panels are slow in degradation if they are sealed properly, which make them durable particularly as they have no movable parts and requires little maintenance. Different modules produce different amount of electricity according to required amount ranging from few watts to megawatts (Loque, A and Hegedees, S (2003). At present, almost 95% of available solar cells are made of silicon. The development of Si - PV technology materials is driven by cost reduction. The development of Si – PV technology materials is driven by cost reduction. The large growth in the PV market and need for lower cost material than monocrystalline make multicrystalline silicon a favorable alternative (Ponce Alcantara, S *et al* 2005). Efficiency of produced power vary from 3% to 17%, depending on different causes such as the kind of technology used, the light spectrum, ambient temperature, system design, semiconductor characteristics and material of solar cell (Farret, F. A and Simoes, GM 2006), (Messenger, R.A and Ventre, J 2004). The literature which has been published about spectral effects on PV – device performance was reviewed by Riordan and Hulstrom. The magnitude of spectral effects mainly depends on the band gap of the cells (a higher band gap leads to larger spectral effects), time period of integration (longer integration periods reduce spectral effects), and the range of environmental conditions taken into account(Fain, P *et al* 1991),(Wilson, H.R and Hennies, M 1989).There were some suppositions that, because of current mismatch in the multiple cell devices under natural solar radiation conditions, spectral effects will cause multiple cell devices to have no advantage over single cell devices, if they are series connected (Chambouleyron, I and Alvarez, F 1985). The parallel and independent configurations as an alternative are less sensitive to spectral fluctuations but require three-or four- terminal cells and therefore involve more complex processing for both forming the grids and mounting the cells in a module (Fan, J.C.C and Palm, B.J 1983), (Gee, J.M 1988). For insolation values above 800W/m^2 there are, in general, no clouds and the zenith angle is less than 60^0, these conditions are close to the AM 1.5 reference spectrum conditions. For insolation values below 200 W/m^2 overcast skies are predominant, under this condition the relative spectral distribution is shifted towards shorter wavelengths (Nann, S and Emery, K 1992), (Nann, S and Riordan, S 1991). As a result the efficiency of the devices increases. Extreme outliers above 1 are caused by clear skies and high angles of incidence when the cells mainly see the blue sky. This mainly happens in summer time, whereas the corresponding situation with low zenith angles but the red sun time, whereas the corresponding situation with low zenith angles but the red sun illuminating the arrays with low angles of incidence happens in winter time and causes very low efficiencies. In between are situations with partly cloudy skies, high of low turbidity, high or low water vapor (Nann, S and Emery, K 1992). Outdoor measurements of modules or systems are often compared with indoor data for the same modules or projected data for the systems after extrapolation to SRC. This enables the system engineer to detect possible alterations, losses and failures within the system. While extrapolating outdoor measurements to SRC the correct determination of the cell temperature is very critical (Knaupp, W 1990), (Blaesser, G and Rossi, E 1988). A calibrated reference cell spectrally matched to the modules under test can be used to minimize spectral effects. The test sequence of polycrystalline PV module for the design qualification and type approval is described in IEC61215; also the stability of peak power of polycrystalline PV module before and after long term outdoor exposure is a crucial parameter for the reliability and durability. However, when evaluating PV performances in environmental operating conditions (EOC), for a practical use, it is difficult to create the measurement conditions identical to STC (Irradiation intensity 1000W/m^2, module temperature 25^{o}C, Air mass 1.5).Therefore, in most cases the PV module output characteristic values measured with I-V curve tracer are converted into STC values based on various methods (Nakamura, H *et al* 1998), (Agroui, K *et al* 2011). This paper summarizes the electrical characterizations of polycrystalline PV modules in outdoor exposure of natural sunlight of Haryana site of India. All results are reported to STC conditions by using methods for comparative study with manufacturer data sheet.

2. PV Modules Description

The tested PV modules are based on multicrystalline solar cells from **WAAREE** and **RELIANCE** manufacturers.
The area of each solar cell is 96.72cm^2. Solar cells are arranged in 9×4series-parallel connected cells configuration.

Specifications given by the manufacturers **of RELIANCE and WAAREE**	
M/S - RELIANCE	**M/S - WAAREE**
Module No – RS 1250	**Module No – WS 50**
Serial No- MM 100402237	**Serial No- WSAZL061002395**
Module Area- 63.4×66.1	**Module Area- 63×67.5**
Cell Area- 15.6×6.2= 96.72	**Cell Area- 15.6×6.2= 96.72**
No of Cells – 36/ Multi C-Si	**No of Cells – 36/ Multi C-Si**
P_{max}- 50W, V_{oc}-21.6V, I_{sc}-3.25A	**P_{max}- 50W, V_{oc}-21.0V, I_{sc}-3.17A**

3. PV Modules Indoor Testing

The leakage current is measured according to IEC 61215. The test is conducted to determine whether or not the module is sufficiently well insulated between current carrying parts terminals and the frame or the exterior surface of terminal box.

