Practical issues for testing thin film PV modules at standard test conditions

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Abstract: Thin film photovoltaic (TF) modules have gained importance in the photovoltaic (PV) market. New PV plants increasingly use TF technologies. In order to have a reliable sample of a PV module population, a huge number of modules must be measured. There is a big variety of materials used in TF technology. Some of these modules are made of amorphous or microcrystalline silicon. Other are made of CIS or CdTe. Not all these materials respond the same under standard test conditions (STC) of power measurement. Power rates of the modules may vary depending on both the extent and the history of sunlight exposure. Thus, it is necessary a testing method adapted to each TF technology This test must guarantee repeatability of measurements of generated power. This paper shows responses of different commercial TF PV modules to sunlight exposure. Several test procedures were performed in order to find the best methodology to obtain measurements of TF PV modules at STC in the easiest way. A methodology for indoor measurements adapted to these technologies is described.

Key words: PV Module Characterization, Light activation, Thin Film, CdTe, CIS
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0 Introduction

Thin film technologies have increased their presence in PV market due to their increasing efficiency and versatility (Tiwari et al., 2011) [24]. Characterisation of these TF modules has therefore a substantial economic impact on the PV market (Virtuani et al., 2010) [25]. Electrical properties of commercial modules are offered under STC (i.e., 1000 W/m^2, AM 1.5, 25ºC, IEC 60904-1) [10]. These usually are not the operating conditions. Nonetheless, operating conditions, such as the season influence parameters as efficiency (Hirata et al., 1998) [8]. Furthermore, owners and installers are interested in knowing if there is any reduction in power supply of the PV modules or the whole plant (Munoz et al., 2010) [19] or signs of early degradation (Munoz et al., 2011) [20]. Thus, some aspects of TF modules, such us the effect of spectral response, transient effects, material related effects (e.g. light soaking), memory effects or storage in the dark and sunlight activation issues must be taken into account.

In the present contribution, we analysed different devices based on TF technology. The main objective was to find the easiest procedure to obtain the I-V parameters at STC adapted to different TF PV technologies. Therefore, discrepancies between indoor and outdoor tests and among testing laboratories can be reduced. The method should be fast allowing the measurement of a large population of modules. Unfortunately, these technologies need to be preconditioned, which is time consuming.

1 Influence of the light spectrum on different technologies.

The IEC 60904-3 [13] standard establishes the spectral distribution of the light (1.5 AM) that should be used for this measurement. Sunlight spectral distribution is not as stable as artificial light spectral distribution indoors. Therefore, a solar simulator makes easier to achieve repeatability of measurements. Each technology has a different spectral response (Muñoz-García M.A. et al., 2012 [21], Minemoto et al., 2009) [18], and the responses are not always linear. According to IEC 61646, when the PV module does not have a linear response to light or temperature, the measurement conditions must be closer to

STC (±5% in irradiance and ±2% in temperature). A-silicon is highly sensitive to light spectrum. In the other hand, c-Si and CIS technologies are the least affected by spectral changes (Huld et al., 2010) [9]. To translate measured electrical characteristics into STC, a spectral correction is needed.

1.1. Amorphous-Si technology

Among TF modules a-Si is now the most used and studied technology. This technology combines the low cost of manufacturing and the maturity of the silicon industry. Nevertheless, a-Si presents an initial reduction in performance (10–15%) during the first hundred hours of light exposure before stabilization (Hegedus, 2006) [6]. This initial drop in performance can be recovered during the hot season due to the annealing (High temperatures >50°C) (Fanni et al., 2011) [4]. Light soaking contributes to metastable defects emergence due to Staebler-Wronski Effect (SWE) (Meyer & Dik 2003) [16]. Efficiency of stabilized a-Si commercial modules is around 4-5% (Midtgard et al., 2010) [17].

