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Characterization of Multi Crystalline PV Modules under Standard Test Conditions and its Comparison with other Module Types

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ABSTRACT

Photovoltaic modules based on the relatively high efficiency crystalline technology are gaining importance in the photovoltaic market. Improving module performance is driven by a focus on lifetime yields and requirements of space – constraints sites. The materials used not only in thin film technologies but also crystalline pose problems in terms of measuring how much power is generated under STC. The fact that the modules power rates vary depends both on the amount of time they have been exposed to the sun and on their history of sunlight exposure in order to know the current state of the module. It is necessary to determine an easily accomplishable testing method that ensures the repeatability of the measurements of the power generated. This is essential because in order to have a reliable sample of the PV module population of a large PV plant, a huge no of modules must be measured. This paper shows different tests performed on different commercial crystalline PV modules both multi and mono, in order to find the best way to obtain measurements. A correlation was tested between sun exposure and power measured. A method for obtaining indoor measurements that takes periods of sunlight exposure into account is proposed. Also, temperature and irradiance coefficients were also determined for different technologies in order to obtain accurate measurements. 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.

Keywords – Crystalline PV Module, CdTe, Light Soaking, power conditioning, thin film.

I. INTRODUCTION

Crystalline Silicon Modules to dominate Solar PV Industry by 2014. A new report from NPD Solar Buzz states that the production of multi crystalline silicon (C-Si) solar photovoltaic (PV) modules is set to dominate the PV manufacturing industry by 2014, with p-type multi C-Si technology accounting for 62% of all modules produced.

According to the report, solar PV manufacturers are gearing up to increase module production by 25%in 2014, up to 49.7GW of modules compared to 39.7 GW produced in 2013.

PV manufacturers continue to prioritize cost reduction across the entire C-Si value chain, with improvements in efficiency coming mainly from high quality multi C-Si wafers.

2014 Solar PV Module production by Technology

C-Si p type Multi Standard	35%
C-Si p type Multi advanced	35%
C-Si p type Mono Standard	35%
C-Si p type Mono advanced	35%
C-Si n type	6%
CdTe (First Solar)	4%
CIS/ CIGS (sputter)	2%
a-Si Glass	2%
All others	1%

The main challenge for C-Si modules is to improve the efficiency and effectiveness of resource consumption through materials reduction, improved cell concepts and manufacturing automation.

Multi C-Si modules have a more disordered atomic structure, leading to lower efficiencies, but they are less expensive and more resistant to degradation due to irradiation. The degradation rate is about 2% per year for multi crystalline technologies. This efficiency is expected to reach 21% in the long term. C-Si PV modules are expected to remain a dominant PV technology until at least 2020, with a forecasted market share of about 50% by that time (Energy

Technology perspectives 2008). This is due to their proven and reliable technology, long lifetimes and abundant primary resources. The main challenge for C-Si modules is to improve the efficiency and effectiveness of resource consumption through material reduction, improved cell concepts and manufacturing automation.

Figure 1 The Photovoltaic Testing Facility Lab of National Institute of Solar Energy at Gurgaon, Haryana, India

The Photovoltaic Testing Facility Lab of National Institute of Solar Energy at Gurgaon, Haryana, India forms the core research group.
During the past years, an important no of PV module installers have asked NISE (PVTF Section) about a reliable method of indoor and outdoor testing crystalline PV modules in order to verify their properties under standard test conditions (STC).
NISE (PVTF) has a significant experience in measuring silicon PV modules and is developing this type of testing method.
This paper presents a method to determine the actual power generated by different crystalline technologies in order to determine the relationship between indoor and outdoor tests. In these kinds of PV modules, the effect of light soaking must be taken into account. In order to create a reliable indoor test, it is necessary to take into account the PV modules history of sunlight exposure as well as the light spectrum and the sunlight activation effect.

II. OBJECT OF ANALYSIS

Different technologies have been analyzed all of them based on thin film technology[1],the main object is to find the best method to obtain the I-V parameters of a PV module at STC in the easiest way. These technologies sometimes need to be preconditioned and also different corrections must be applied.

2.1 INFLUENCE OF LIGHT SPECTRUM IN DIFFERENT TECHNOLOGIES

The IEC 60904-1 standard established the general method for measurement of photovoltaic current-voltage characteristics [2] and besides this, the IEC 60904-3 standard established the spectral distribution of the light that should be used when a measurement of the electrical characteristics of a PV module is made. It is known as 1.5AM and the actual spectral distribution of the sunlight should be measured in any electrical test of a module under sunlight exposition.

Sometimes it is not possible and it is very difficult to assure 1.5AM spectral distribution both indoors and outdoors [3]. Nevertheless using sunlight the spectral distribution is not as stable as indoors therefore into a solar simulator the repeatability of the measurement is easier to achieve [4]. In this case the problem is reduced to take periodically a measurement of the light spectrum inside the simulator.

Each technology has a different spectral response (Fig.2). As the measurement of the electrical characteristics must be translated to STC, a spectral correction must be applied [5]. It usually means that the obtained current has to be multiplied by a spectral factor that depends on the spectral response of the technology under analysis and the spectral distribution of the light.
It is also possible to use a calibrated cell of the same technology and type of the PV module under analysis for the control of the light of the simulator. In this case the problem is that changing this cell often could imply a risk in the repeatability of the measurements of the solar simulator. For this reason a spectral correction for each technology is preferred.

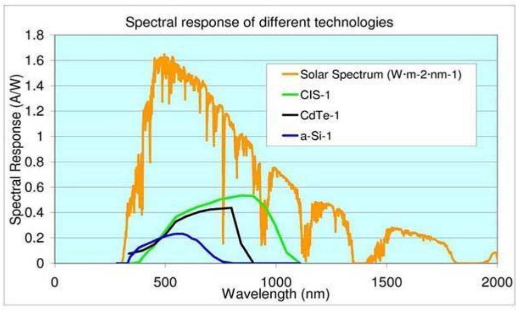

Figure 2 Typical spectral responses of different thin film technologies and AM 1.5 spectral distribution

As clear from the above figure, the a-Si modules (blue curve) has its spectral response in the narrow band of about 300nm-800nm. CdTe (black) and CIS (green) show similar curves with SR values from

350-1000nm. These results obtained by the Rural Engineering Department, Electrotechnical Section, EUITA Agricola, UPM, Madrid, Spain were similar to the results obtained by the TUV Rheinland (Arizona).