Applicable Specifications

The test was conducted on the modules as per the IEC standard 68-1 at an ambient temperature of the surrounding atmosphere and in a relative humidity not exceeding 75%.

Test Set Up

The test is performed by using Insulation Tester of FLUKE Company of model no 1550C/1555 for DC insulation testing with a current limitation. For modules with an area of less than $0.1m^{-2}$ the insulation resistance shall not be less than 400MΩ, for modules with an area of more than $0.1m^{-2}$ the insulation resistance times the area of the module shall not be less than 40MΩ m^{-2}.

Table 1 Insulation Test Data

S.No.	Module S. No.	D.C.Voltage Applied (V)	Insulation Resistance (GΩ)	Leakage Current (μA)
1.	Reliance RS1250	1000V	26.5GΩ	0.0377
2.	Waaree WS-50	1000V	4.53GΩ	0.2207

Reliance RS-1250 and **Waaree WS-50**, both the modules pass successfully the Hi-Pot test. As the leakage current requirement must be less than 50 μA and the insulating resistance greater than 50MΩ at $500V_{DC}$ as the pass criteria.

Table 2 summarizes PV modules performances prior to any outdoor exposure and established through indoor measurement with sun simulator under standard test condition(STC) as controlled indoor conditions(100mW/cm^2, AM 1.5, Global Spectrum, 25^{o}C) using a calibrated ENDEAS QUICKSUN 700A Solar simulator.

Table 2 PV modules performances at STC Conditions

PV Module	Pmax (W)	Isc (A)	Voc (V)	Rs (Ω)	Rsh (Ω)	η (%)
Reliance RS-1250	56.3	3.441	21.95	694	160	13.4
Waaree WS-50	49.9	3.249	21.84	748	89	11.7

The measured PV module maximum power is compared to the manufacturer's rated maximum power, P_{max} rated are as follows :-

PV Modules Manufacturers Rated Maximum Power

	Reliance RS1250	Waaree WS50
P_{max}, rated (W)	50W	50W

The **Reliance RS-1250** PV module has an initial measured P_{max} value at STC higher than the rated power specified by the manufacturer. This is only a guide to the modules ultimate performances where no as expected photo-degradation is given by the manufacturers.

Measurement of Temperature Coefficients

The temperature coefficient of current and voltage for the modules are determined to assess the behavior of the module current voltage parameter at different trial temperatures. These coefficients are valid at the irradiance at which the measurements are made. For linear modules these are also valid over an irradiance range of ± 30% of the irradiation level at which these are measured for the module. Temperature coefficients of PV module are typically measured by placing PV module on a temperature controlled test fixture, illuminating the PV module with a solar simulator, measuring the PV module current-voltage (I-V) curve over a range of cell temperatures and then calculating the rate of change of the desired parameter with temperature.

Table 3 summarizes indoor measurements of effective temperature coefficients for a variety of commercially available photovoltaic modules.

Table3: Reduced PV modules coefficient temperature

PV Module	α'_m (% / ^{O}C)	β'_m (% / ^{O}C)	γ'_m (% / ^{O}C)
Reliance RS-1250	0.00029	-0.00333	-0.00458
Waaree WS-50	-0.00187	-0.00341	-0.00453

In this **Table,** the units for the temperature coefficients have been normalized to 1/^{o}C by dividing the coefficient by the value for the parameter at STC. The normalized coefficients are more easily applied to different photovoltaic array configurations with different series/parallel combinations of modules. These coefficients are symbolized by $\alpha'_{m,}$ β'_m and γ'_m corresponding short circuit current, open circuit voltage and maximal power of the module.

4. PV Module Outdoor Testing In Composite Climate

The outdoor measurements were performed in the site of Solar Energy Centre, MNRE, 19th Milestone Gwalpahari, Gurgaon–Faridabad Road, Haryana, as specific composite climate environment, characterized by high irradiation and temperature levels. The geographic characteristics of SEC site are North latitude 28.4700^{o}N, East Longitude 77.0300^{o}E, Elevation from sea level is 216 m.

An open rack is used to mount the module outside in the sun with a pyranometer installed in a specified manner. The rack is designed to minimize heat conduction from the module and to interfere as little as possible with the free radiation of heat from the front and rear surface of the module. Both the modules are positioned in a way so that it is normal to the solar beam (within ±5^o) at local solar noon. The bottom edge of the module is 0.6m above the horizontal plane i.e., ground level as illustrated in figure 1.

Fig.1 PV modules of **Reliance** and **Waaree** in outdoor exposure

Experiments are carried out using a modern test facility containing a data acquisition system based on Peak Power Measuring Device Tracer (PVPM 2540) as illustrated in figure 2.

Fig. 2 PVPM 2540

The reference solar cell used in our experimental investigation is based on multicrystalline silicon with integrated Pt 1000 temperature sensor. The PV modules under test receive an electrical performance (I-V), under environmental conditions for different values of solar irradiance and an ambient temperature on clear sunny day.

