Chapter

Influence of the Incidence Angle Modifier and Radiation as a Function of the Module Performance for Monocrystalline Textured Glass and No Textured in Outdoor Exposed

Issa Faye, Ababacar Ndiaye and Elkhadji Mamadou

Abstract

The variation of the incidence angle over the year is an important parameter determined the performance of the module. The standard orientation of the module or a PV system, the perpendicular positioning of the sun to the module's surface occurs twice a year. In outdoor exposed, angular losses of the module decrease the output of the PV or the system of PV. Although these losses are not always negligible, they are commonly not taken into account when correcting the electrical characteristics of the PV module or estimating the energy production of PV systems. This chapter is focused on the measurement of the angular response and spectral radiation (global and direct radiation) of solar cells based on two different silicon technologies, monocrystalline textured (m-Si) and non textured (mc-Si). The analysis of the source of deviation from the theoretical response, especially those due to the surface reflectance. As main contributions, the effects of glass encapsulation on the angular response of the modules are investigated by comparing the electrical parameter of the textured module to no textured and quantify electrical angular losses in this measurement area.

Keywords: textured, cell center, incidence angle

1. Introduction

The conversion of solar energy in solar modules is subject to electrical and optical losses [1, 2]. Optical losses are substantially depending on light incidence angle relative to the module plane. Manufactures information of photovoltaic panels typically provide electrical parameters at only one operating condition. Photovoltaic panels operate over a large range of conditions so the manufacturer information is not sufficient to determine overall performance. The electrical power output from a photovoltaic panel depends on the solar incidence irradiation, the cell temperature, the solar incidence angle [1, 3, 4]. To minimize reflection losses and thus maximize the electric yield, the PV industry introduced several different concepts and materials, such as antireflective coatings or structured glass with inverted pyramids [5]. To measure the nominal power, the incidence angle at normal incidence in standard test conditions is allowed. In real conditions, modules are exposed in different environments conditions. In some location, the main losses mechanism performance of PV or a system of PV is that the angle dependence. The PV module characteristics can help the company to predict accurately the PV performance. A new standard for performance testing and energy rating is under development [6]. The angle dependence losse of a PV module or a cell can be measured in several manner such the angle dependence reflectance. While reflectance measurements do not account for absorption losses, common I – V curve measurements can suffer from incorrect injection dependence and mismatch corrections.

Precise characterization methods and measurement systems are needed to assess angular dependent module performance. The incidence angle is measure of deviation from the direct solar radiation to the PV panel surface. The incidence angle is directly involved in the determination of the radiation incident angle affects the amount of solar radiation transmitted through the projective cover and converted to electricity by the cell [3, 7]. Significant effects of inclination occur at incidence angles greater than 65 degree [8]. The main of this paper is to evaluate and a comparative study of two crystalline silicone technologies in reel outdoor pyramidal textured and non-textured for different incidence angles and spectral radiation. The major difference between outdoor operation in natural sunlight and the laboratory test conditions is the existence of diffuse light, which is dependent on the climatic conditions on the location.

2. Incident angle distribution

The incident angle of the light on a PV module depends on tree parameter such as the module orientation, the time of the year and the geographical location [9]. However, due to cosine losses in those operation times with higher AOI, this only corresponds to 29% of the energy share in energy share in module plane [5]. To effectively reduce angular of incidence loss mechanisms and to utilize effects which boost the performance at lower angles of incidence it is crucial to effectively separate the different mechanisms which play a role when the AOI is varied. The **Figure 1**, shows the situation in which oblique incidence plays an important role for the performance.

Advances in solar glass production.

In the past few years, glass–glass module received a significant increased in attention, triggered by number of reasons.

Light trapping glass.

A major requirement for front cover glass in solar modules is high transmission in the wavelength range of the semiconductor material. One option to boost transmission is texturing the front surface in a similar manner to crystalline silicon solar cells.

Reduction of reflection at oblique light incidence.

As show in **Figure 2,** the light reflection on a mountain lake. In the front, the observer can see through the water surface: the reflection is low. With increasing angles, the reflection constantly increases and in the background only the mountains can be seen on the water surface.

Hence, the reflection is higher than the transmission at oblique light incidence. The reflection for equally (uniformly) polarized light can be described by the following equation.