1.2. CIS technology

While less studied, TF technologies based on copper indium gallium diselenide $Cu(In,Ga)Se_2$ (CIGS) offer advantages, such as stability, efficiency, and low energy consumption in manufacturing (Knapp and Jester (2000) [15], what makes then competitive with Si-based modules. Materials used for CIGS technology are limited resources (In and Ga) compared to the abundance of Silicon. Nonetheless, CIGS cells reach the highest efficiency of TF technology (almost 20%), may forego the passivation process, and are highly stable (self-healing). However, to achieve a similar extension as a-Si modules is required the correct measurement of their electrical characteristics (Kessler and Rudmann, 2004) [14]. CIS and CIGS PV modules also present initial reduction in performance as in a-Si technology.

1.3. Cadmium Telluride technology

Modules based on CdTe carry the stigma of hazardous heavy metal in their composition (Cd). The theoretical limit for this technology is 29% (Dobson et al., 2000) [3]. Nonetheless, the highest efficiency achieved to-date is 16.7% for a cell. Green et al. (2011) [5] achieved 12.5% efficiency for a submodule. As CIS technology CdTe modules also present light activation effect (Pantoja and Mathew 2003 [22]. However, in CdTe technology power decreases more rapidly when the module is situated in the dark. This poses a problem for indoor measurements.

2. Analysis procedure and results

2.1. Preconditioning in different technologies

The current certification standard for TF PV modules (IEC 61646) [12] was designed to account for SWE changes in a-Si modules and did not consider specific characteristics of CdTe or CIGS devices Deline et al, (2012) [1]. A key factor to improve measurement repeatability is to achieve module stable state and performing tests under reproducible measurement conditions (Herrmann et al. 2008) [7].

2.1.1. <u>Amorphous Silicon</u>

As mentioned above, this technology presents an initial power reduction known as power stabilization. IEC-61646, considers power stabilization when at least 43kWh/m^2 is applied to the module until the incremental relative changes in measured power are ±2% or less.

In this study, two a-Si modules were exposed to sunlight until power declined less than 1% in a month (in our case 5 months) in order to determine the period required for stabilization.. At this point it can be said that stabilization was achieved and the characterization of the module can be conducted. Once the module is stabilized, a power measurement can be obtained outdoors or indoors in a solar simulator. The latter, requires a stable and well-known light spectrum, and spectral correction of the measurements.

2.1.2. CIS

When CIS modules are exposed for the first time to sunlight radiation for several days, an initial degradation effect may appear which may cause an initial power reduction of up to 3%. This initial performance decrease is not reversible (Figure 3). After initial degradation, to achieve the complete power stabilization, modules should be stored in the dark for at least ten days and reactivated by means of light soaking. Additional periods of darkness will decrease PV performance but in a reversible way. This is known as “dark aging” (Voc and FF drop in the dark), (Delahoy et al., 1998) [2].The module can be re-activated by exposing it to sunlight conditions (“light activation”). Performance recovery is correlated to efficiency losses, larger light-soaking exposures and repetition of dark aging/light-soaking cycles lead to better results in Voc, Isc and FF. Thus, CIS PV modules must be exposed to sunlight for at least one hour at 1000 W/m^2.

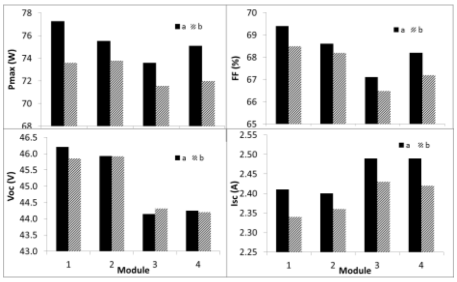


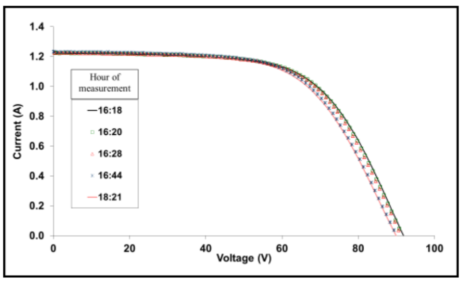
Figure 3.- Measurements before (a) and after (b) the initial power stabilization of CIS modules. Test represented with letter “b” were obtained after 8 days of sunlight exposition.