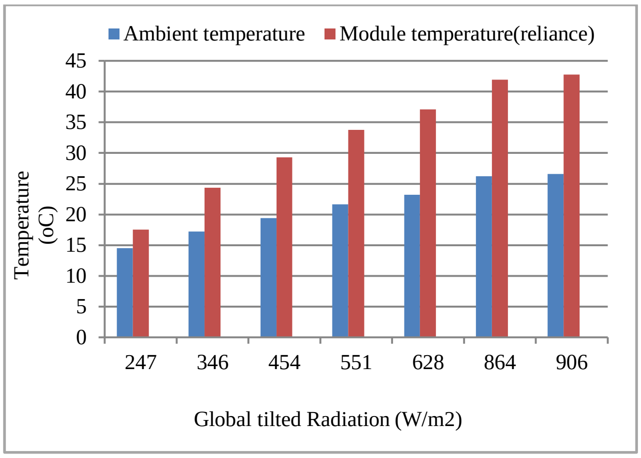

Fig.4 Variation of Global Tilted Radiation (W/m^2) with ambient and module temperature (^{o}C) respectively for RS 1250 Reliance multi- C-Si PV module

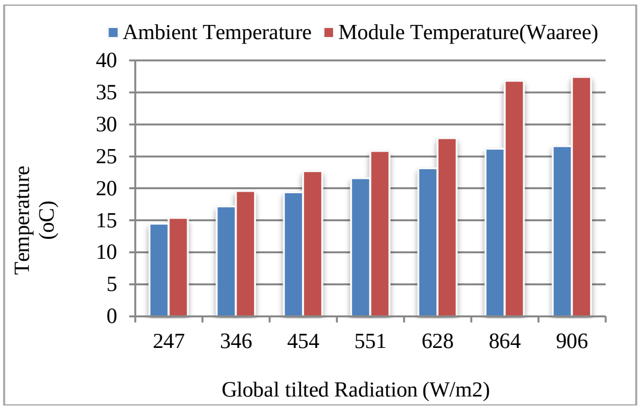

Fig.4 Variation of Global tilted Radiation (W/m^2) with ambient and module temperature (^{o}C) respectively for WS 50 Waaree multi- C-Si PV module

Figure 6 and 7 show the I-V curves of PV modules RS1250 and WS50 respectively in environmental conditions EOC.

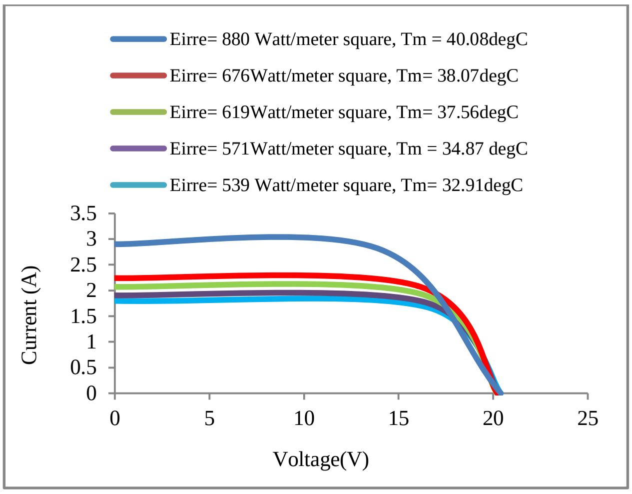

Fig.6WS-50(Waaree) PV module I-V characteristics in outdoor testing

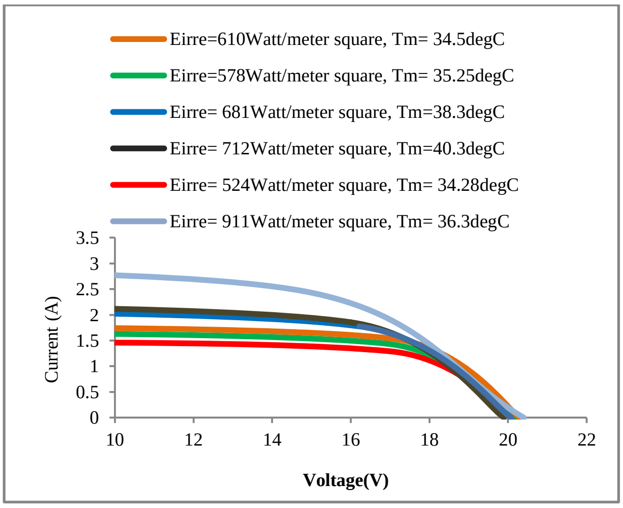

Fig.7 RS-**1250** **(Reliance)** PV module I-V characteristics in outdoor testing