As to study the spectral response of different specimens, previously TUV Rheinland had configured a unique measurement station to determine the spectral response on a module basis, where the system allows non destructive measurement of single and multi junction modules in a wavelength range between 300nm to 1200nm and in wavelength intervals of 1nm. As expected, the results showed significant differences between the different single - junction and multi junction PV module technologies. The SR curve of a CIGS module falls into the same range as those of C-Si modules (350nm-1200nm), but for some CIGS modules, the SR data attains values higher than 1200nm. Due to this situation, the classification of IEC 60904-9 (up to 1100nm) may be insufficient for some module flasher combinations [6].

2.2 INITIAL DEGRADATION IN CRYSTALLINE SILICON

In mono C-Si, based on field exposure and failure of degraded modules, more stress is laid on providing valuable information toward later standards such as module qualification standard IEC 61215[7,8].

Because crystalline Si technology is the oldest module technology, several outdoor studies exceeding 20 years can be found [9,10, 11,12-15,16-25,26,27,28], Quintana et al [29] documented the increased degradation rate for an entire system compared with module degradation. The module degradation rate was a remarkable 0.5% per year; however the system degradation rate was much higher 2.5% per year.

Osterwald et al [30] made similar observations for a set of two monocrystalline and two multi crystalline modules. The rapid initial degradation was attributed to oxygen contamination in the bulk of silicon junction, whereas the slow long term degradation correlated linearly with ultraviolet exposure. However it appeared unlikely that the slow loss was due to EVA, browning [30]. Sakamoto and Oshiro [31] confirmed similar findings through the inspection of more than 2000modules, 150 of which were studied in more detail. The average degradation rate was less than 0.5% per year with dominant losses in fill factor (FF) and Isc [32].

D. L. King found a medium degradation rate of 0.5% per year in a mono Si system and traced the decline to the solder joints in the modules [33]

In another study, Wohlgemuth with his co workers did an extensive survey of field returns of more than 4000 modules and found that more than 90% of field failures were caused by corrosion and interconnect breakage [34].

Significant variations have been observed when comparing the first year initial degradation results obtained at AM 1.5 (morning and afternoon) and during the noon (high irradiance) using the same normalization technique of manufacturer temperature coefficient (Y_{mpp}) and solar simulator DC power.

All technologies showed lower losses when comparing the power as the day progressed which can be attributed to the spectral changes during the day. Mono and Multicrystalline technologies showed deviations up to 6% and 3% respectively whereas thin film up to 5% when all the normalization techniques were considered for noon extracted data sets; it was clear that worth CIGS system showed no degradation over the first year. Multicrystalline technologies showed lower average degradation, 1% in comparison to the average high efficiency mono-crystalline and thin film degradation of 4%.

2.3 LIGHT ACTIVATION IN CRYSTALLINE – SILICON AND OTHER TECHNOLOGIES (CIS/CIGS, CdTe)

2.3.1 In C-Si

Discussion of light–induced metastabilities typically focuses on thin film materials, but PV devices using boron doped Czochralski-grown monocrystalline silicon (Cz-Si) also exhibit an initial light induced degradation effect, corresponding to ~4% power output degradation during the first ~5 hrs of light soaking [35,36], the effect is reversed upon anneal or dark storage. It is due to the light induced activation of a metastable boron-oxygen defect which looses carrier lifetime.

The effect can be greatly reduced using either Ga doped Cz-Si or low oxygen content-Cz-Si [35]. The effect is not present in cast multi – crystalline silicon (mc-Si) devices, which have lower oxygen impurity, although the efficiencies of these devices are somewhat lower and therefore similar to those of Cz – Si following light soaking. The IEC61215 qualification procedure for crystalline silicon PV modules requires a 5 hour light soak prior to testing, which ensures that Cz-Si modules are stabilized.

2.3.2 In CIS/ CIGS

PV modules based on CIS or CIGS technology present an effect of light activation after light soaking that allows recovering the efficiency lost

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during a period in dark conditions known as dark aging [37].

That is the reason why previously to a measurement of a PV module of this technology it must be exposed to sunlight for at least one hr at ~ 1000W/m^2. Besides the effect of light activation, an initial loss of power or power stabilization that cannot be recovered with light soaking is present. To obtain a correct measurement of a CIS PV module, this stabilization should be achieved. This can be performed storing the module in dark conditions for ten days and reactivating it by means of light soaking after this initial period. Further periods of dark will decrease the efficiency of the PV module but in this case the effect will be reversible by means of light soaking cycles.

2.3.3 In CdTe

Different studies have showed the light activation effect that occurs in Cadmium Telluride PV modules [38].This effect consists of an increase in the maximum power that the PV module can supply after it has been exposed to sunlight for some hours.

The difference in power before and after exposure depends on the thickness of the cell [39] and affects to $V_{oc.}$ The effect is similar to that described for CIS PV modules but in this case the power decrease more rapidly when the module is situated indoors. This can pose a problem when indoor measurements are going to be obtained.

In order to determine the power that a module could lose during the first days of operation a sample module should be exposed to sunlight in order to accumulate from 20KWh/m^2 to 40 KWh/m^2 according to EN50380 [40] and measurements must be taken before and after exposure in the same conditions (after been stored in dark conditions for a week).

For each PV module the light soaking effect must be taken into account and it should be exposed to direct sunlight for at least 4 hrs before a measurement is taken outdoors or indoors.

III ANALYSIS PROCEDURE

3.1 PV MODULES DESCRIPTION

The tested PV modules are based on two multicrystalline and two monocrystalline PV modules from **WAAREE** and **RELIANCE** manufacturers and **REIL** and **PREMIER SOLAR** manufacturers respectively.

For Multicrystalline PV modules

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-	Serial No-
MM 100402237	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 –	No of Cells –
36/ Multi C-Si	36/ Multi C-Si
P_{max} - 50W, V_{oc}-21.6V,	P_{max} - 50W, V_{oc}-21.0V,
I_{sc}-3.25A	I_{sc}-3.17A

For Monocrystalline PV modules

The area of each solar cell is 119.43cm^2. Solar cells are arranged in 9×4series-parallel connected cells configuration.

Specifications given by the manufacturers of **REIL** and **PREMIER SOLAR**

M/S - REIL	**M/S - PREMIER SOLAR**
Module No – 75W36	Module No – PSS1275
Serial No-	Serial No-
200952888	NSM130589549
Module Area- 103.5×53.4	Module Area- 103.5×53.4
Cell Area- 119.43	Cell Area- 119.43
No of Cells –	No of Cells –
36/ Mono C-Si	36/ Mono C-Si
P_{max} - 75W, V_{oc}-22V,	P_{max} - 75W, V_{oc}-22V,
I_{sc} - 5A	I_{sc} - 5A

3.2 PRECONDITIONING OF MODULES

Before starting the tests, preconditioning is done by exposing all the crystalline PV modules to sunlight to an irradiation level of 5 KWh/m^2 to 5.5 KWh/m^2 while open circuited.