2.1.3. Cadmium Telluride

Long-term storage in dark conditions results in a deterioration of electrical performance of CdTe PV modules. Thus, before taking a measurement, both the stabilized power and the activation effects should be achieved, similarly to CIS technology. The module should be exposed to direct sunlight for at least four hours (operating under load, not Voc) before a measurement is taken outdoors or indoors. Increase of power of up to 2-3% can be attained after a period of sunlight exposure.

Indoor measurements were taken very shortly after a period of activation in which six CdTe modules were exposed to direct sunlight for at least four hours on a clear day, including the central hours of the day. To attain the required 25°C, modules were cooled by watering the back sides until they reached this temperature. Pm and Voc loss was detected in all of the modules during the two first hours of indoor measurement (Figure 1a). It can be observed that the Voc, Pmax and the FF (Figure 2b) decrease faster at the beginning while the PV module is not receiving sunlight. After 20 minutes, the electrical characteristics do not decrease significantly.

a)



b)

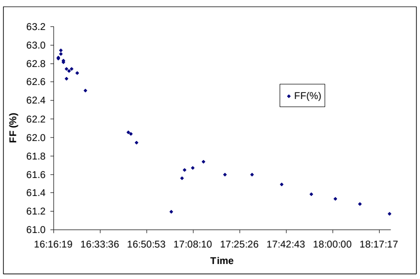


Figure 1.- CdTe PV module deactivation (a) and FF (%) reduction (b).

3. Conclusions

A reliable characterization of the new TF PV technologies at STC is required. This method should: be easy to accomplish, takes into account main sources of measurement errors (p.e. spectral mismatch, transient effects, and meta-stablility) and be adapted for each technology. In order to guarantee repeatability of measurements of electrical characteristics, we suggest indoor test in a solar simulator combined with the correct preconditioning for each TF technology. This preconditioning implies a period of sunlight exposure in order to achieve the stabilized power state. This period range from days (CIS and CdTe) to several months (a-Si). Some technologies such as CIS and CdTe also need to receive sunlight for several hours to allow for the activation effect. In the case of CdTe, we found a rapid power reduction after sunlight activation. Our recommendation to avoid big changes in electrical characteristics is to measure as soon as possible (less than five minutes) after the sunlight activation.

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5. Bibliography

[1] Deline C.; Joseph del Cueto ; David S. Albin and Steve Rummel. 2012. Metastable electrical characteristics of polycrystalline thin-film photovoltaic modules upon exposure and stabilization. Journal of Photonics for energy. 2(1), 022001 http://dx.doi.org/ 10.1117/1.JPE.2.022001.

[2] Delahoy, A.E., Britt, J.S., Kiss, Z.J., 1998. National renewable energy laboratory. CIS Photovoltaic Technology Final Technical Report 12 January 1997–15 April 1998.

[3] Dobson, K. D., Visoly-Fisher I., Hodes G., Cahen D., 2000. Stability of CdTe/CdS thin-film solar cells. Solar Energy Materials and Solar Cells 62(3)(5/15), 295–325. http://dx.doi.org/10.1016/S0927 0248(00)00014-3.

[4] Fanni, Lorenzo, Virtuani, Alessandro, Chianese, Domenic, 2011. A detailed analysis of gains and losses of a fully-integrated flat roof amorphous silicon photovoltaic plant. Solar Energy, 85 2360–2373. http://dx.doi.org /10.1016/j.solener.2011.06.029.

[5] Green, Martin A., Emery, Keith, Hishikawa, Yoshihiro, Warta, Wilhelm, 2011. Solar cell efficiency tables (version 37). Progress in Photovoltaics: Research Application. http://dx.doi.org/10.1002/pip.1088.

[6] Hegedus S., 2006. Thin Film Solar Modules: The Low Cost, High Throughput and Versatile Alternative to Si Wafers. Prog. Photovolt: Res. Appl. 2006; 14:393–411. DOI: 10.1002/pip.704.

[7] Herrmann W, Zamini S, Fabero F, Betts T, van der Borg N, Kiefer K, Friesen G, Zaaiman W. 2008. Results of the European performance project on the development of measurement techniques for thin-film PV modules. Proceedings of the 23rd European PVSEC, Valencia, 2719–2722.

[8] Hirata, Youichi, Inasaka, Tutomu, Tani, Tatsuo, 1998. Output variation of photovoltaic modules with environmental factors – II: seasonal variation. Solar Energy 63 (3), 185–189.

