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Controlled conditioning of a-Si:H thin film modules for efficiency prediction

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Abstract

It is known for a-Si:H modules that seasonal variations in performance occur because of the effects of meta-stable degradation mechanisms. These changes in Standard Test Condition (STC) performance are driven by the history of exposure to light and temperature with different time constants and thermal annealing activation energies. The present study provides a link between performance changes following varied indoor controlled conditioning and during outdoor exposure through different seasons. Varying exposure conditions were simulated indoor at different light levels and temperatures as functions of time. During these controlled conditioning experiments the extrapolated STC performance was found to change significantly, and coefficients determining the change in efficiency as a function of light and temperature exposure have been estimated. Using these coefficients the module performance has been modelled as a function of real irradiance and temperature variations over a year leading to a good match to the actual measured performance over the same year.

Keywords: a-S:H modules; Seasonal variations; Controlled conditioning; Efficiency prediction

1. Introduction

Accurate performance measurement remains a major issue in thin-film PV technology especially for silicon based thin film modules due to their meta-stability that has been regularly reported [1,2,3]. A major difficulty created by this meta-stability is immediately evident when rating at Standard Test Conditions is required. The measured power will be a function of its previous light exposure and temperature history, and appropriately defining these pre-conditioning steps to ensure good repeatability requires a good understanding of the individual effects.

All these difficulties in predicting instantaneous module efficiency create a further problem when it becomes necessary to estimate the energy production of a module in real outdoor conditions. Existing energy rating methods assume a time-invariant module performance, however, the meta-stability of a-Si modules commonly leads to seasonal fluctuations in output power, and a complete energy rating procedure will need to take these into account. In practice, the interpretation of analysis of outdoor performance is complicated since all environmental conditions change simultaneously. Changes in module performance due to different causes are superimposed and it becomes difficult to separate these contributions to the overall performance of the module.

A variety of possible explanations for the seasonal variations of a-Si:H module performance have been proposed, alternatively in terms of the irradiance level [4] and/or high temperature of the module [1,5,6] or in response to spectral changes [7,8].

In the present work, the long-term stability of an a-Si:H thin film module placed outdoors from 2002 to 2007 has been investigated. Indoor control measurements of the module at STC (25 °C, 1000 W/m^2, AM1.5) taken regularly capture the state of the material as it has been modified by the outdoor conditions it has been exposed to.

The outdoor measurements were performed on a fixed south facing open rack. Module I–V curves were measured at frequent intervals during the investigated period. Furthermore, the spectral mismatch factor (MMF) for all measurement points was estimated from previously measured spectral data and applied to correct the measured module data. The presented data have been filtered to include only clear sunny days for which this MMF correction can be performed. In order to be able to compare indoor and outdoor data at the same conditions, corrections of the outdoor data to STC according to the IEC 60891 translation equations [9,10] have been made.

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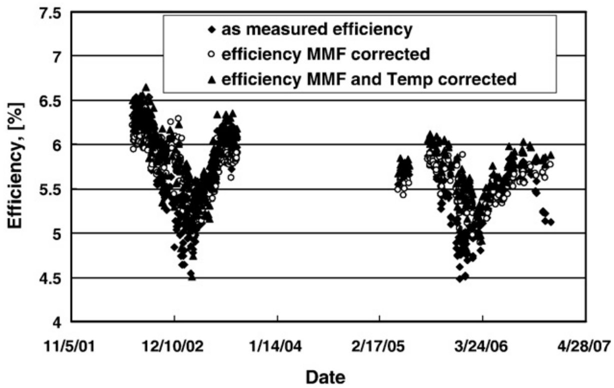

Fig. 1. Outdoor a-Si module efficiency measured in 2002–2003 and 2005–2006. The data were filtered to select clear sky days for clarity.

The susceptibility of a second identical a-Si:H module to light exposure and varying temperatures has also been characterized. The degradation and annealing effects were simulated indoor at different light soaking (LS) levels and temperatures as functions of time. This study gives a link between measurements at various indoor conditions and at outdoor exposure at different seasons, and a model for efficiency prediction based on this controlled module conditioning is presented.