This preconditioning is applied to fit the conditions that manufacturers indicate for their PV modules and it must be taken into account that measurements should be done in a very short time after the preconditioning, otherwise module could lose the activated state and the measurements would not be valid.

3.3 INDOOR MEASUREMENTS

In order to obtain a repeatable measurement of the I-V characteristic curve, a calibrated ENDEAS

QUICKSUN 700A solar simulator was used. I-V curve measurement was performed according to IEC 61215 what permits to obtain main parameters Isc, Voc, Im, Vm, Pm and FF at STC.

- Irradiance 1000W/m^2
- Cell Temp : 25°C
- Spectral Distribution: AM 1.5G
- Normal Incidence

Figure 3 ENDEAS QUICKSUN 700A solar simulator

Table 1 Multi Crystalline 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

Table 2 Mono Crystalline PV modules performances at STC Conditions

PV Module	Pmax (W)	Isc (A)	Voc (V)	Rs (Ω)	Rsh (Ω)	η (%)
Reil 75W36	77.8	5.65	22.59	524	57	12.7
Premier Solar PSS1275	75.6	4.88	23.07	477	127	14.3

The initial stabilization of the electrical characteristics should be taken into account before the measurement of maximum power at STC. This initial power loss typically can be around higher usually may appear in the first months of use.

Module Outdoor Testing In Composite Climate

The outdoor measurements were performed in the site of National Institute of Solar Energy, 19th Milestone Gwalpahari, Gurgaon–Faridabad Road, Haryana, as specific composite climate environment, characterized by high irradiation and temperature levels. The geographic characteristics of NISE site are North latitude 28.4700°N, East Longitude 77.0300°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°) at local solar noon. The bottom edge of the module is 0.6m above the horizontal plane i.e., ground level as illustrated in Fig4 and5.

Figure 4 PV modules of Reliance and Waaree in outdoor exposure

Figure 5 PV modules of Reil and Premier Solar 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 Fig

Figure 6 Peak Power Measuring Device Tracer (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.

3.4 INITIAL STABILIZATION

In this study four crystalline modules, two multi and two mono were exposed to sunlight in order to achieve its stabilized state.

The results of all the PV modules can be observed in the given Figures

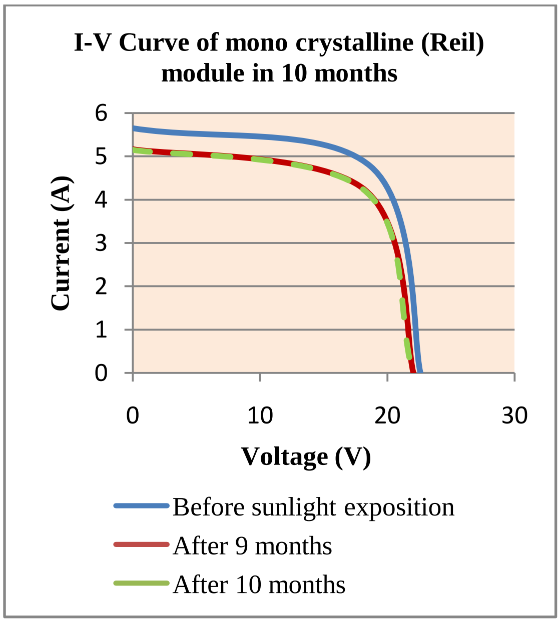

Figure 7 Initial power stabilization in mono crystalline (Reil) module tested in NISE

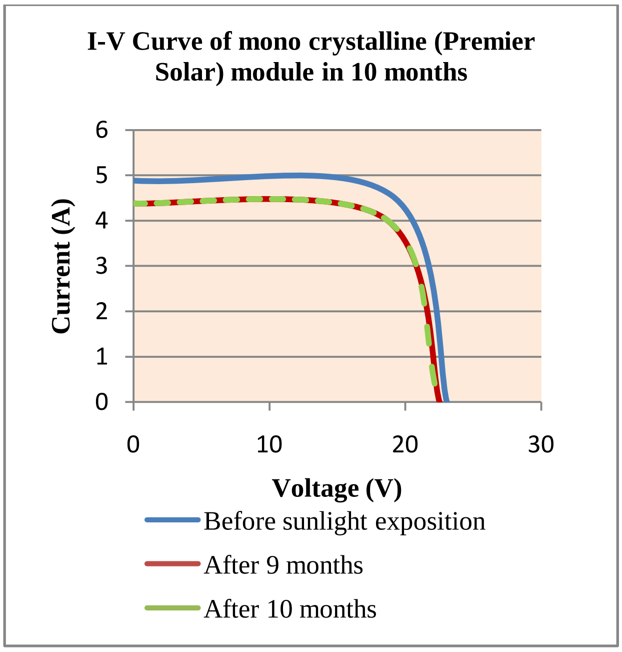

Figure 8 Initial power stabilization in mono crystalline (Premier Solar) module tested in NISE

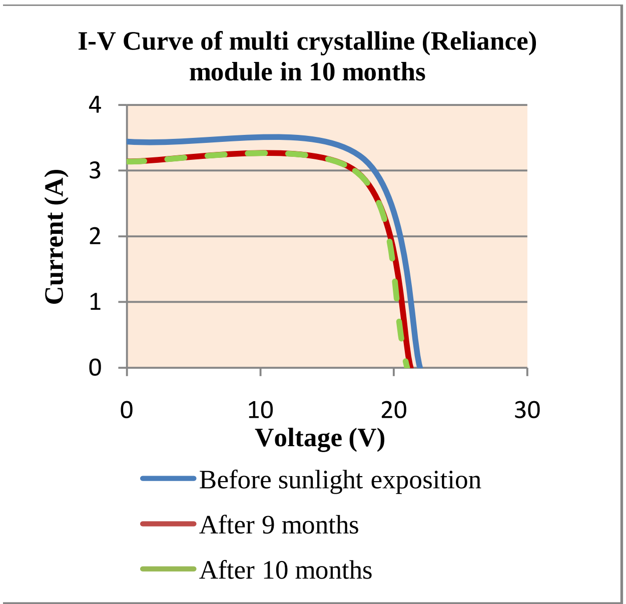

Figure 9 Initial power stabilization multi crystalline (Reliance) module tested in NISE