[9] Huld, Thomas, Gottschalg, Ralph, Beyer, Hans Georg, 2010. Mapping the performance of PV modules, effects of module type and data averaging. Solar Energy 84, 324–338. http://dx.doi.org/10.1016/ j.solener.2009.12.002.

[10] International Electrotechnical Commission, 2006. Standard IEC 60904-1: Photovoltaic Devices.

Part 1: Measurement of Photovoltaic Current–Voltage Characteristics. IEC Central Office, Geneva.

[11] International Electrotechnical Commission, 2007. Standard IEC 60904-9: Photovoltaic Devices. Part 9: Solar Simulator Performance Requirements. IEC Central Office, Geneva, Switzerland.

[12] International Electrotechnical Commission, 2008. Standard IEC 61646: Thin-film photovoltaic (PV) modules – Desing qualification and typ approbal" IEC Central Office, Geneva, Switzerland.

[13] International Electrotechnical Commission, 2008. Standard IEC 60904–3: Photovoltaic Devices. Part 3: Measurement Principles for Terrestrial Photovoltaic (PV) Solar Devices with Reference Spectral Irradiance Data. IEC Central Office, Geneva, Switzerland.

[14] Kessler, Friedrich, Rudmann, Dominik., 2004. Technological aspects of flexible CIGS solar cells and modules. Solar Energy 77 (6), 685–695. http://dx.doi.org/10.1016/j.solener.2004.04.010.

[15] Knapp, K.E., Jester, T.L. 2000. Initial empirical results for the energy payback time of photovoltaic modules. In: Proceedings of 16th European PVSEC,Glasgow Scotland, pp. 2053–2056.

[16] Meyer, E.L., van Dyk, E.E., 2003. Characterization of degradation in thin film photovoltaic module performance parameters. Renewable Energy 28, 1455–1469.http://dx.doi.org/10.1016/ S0960-1481 (02)00062-9 .

[17] Midtgard, Ole-Morten, et al., 2010. A qualitative examination of performance and energy yield of photovoltaic modules in Southern Norway. Renewable Energy 35, 1266–1274.

[18] Minemoto, Takashi, Fukushige, Shunichi, Takakura, Hideyuki, 2009. Difference in the outdoor performance of bulk and thin-film silicon based photovoltaic modules. Solar Energy Materials and Solar Cells 93, 1062–1065.http://dx.doi.org/10.1016/j.solmat.2008.11. 051.

[19] Munoz, M.A., Chenlo, F., Alonso-García, M.C., 2010. Influence of initial power stabilization over crystalline-Si photovoltaic modules maximum power. Progress in Photovoltaics: Research Application, 417–422. http://dx.doi.org/10.1002/pip.1052.

[20] Munoz, M.A., Alonso-García, M.C., Vela, Nieves., Chenlo, F., 2011. Early degradation of siliconPVmodules and guaranty conditions. Solar Energy 85 (9), 2264–2274. http://dx.doi.org/10.1016/ j.solener.2011.06.011.

[21] Munoz-García M.A., Marin O., Alonso-García M.C., Chenlo F., 2012. Thin film modules characterization under standard test conditions. Solar Energy 86 3049-3056. http://dx.doi.org/10.1016/ j.solener.2012.07.015

[22] Pantoja, Joel Enríquez, Mathew, Xavier, 2003. Influence of the thickness on structural, optical and electrical properties of chemical bath deposited CdS thin films. Solar Energy Materials and Solar Cells 76, 313–322. http://dx.doi.org/10.1016/S0927-0248(02)00283-0.

[24] Tiwari, G.N., Mishra, R.K., Solanki, S.C., 2011. Photovoltaic modules and their applications: a review on thermal modelling. Applied Energy, 2287–2304.doi.org/10.1016/j.apenergy. 2011.01.005.

[25] Virtuaniy, A., Mullejans, H., Dunlop, E.D., 2011. Comparison of indoor and outdoor performance measurements of recent commercially available solar modules. Progress Photovoltaics: Research Application. 19, 11–20. http://dx.doi.org/ 10.1002/ pip.977 .