2. Experimental methods

2.1. Indoor measurements

The modules were characterized using standard indoor measurement methods employing pulsed solar simulators. Periodically during the outdoor, LS or annealing measurements the modules, were characterized at Standard Test Conditions (1000 W/m^2, 25 °C and irradiances distribution corresponding to IEC 60904-3 (AM1.5)) using a large area pulsed solar simulator (LAPSS).

2.2. Outdoor measurements

The modules were mounted a south facing rack at a fixed 45° elevation all year round. The back-of-module temperature T_{mod} was measured with a Pt-100 temperature sensor attached to the rear of the modules. The ambient temperature T_{amb} was recorded by a meteo station located close to the module. The I–V curves of the device under test were recorded at 4 min intervals. The measurement of the I–V curve was performed automatically by a LABVIEW© program, which controlled a bipolar power operational amplifier used as an active load, and a data logger. The module was kept at the last calculated maximum power point after each measurement to simulate connection to a maximum power point tracker. The in-plane irradiance was also recorded with each I–V curve with a crystalline-Si reference device and a pyranometer.

2.3. Light soaking and annealing set-up

In order to study the effects of light soaking an identical module was subjected to a series of light soaking and thermal annealing cycles at a range of conditions. The light soaking was performed in an indoor chamber at available irradiance levels of 100, 240 and 600 W/m^2 at constant temperatures. A measurement at STC was performed at frequent intervals during the light soaking.

Following each light soaking cycle, the same module was thermally annealed in a series of constant temperatures of 50, 55 and 60 °C in an environmental chamber. A measurement at STC was made at frequent intervals during the annealing.

3. Results and Discussions

3.1. Long term outdoor measurements of an a-Si:H module

To study the long-term stability of the module, the I–V characteristics during outdoor measurements over five years from 2002 to 2007 under various conditions were analyzed principally in relation to irradiance and temperature, but also taking into consideration spectral changes.

In order to be able to compare indoor and outdoor data at the same conditions, the outdoor data were corrected to STC. The correction to 25 °C was made using previously established coefficients for temperature of the maximum power P_{max} [11] and made according to the IEC 60891 translation equations [9]. Fig. 1 shows the outdoor module efficiency over a period of two full years of exposure. This figure presents filtered data containing only clear sunny days and furthermore only the values between 11:30 h to 13:30 h which have been averaged in order to reduce noise in the graph. Performing the analysis on only these selected data means that the magnitude of corrections, and hence their errors, are minimized, and therefore each data point will be a good representation of the real instantaneous STC condition of the module. The values of efficiency were corrected to AM1.5 using a spectral mismatch factor (MMF), using a dependence of MMF on Air mass that has been previously established for this module [12]. Note that this MMF (AM) dependence is valid only for clear sky conditions, which is the case for the data selected for analysis.

The validity of the applied corrections for temperature and MMF has been examined by performing similar corrections to a c-Si module sited on the same outdoor rack over the same time period. Here, the MMF corrections are based on the irradiance

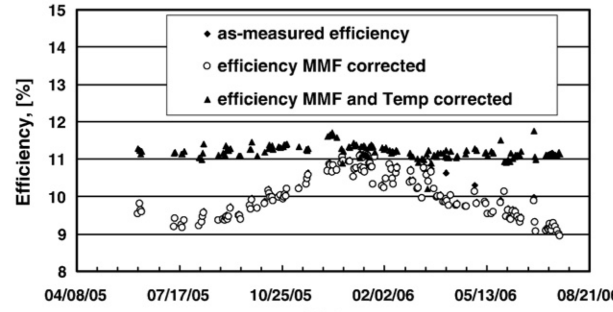

Fig. 2. Outdoor efficiency for the c-Si module as-measured and corrected using the same procedure as for the a-Si module.