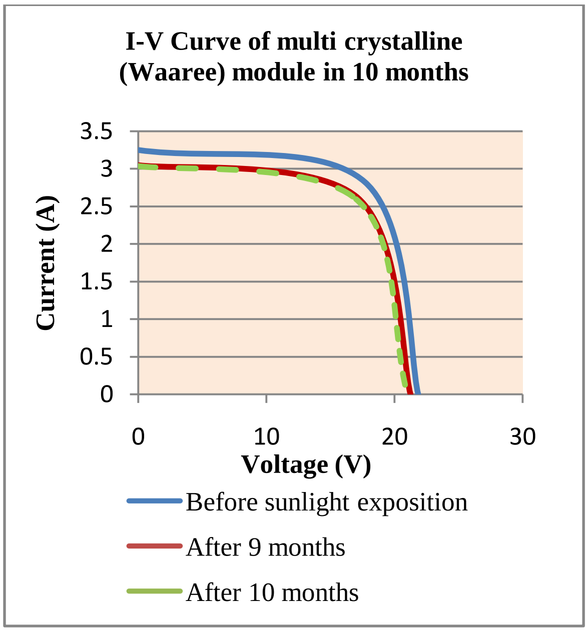

Figure 10 Initial power stabilization of multi crystalline (Waaree) module tested in NISE

The results of all the modules can be observed in the above figures. Measurements of the electrical characteristic were taken periodically in order to determine if the stabilized power was achieved. Manufacturers of C-Si PV modules trend to assure a maximum power loss by year that is referred to the stabilized power.

3.5 TEMPERATURE COEFFICIENTS FOR C-Si

Besides the non stability of module performance, spectral response, in order to explain the significant differences in the performance of different PV module types we must take clear look at characteristics like temperature dependence [41]. Laboratory and outdoor measurements have shown substantial differences in the temperature and low irradiance behavior of the different technologies.

The method to obtain temperature coefficients must take into account that only temperature should vary during the test. Besides, in C-Si technology the activation effect due to sunlight must be considered.

For this reason it is not allowed to shadow the module to reduce the temperature but a mechanism based on watering was used. The modules were refrigerated using water on its front side until it reached a temperature below 25°C. Later on, measurements of irradiance, temperature and variable under test (Voc or Isc), were obtained every 10s for 15 min.

During this time the temperature increased from about 25°C to 50°C. A day with no clouds and the central hours of the day were chosen. The test was performed over 2 different C-Si module technologies. In the next figure, the results of the test over all the C-Si PV modules are shown.

The temperature coefficient for Isc must take into account the stability of the irradiance during the test. As the irradiance is registered the Isc is adjusted to what would be obtained at $1000W/m^2$ in order to avoid its influence.

Outdoor Measurements of Effective temperature Coefficients for Crystalline PV module

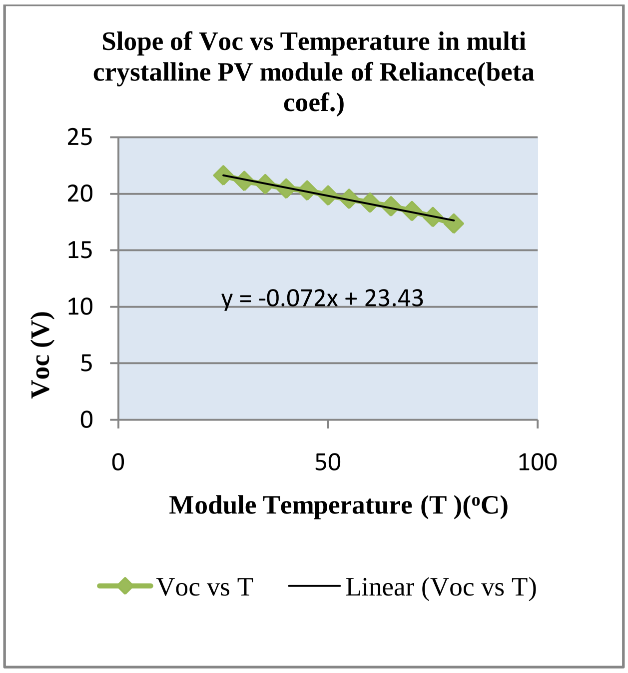

Figure 11 Temperature coefficient for Voc of Multi C-Si PV module of Reliance (beta coef)

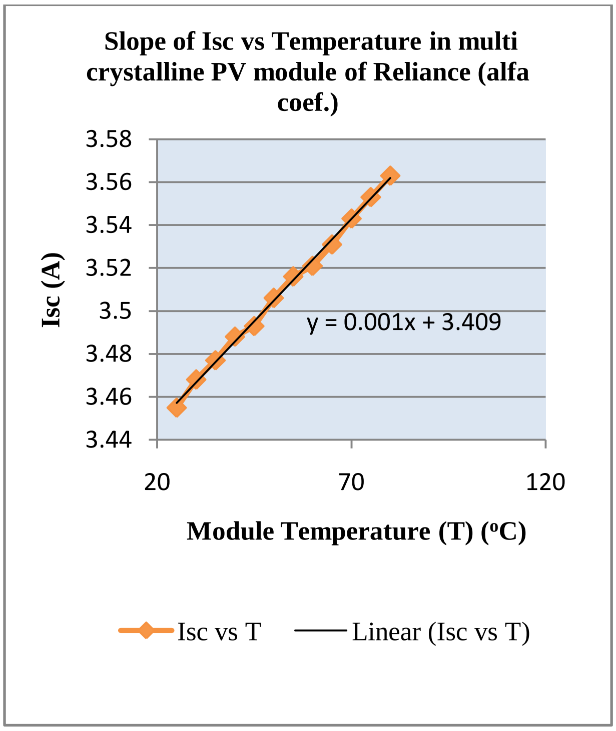

Figure 12 Temperature coefficient for Isc of Multi C-Si PV module of Reliance (alfa coef)

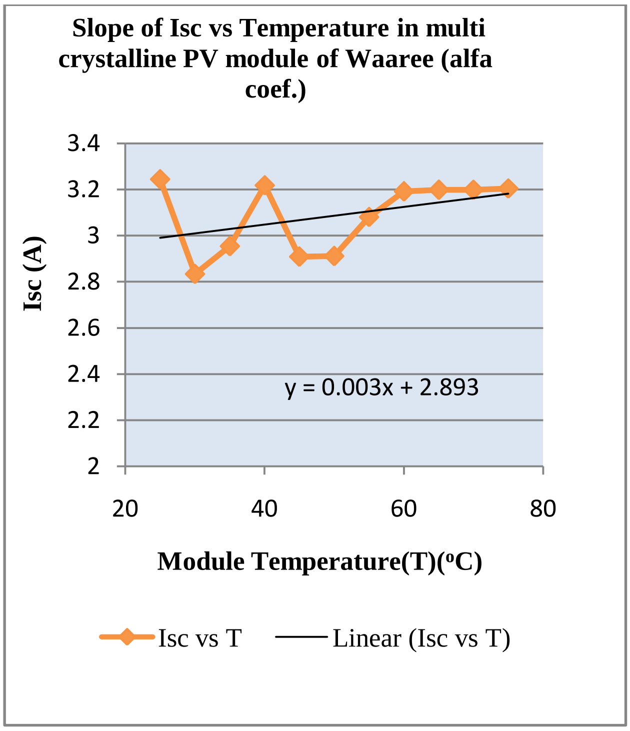

Figure 14 Temperature coefficient for Isc of Multi C-Si PV module of Waaree (alfa coef)