5. Conversion Methods to STC

Some previous studies based on performance of thin films solar cells has been done where the data acquired from environmental operating conditions was converted into solar module output characteristics at standard test conditions by using different methods (Agroui, K *et al* 2011).The data acquired in this study for EOC on a clear sunny day was converted into solar output characteristics in STC by using two conversion methods suggested by J.Anderson and G.Blaesser. The value of irradiance dependency coefficient (μ) is deduced from the literature reference (Marion, B., Kroposki, B. *et al)* Table 4 shows the STC conversion equations

Table 4 STC Conversion methods

I_{sc} Short Circuit Current

Anderson's Method

$$I_{SC,2} = I_{SC,1} \;/\; [1 + \alpha'_m \times (T_1-T_2)] \times [E_2/E_1]$$

Blaesser's Method

$$I_{SC,2} = I_{SC,1} \times E_2/E_1 \times (1 + \alpha'_m \times (T_2-T_1))$$

V_{oc} Open Circuit Voltage

Anderson's Method

$$Voc_{,2} = Voc_{,1}/ [1 + \beta'_m \times (T_1T_2)]\times[1+\mu \times \ln (E1/E2)]$$

Blaesser's Method

$$Voc_{,2} = Voc_{,1} \times (1+Dv)$$
$$Dv = \delta \,\mathrm{Ln}\, (E_2/E_1) + \beta'_m \times(T_2-T_1)$$

I-V Curve

Anderson's Method

$$V_2 = V_1 \times (Voc_{,2} / Voc_{,1})$$
$$I_2 = I_1 \times (Isc_{,2} / Isc_{,1})$$

Blaesser's Method

$$V_2 = V_1 + DV + Rs \times (I_1 - I_2)$$
$$DV = Voc_{,2} - Voc_{,1}$$
$$I_2 = I_1 \times (Isc_{,2} / Isc_{,1})$$

P_{max}, Maximum Power

Anderson's Method

$$Pmax_{,2} = Pmax_{,1} \times E_2/E_1 \times \frac{1}{[1 + \gamma'_m \times (T_2-T_1)][1 + \mu \ln\times (E_2/E_1)]} \times 1$$

Blaesser's Method

$$Pmax_{,2} = FF_2 \times Voc_{,2} \times I_{SC,2}$$
$$FF_2 = FF_1 \times (V_{mp,2} / V_{mp,1})$$

Range of Application

Anderson's Method-Crystalline - Amorphous; Irradiance 100-1000W/m², Module Temperature: 25 -75°C.

Blaesser's Method – Crystalline, Irradiance ≥600W/m².

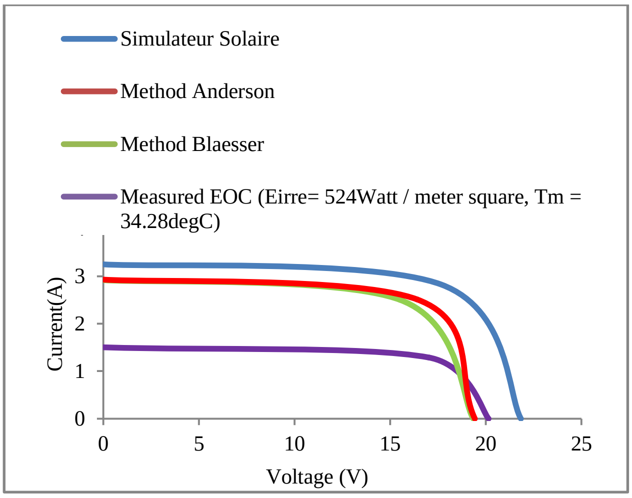

Fig. 8(a)

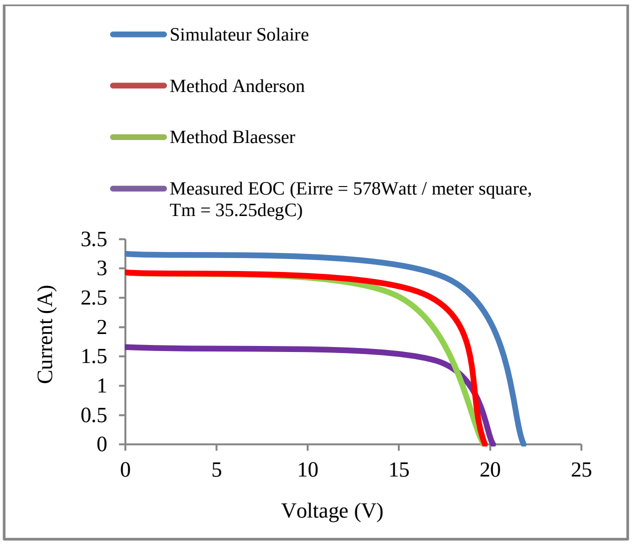

Fig. 8(b)