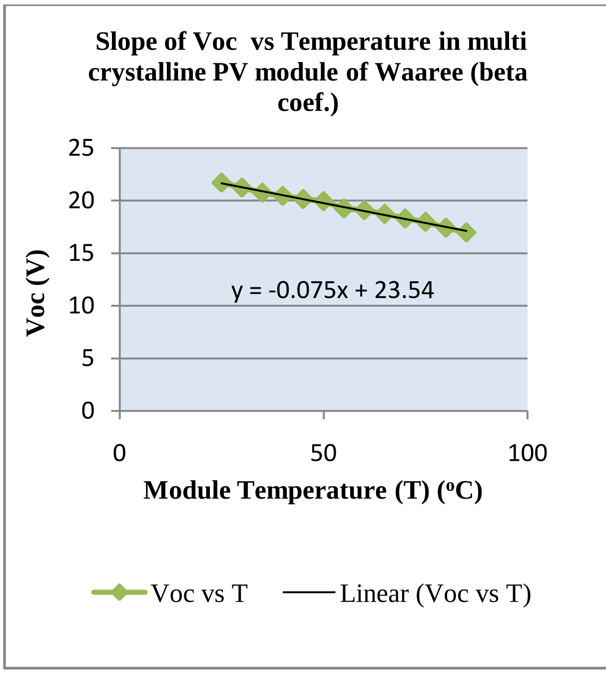

Figure 13 Temperature coefficient for Voc of Multi C-Si PV module of Waaree (beta coef)

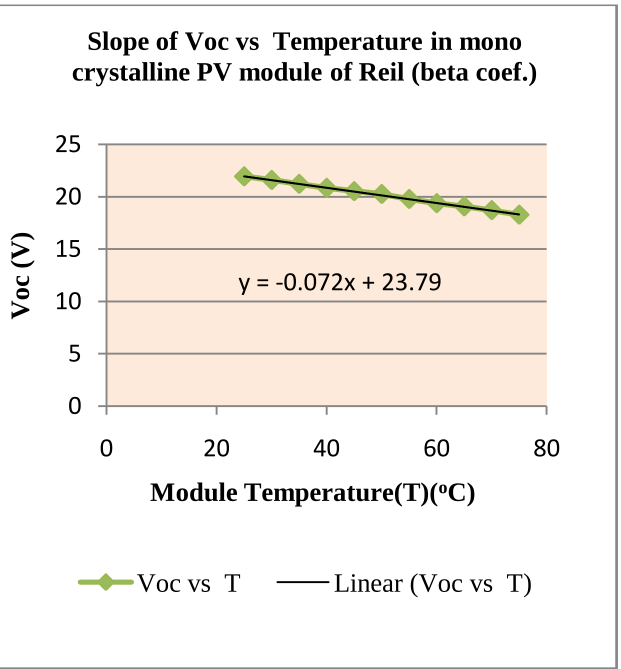

Figure 15 Temperature coefficient for Voc of Mono C-Si PV module of Reil (beta coef)

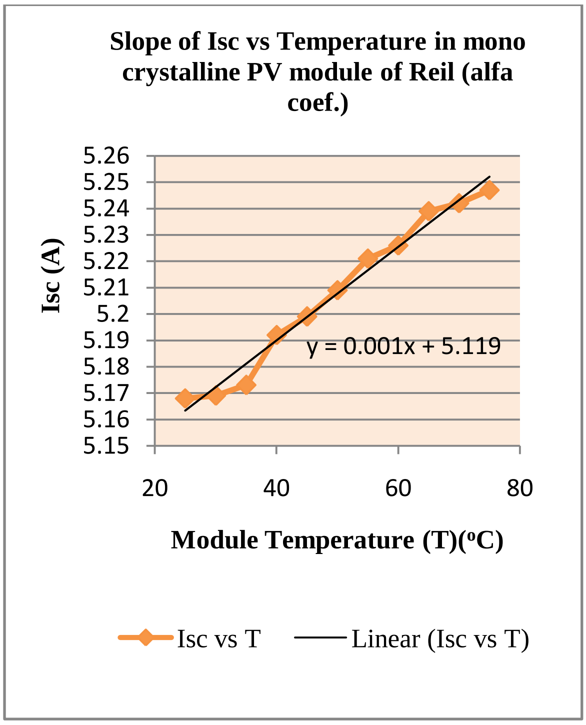

Figure 16 Temperature coefficient for Isc of Mono C-Si PV module of Reil (alfa coef)

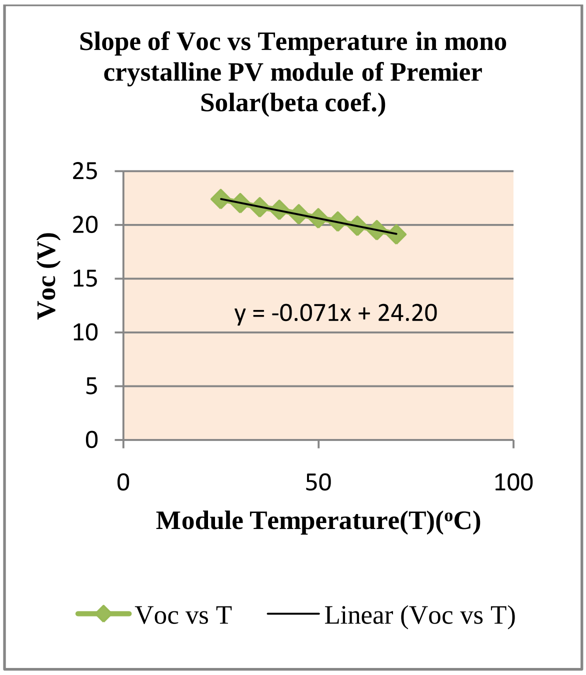

Figure 17 Temperature coefficient for Voc of Mono C-Si PV module of Premier Solar (beta coef)

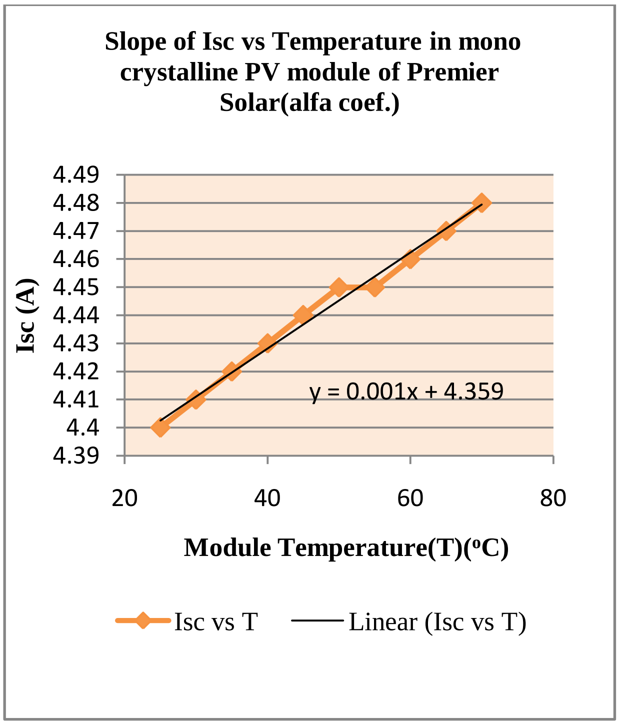

Figure 18 Temperature coefficient for Isc of Mono C-Si PV module of Premier Solar (alfa coef)

In a-Si and CIS technologies temperature coefficients are better known than in CdTe. For this reason these coefficients were obtained at CIEMAT for CdTe [1].

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 irradiance level at which these are measured for the module.
Temperature coefficients of PV module are typically measured indoors, 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 temperature and then calculating the rate of change of the desired parameter with temperature.

3.6 OUTDOORS AND INDOORS MEASUREMENTS FOR C-Si

Indoor measurements were taken after a period of sunlight activation exposing the PV module to direct incidence of sunlight in a sunny day for at least four hours including the central hours of the day. The temperature was reduced before the indoor test using water refrigeration, watering the PV module just before the measurements.

In order to determine the accuracy of indoor measurements a set of outdoor measurements were committed.

Four modules of two different technologies were tested under conditions very close to STC. The method to assure a stable temperature close to 25^{o}C consisted of several water circulation or flow on the module. Once the module had a stabilized temperature around 25^{o}C and the irradiance was close to 1000W/m^2 four measurements were taken in order to determine if all of them were well obtained. Despite of conditions were very close to STC, these measurements were extrapolated to STC using the irradiance and temperature coefficients.

Finally outdoor measurements were compared to measurements taken indoors. It must be noticed that both measurements (outdoors and indoors) were obtained after a period of at least five hours of sunlight exposition of the modules in order to achieve the light activation state of them.

It can be observed in the given figure below that when the explained coefficients are applied, measurements taken outdoors and indoors are quite similar and differences around 1% in Pm indicate this situation.

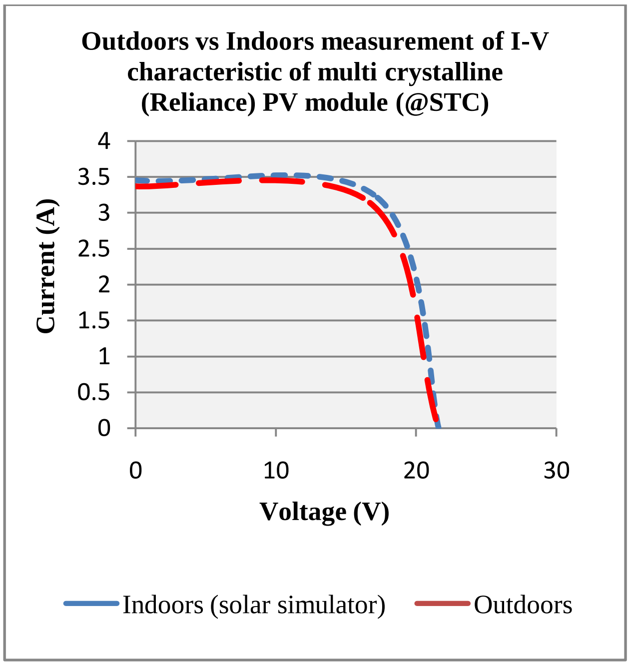

Figure 19 Comparison of outdoor and indoor measurement of I-V characteristic of multi crystalline (Reliance) PV module at STC after sunlight activation

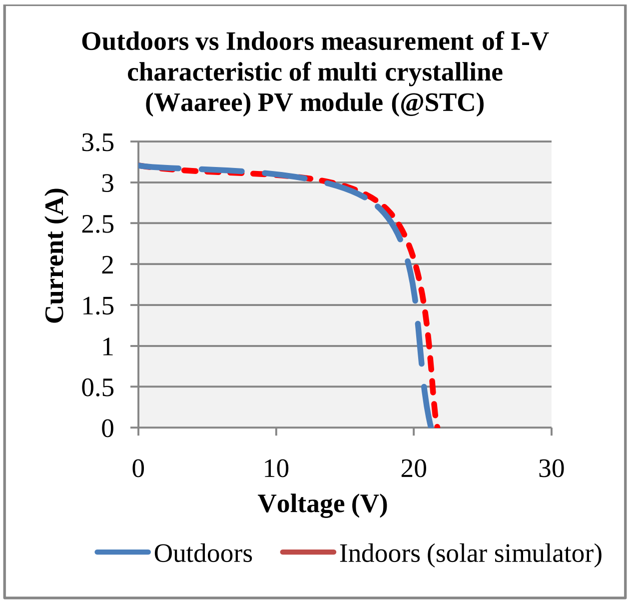

Figure 20 Comparison of outdoor and indoor measurement of I-V characteristic of multi crystalline (Waaree) PV module at STC after sunlight activation