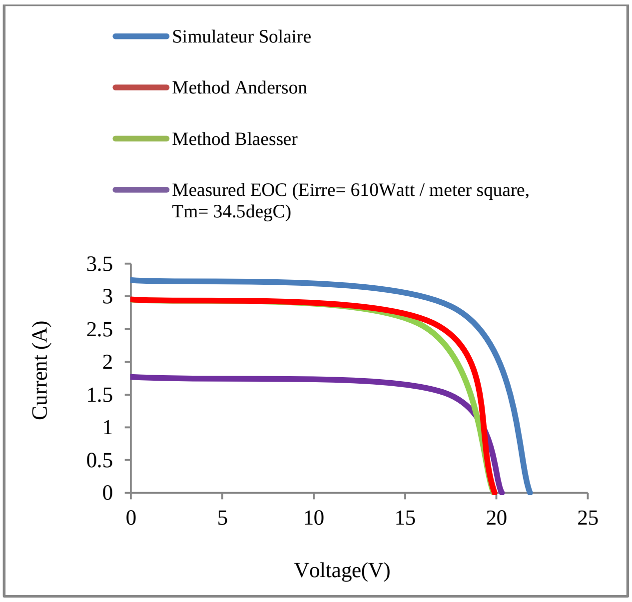

Fig. 8(c)

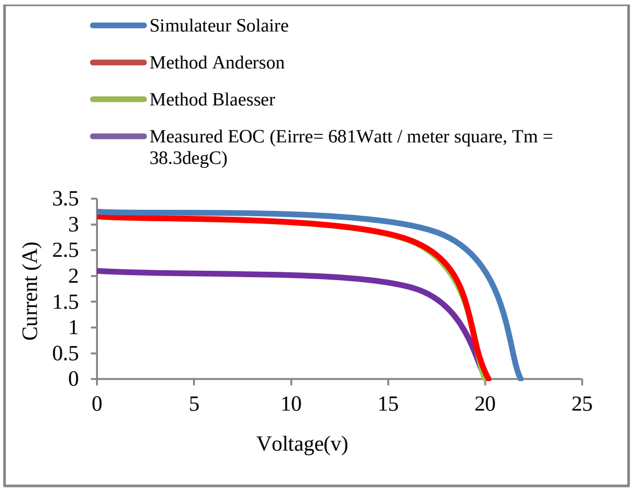

Fig. 8(d)

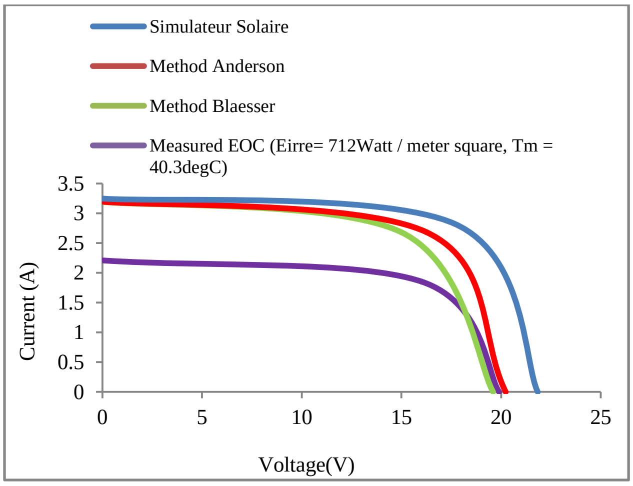

Fig. 8(e)

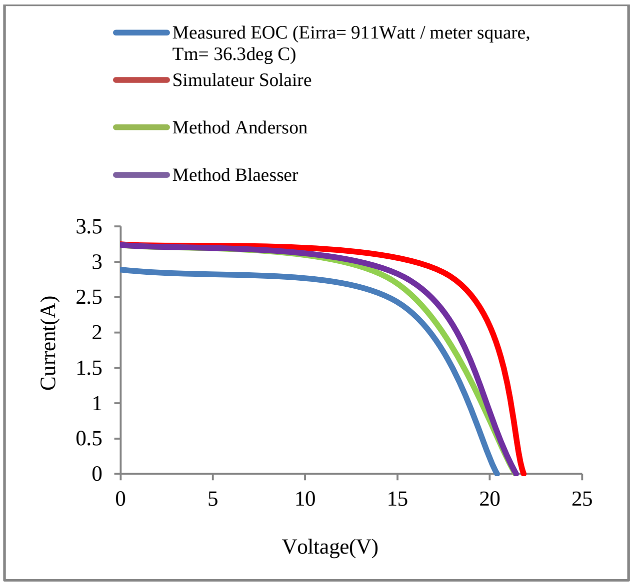

Fig. 8(f)

Figure 8 WS-50(Waaree) PV module I-V characteristics reported to STC conditions based on conversion methods