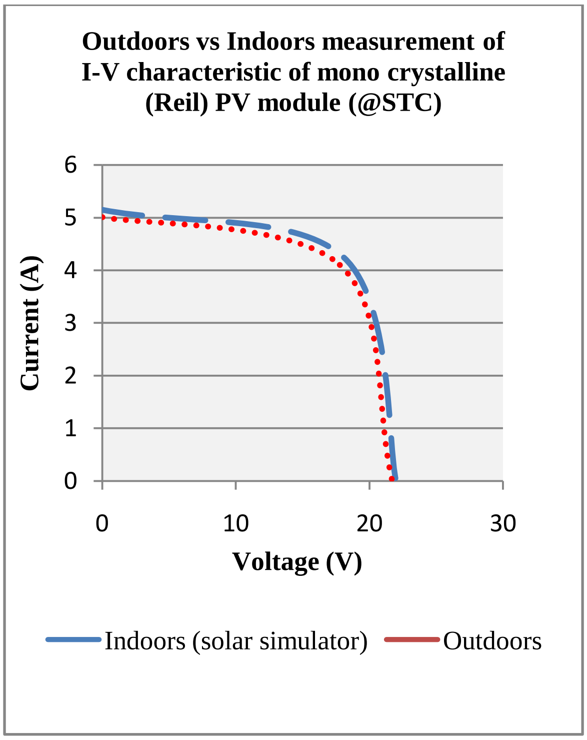

Figure 21 Comparison of outdoor and indoor measurement of I-V characteristic of a mono crystalline (Reil) PV module at STC after sunlight activation

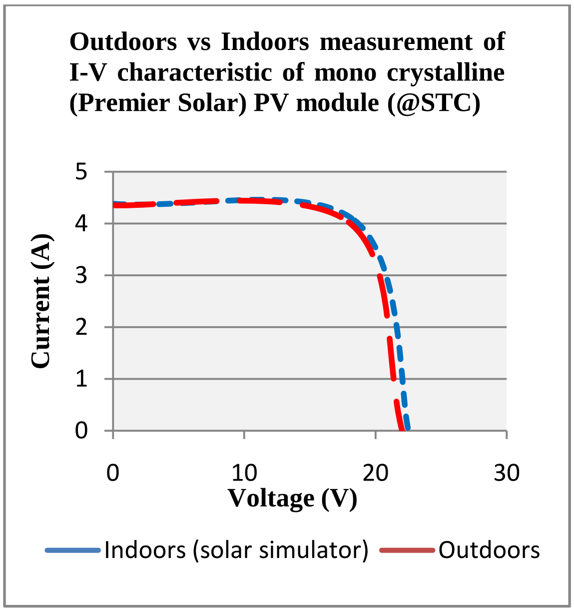

Figure 22 Comparison of outdoor and indoor measurement of I-V characteristic of a mono crystalline (Premier Solar) at STC after sunlight activation

3.7 TEST OF TIME FOR DEACTIVATION IN C-Si

This test was performed indoors due to the fact that a comparative analysis was necessary instead an exact measurement of the actual power in order to determine the time that could pass after the sunlight activation until a power measurement is taken. Nevertheless prior to the measurements indoors every module under analysis was preconditioned by being exposed to sunlight in a sunny day for at least four hours and its temperature was reduced using the same method explained before for outdoor measurements (watering).

Many tests were performed successfully over two monocrystalline PV modules. The performance of each PV module was not always the same but in all of them a Pm and Voc loss was detected as the time passed.

In the next, it can be seen how PV module power decreases as time passes.

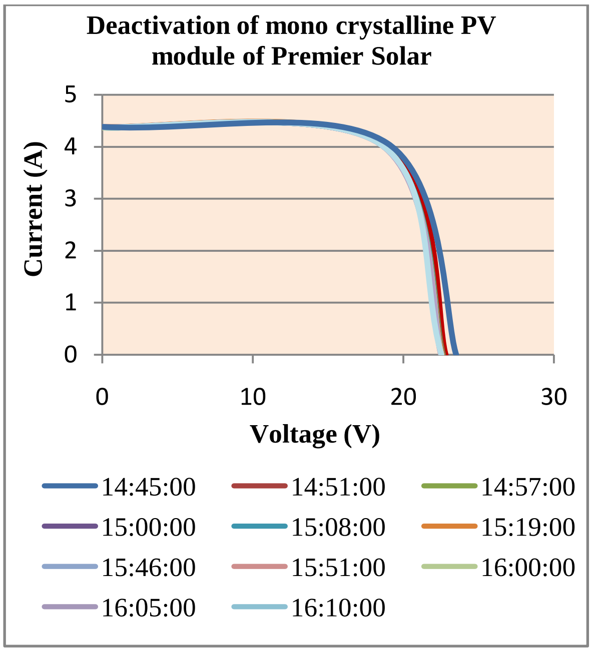

Figure 23 Deactivation of mono crystalline PV module of Premier Solar along 2 hours

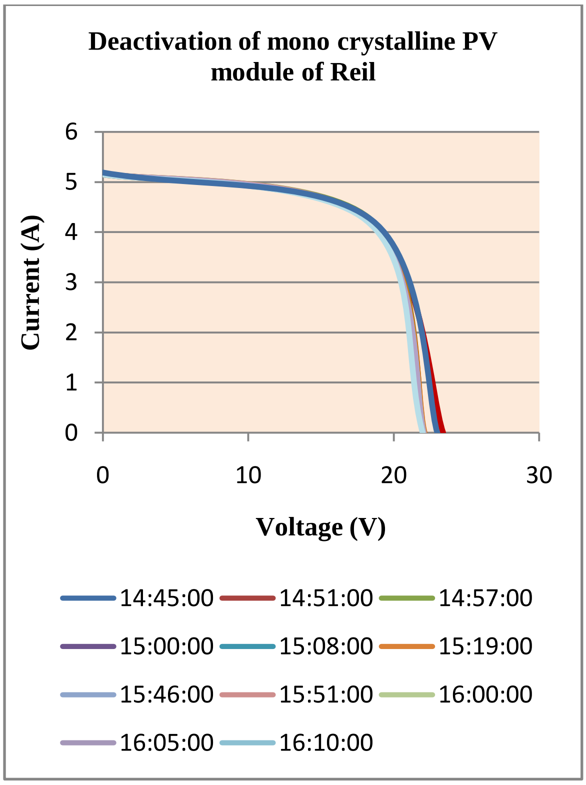

Figure 24 Deactivation of mono crystalline PV module of Reil along 2 hours

Not only the Pm and Voc was affected by the deactivation but also fill factor [1].

In the next figure can be observed how these three parameters descended during the deactivation of the PV module.

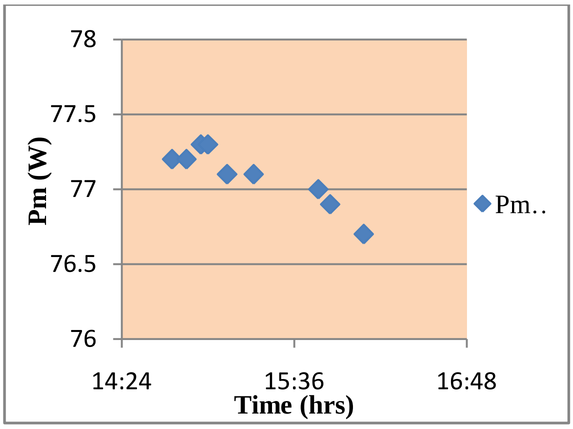

Figure 25 Deactivation effect over Pm (W) parameter in mono crystalline PV module of Reil along 2 hours

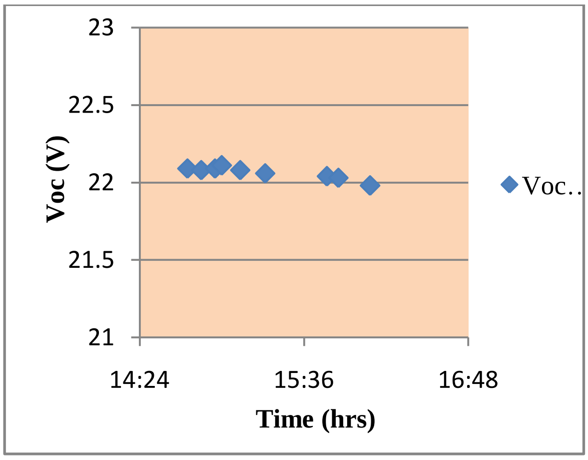

Figure 26 Deactivation effect over Voc (V) parameter in mono crystalline PV module of Reil along 2 hours

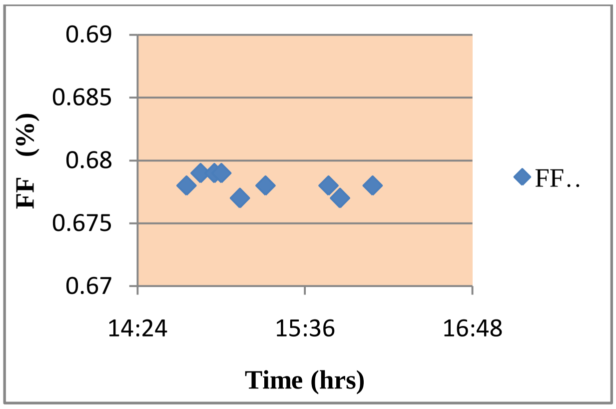

Figure 27 Deactivation effect over FF (%) parameter in mono crystalline PV module of Reil along 2 hours

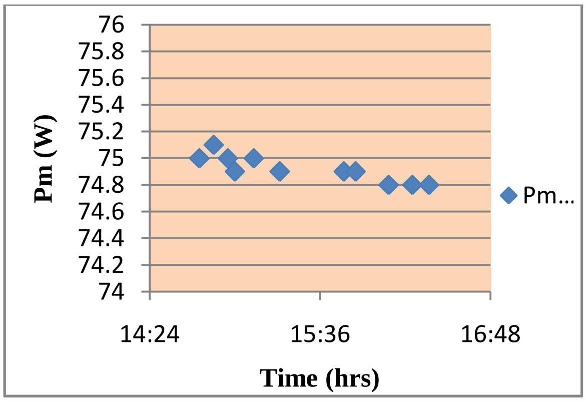

Figure 28 Deactivation effect over Pm (W) parameter in mono crystalline PV module of Premier Solar along 2 hours

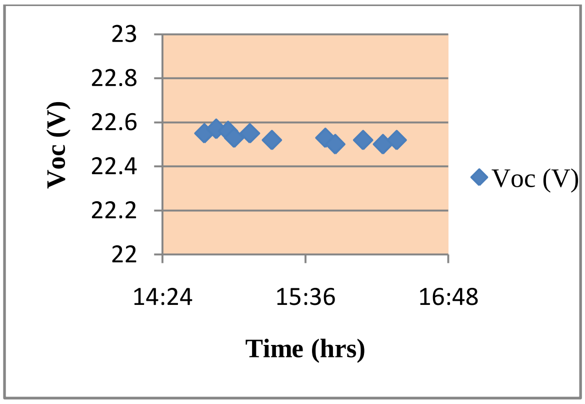

Figure 29 Deactivation effect over Voc (V) parameter in mono crystalline PV module of Premier Solar along 2 hours

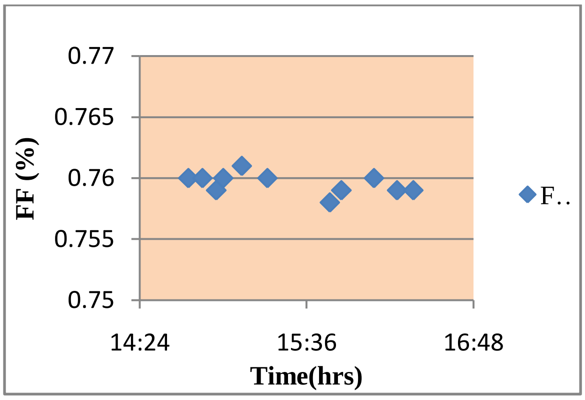

Figure 30 Deactivation effect over FF (%) parameter in mono crystalline PV module of Premier Solar along 2 hours

III. CONCLUSION

A reliable method for measuring electrical characteristics of Crystalline PV modules is desirable.

Different tests performed indoor and outdoor and further the comparison done between indoor-outdoor results reveal that in most measurements, difference in most performance parameters were small considering the measurement uncertainty of 1 %.

It is necessary to include a method that should be easy to accomplish so that manufacturers could use it. To accomplish this, measurements indoors in a solar simulator is always suggested observing the preconditioning for each PV technology. This preconditioning always implies a period of time receiving sunlight for several days or several months depending upon the type of technology, in order to achieve the stabilized power state.

Some technologies such as CIS and CdTe also need to receive sunlight for several hours prior to obtain a reliable measurement that take into account the activation effect in these technologies [1].

The effects on module performance of controlled module conditioning (light soaking) have been previously studied and observed for thin film modules [1].

The resultant effects for C-Si PV modules conclude that the range of performances actually observed in all the modules of crystalline technology broadly correspond to those in the modules that are subjected to controlled conditioning. The module performance drops during the cool months due to accumulated light, exposure at low temperatures and improves in the hot months due to the accumulated effects of higher module operating temperature.

Characterizing the performance of C-Si modules is found to be a non trivial task, due to variations caused by time – dependent and reversible effects such as light soaking.

An important observation is that four manufacturers of two different technologies are chosen here, while in the future, similar studies can be repeated with larger amount of samples from varying manufacturers so that a consensus would be reached as to which level is the correct one to be used for characterizing the performance of PV modules under STC, and can be used in future module labeling.

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