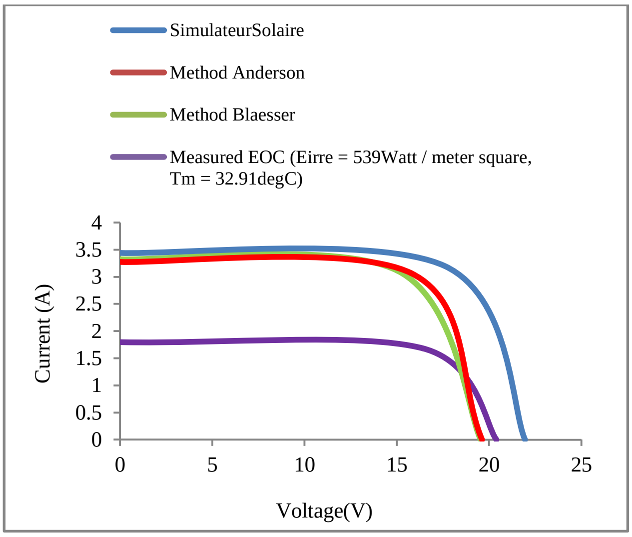

Fig. 9(a)

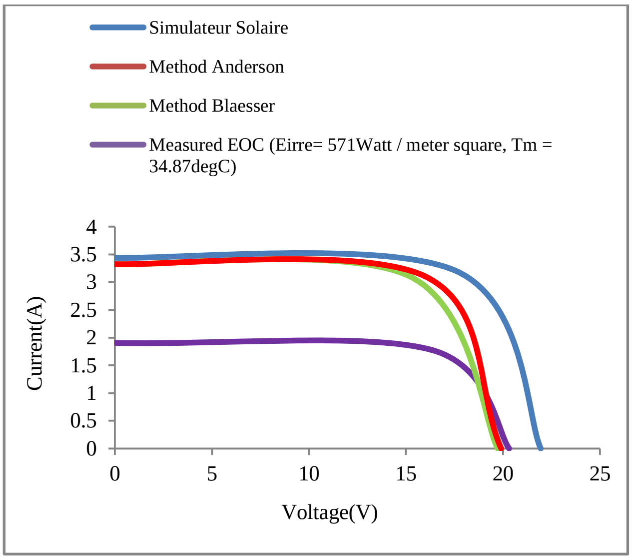

Fig. 9(b)

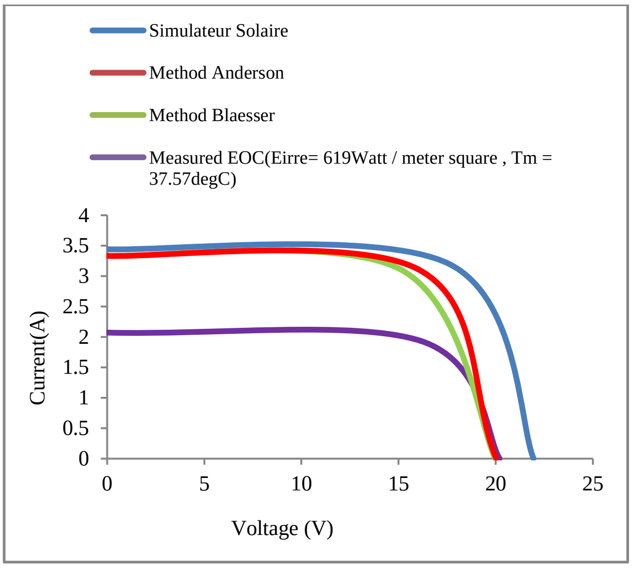

Fig. 9(c)

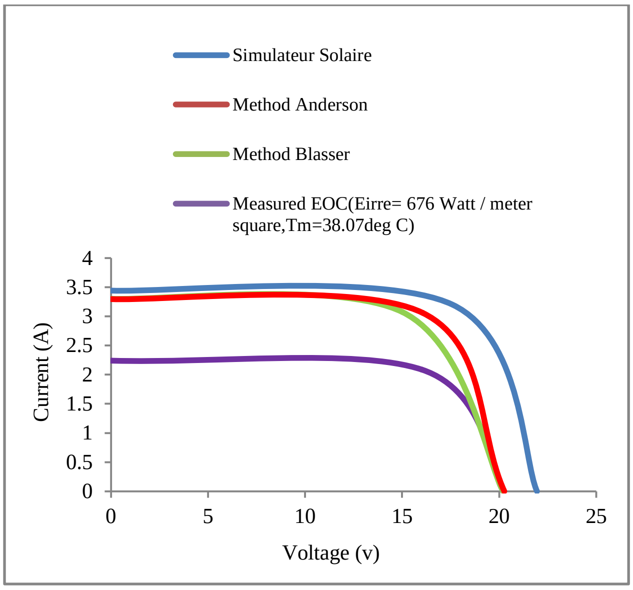

Fig. 9(d)

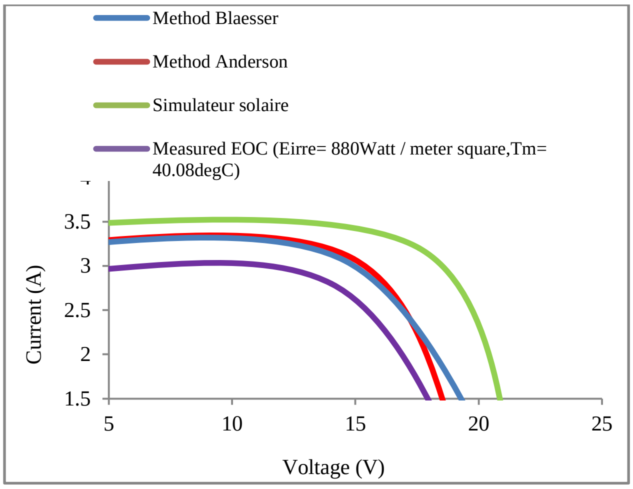

Fig. 9(e)

Fig.9 RS 1250(Reliance) PV module I-V characteristics reported to STC conditions based on conversion methods The results of the translation are summarized in Table 5

Table 5(a) PV module maximum power translated to STC Conditions (E_{ire} =524W/m^2, T_m= 34.28^{o}C)

	Maximum Power of Waaree (W)	Deviation of Maximum Power (%)
Under EOC	21.93	
Under J.Anderson Method	46.07	7.60%
Under G. Blaesser Method	42.43	14.60%
By Solar Simulator	49.90	

Table 5(b) PV module maximum power translated to STC Conditions (E_{ire} =578W/m^2, T_m= 35.25^{o}C)

	Maximum Power of Waaree (W)	Deviation of Maximum Power (%)
Under EOC	24.33	
Under J.Anderson Method	46.21	7.60%
Under G. Blaesser Method	43.67	12.40%
By Solar Simulator	49.90	

Table 5(c) PV module maximum power translated to STC Conditions (E_{ire} =610W/m^2, T_m= 34.5^{o}C)

	Maximum Power of Waaree (W)	Deviation of Maximum Power (%)
Under EOC	26.26	
Under J.Anderson Method	47.01	5.70%
Under G. Blaesser Method	44.35	11.12%
By Solar Simulator	49.90	

Table 5(d) PV module maximum power translated to STC Conditions (E_{ire} =681W/m^2, T_m= 34.28^{o}C)

	Maximum Power of Waaree (W)	Deviation of Maximum Power (%)
Under EOC)	28.76	
Under J. Anderson Method	49.07	1.60%
Under G. Blaesser Method	47.06	5.60%
By Solar Simulator	49.90	

Table 5(e) PV module maximum power translated to STC Conditions (E_{ire} =712W/m^2, T_m= 40.3^{o}C)

	Maximum Power of Waaree (W)	Deviation of Maximum Power (%)
Under EOC	29.65	
Under J. Anderson Method	48.53	2.70%
Under G. Blaesser Method	46.61	6.50%
By Solar Simulator	49.90	

Table 5(f) PV module maximum power translated to STC Conditions (E_{ire} =911W/m^2, T_m= 36.3^{o}C)

	Maximum Power of Waaree(W)	Deviation of Maximum Power (%)
Under EOC	49.00	
Under J.Anderson Method	46.82	6.10%
Under G. Blaesser Method	53.45	7.10%
By Solar Simulator	49.90	

Table 6(a) PV module maximum power translated to STC Conditions (E_{ire} =539W/m^2, T_m= 32.91^{o}C)

	Maximum Power of Reliance(W)	Deviation of Maximum Power(%)
Under EOC	27.65	
Under J. Anderson Method	55.05	2.20%
Under G. Blaesser Method	52.62	6.50%
By Solar Simulator	56.30	

Table 6(b) PV module maximum power translated to STC Conditions (E_{ire} =571W/m^2, T_m= 34.87^{o}C)

	Maximum Powerof Reliance (W)	Deviation of Maximum Power (%)
Under EOC	29.06	
Under J. Anderson Method	54.23	3.60%
Under G. Blaesser Method	53.18	5.50%
By Solar Simulator	56.30	

Table 6(c) PV module maximum power translated to STC Conditions (E_{ire} =619W/m^2, T_m= 37.56^{o}C)

	Maximum Power of Reliance(W)	Deviation of Maximum Power (%)
Under EOC	31.12	
Under J. Anderson Method	52.56	6.60%
Under G. Blaesser Method	54.12	3.80%
By Solar Simulator	56.30	

Table 6(d) PV module maximum power translated to STC Conditions (E_{ire} =676W/m^2, T_m= 38.07^{o}C)

	Maximum Power of Reliance (W)	Deviation of Maximum Power (%)
Under EOC	33.40	
Under J.Anderson Method	51.64	8.20%
Under G. Blaesser Method	54.11	3.80%
By Solar Simulator	56.30	

Table 6(e) PV module maximum power translated to STC Conditions (E_{ire} =880W/m^2, T_m= 40.08^{o}C)

	Maximum Power of Reliance(W)	Deviation of Maximum Power (%)
Under EOC	40.30	
Under J. Anderson Method	53.96	4.10%
Under G. Blaesser Method	54.96	2.30%
By Solar Simulator	56.30	

Table 7 Comparison of PV technologies maximum power translated to STC conditions (CIS and a-Si triple junction solar cell (Agroui, K *et al* 2011) with multicrystalline PV modules)

	Maximum Power of CIS module (W)	Maximum Power of a-Si triple junction module (W)	Maximum Power of Multi C-Si Waaree module (W)	Maximum Power of Multi C-Si Reliance module (W)
Under EOC	32.50	62.50	49.00	40.30
J.Anderson	39.80	78.24	46.82	53.96
G.Blaesser	39.80	79.40	53.45	54.96
Solar Simulator	41.10	79.10	49.90	56.30

Table 8 Comparison of PV technologies deviation from maximum power of (CIS and a-Si triple Junction solar cell (Agroui, K *et al* 2011) with multicrystalline PV modules)

	Deviation of Maximum Power of CIS module (%)	Deviation of Maximum Power of a-Si triple junction module (%)	Deviation of Maximum Power of Multi C-Si Waaree module (%)	Deviation of Maximum Power of Multi C-Si Reliance module (%)
J.Anderson Method	3.10%	1%	6.10%	4.10%
G.Blaesser Method	3.10%	0.40%	7.10%	2.30%

6. Results and Discussion

The **WS 50** PV module (Multi C-Si, Waaree) has an initial P_{max} value which is essentially equal to its rated value. The deviation of maximum power is 6.1% and 7.1% by using *A.J.Anderson* and *G.Blaesser* methods respectively as shown in Table8.

The **RS1250** PV module (Multi C-Si, Reliance) has an initial P_{max} value which is essentially not equal to its rated value. The deviation of maximum power is 4.1% and 2.3% by using *A.J.Anderson* and *G.Blaesser* methods respectively as shown in Table8.

The **ST40** PV module (CIS) has an initial P_{max} value which is essentially equal to its rated value. The deviation of maximum power is 3.1% and 3.1% by using *A.J.Anderson* and *G.Blaesser* methods respectively as shown in Table 8 (Agroui, K *et al* 2011).

For **US64** PV module, the deviation of maximum power is 1% and 0.4% by using *A.J.Anderson* and *G.Blaesser* methods respectively as shown in Table8. (Agroui, K *et al* 2011).

The deviation includes various factors that lower solar module output such as: Effects of spectral changes over time, module temperature, effects of reflection by PV incident angles, effects of solar spectrum according to measurements conditions. (Kenny R.P., Loannides, A., Mullejans, H., Zaaiman, W. and Dunlop, E.D. 2006).

Conclusions

These tests have shown that the STC values quoted by manufacturers for their multi C-Si PV modules do not necessarily match those observed in STC measurements.
So far the measured maximum power values have not remained within the values guaranteed by the manufacturers, for multi C-Si waaree module there are significant differences found among the conversion equation methods in P_{max} deviation as compared to multi C-Si Reliance module. It is seen that for lower values of radiation, the deviation in the maximum power is more as compared to higher values of radiation for Blaesser method.

One of the reasons is that the Blaesser method is applicable for crystalline PV modules having irradiance ≥ 600 W/m^2. Other reasons include not only various factors that lower solar module output such as: Effects of spectral changes over time, module temperature, effects of reflection by PV incident angles, effects of solar spectrum according to measurements conditions (Kenny R.P., Loannides, A., Mullejans, H., Zaaiman, W. and Dunlop, E.D. 2006) But also the Light Induced Degradation (LID) in Crystalline Silicon.

In IEC 61215 Preconditioning **-** Qualification for C-Si modules requires 5 hours of preconditioning at 1000 W/m^2 prior to power output measurement.

Light Induced Degradation may also be present in upgraded metallurgical grade or low cost silicon. The effects of light exposure on different PV module technologies including a-Si, CIS, CdTe and C-Si which include addressing : the physical mechanisms of light induced changes in each PV technology, long term light induced degradation effects and knowledge of PV module preconditioning for accurate power output determination have been studied (Gostein, M. and Dunn, L. 2011). As light exposure of PV modules can produce a variety of effects including reversible metastable phenomena which influence the accuracy PV module power output determination and long term phenomena which effect power output stability of installed modules.

Nomenclature

E **:** Irradiance (W/m^2)
T **:** Temperature (deg C)
FF **:** Fill Factor(%)
Rs **:** Module series resistance (Ω)
α'_m **:** Reduced Temperature Coefficient of I_{sc}
β'_m **:** Reduced Temperature Coefficient of V_{oc}
γ'_m **:** Reduced Temperature Coefficient of P_{max}
μ **:** Irradiance Dependency Coefficient
P **:** Power (W)
I **:** Current (A)
V **:** Voltage (V)
EOC **:** Environmental Operating Conditions
STC **:** Standard Test Conditions
PVPM: Peak Power Measuring Device Tracer
SEC **:** Solar Energy Centre
SRC **:** Standard Rating Conditions
LID **:** Light Induced Degradation
1 and 2: represent conditions at a specific irradiance and cell temperature**.**

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