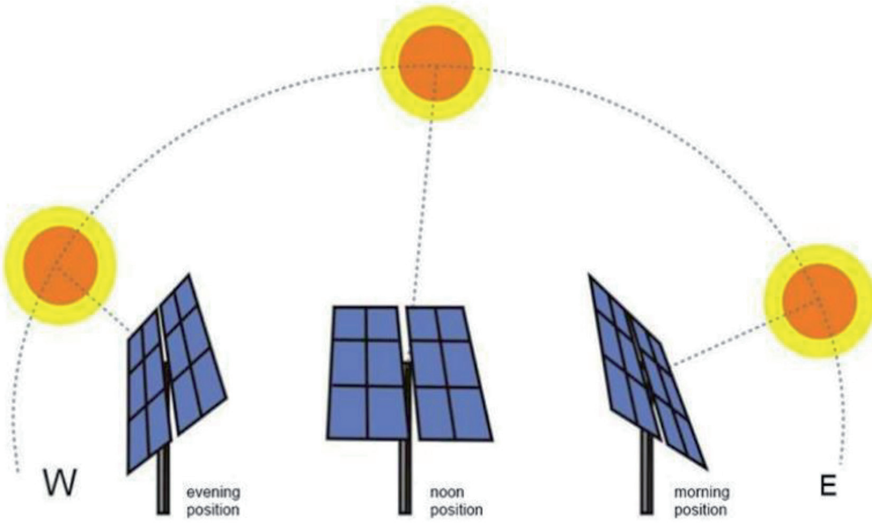

Figure 1.
Situations in which oblique light incidence plays an important role for the performance of the PV-module. The important part of light is normal to the module surface. This enormous part of light derive under diffuse light. Thus, understanding the oblique light performance of solar modules is crucial to understand its diffuse light performance.

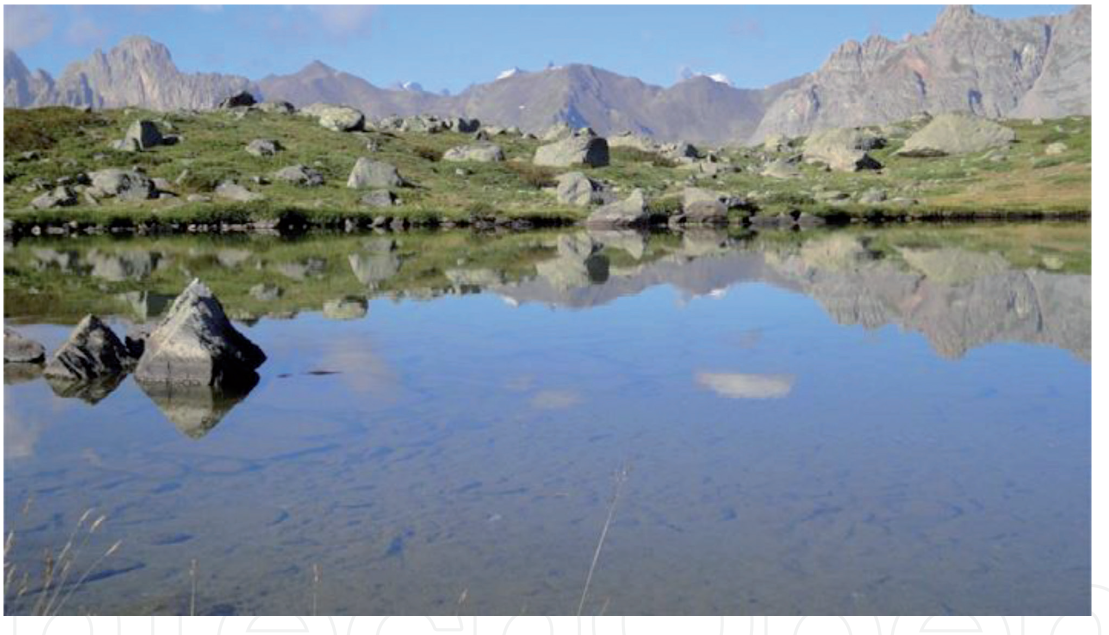

Figure 2.
Light reflection as function of observed angle [10].

3. Methods of solar tracking

To track a maximum power point (MPPT) of a PV module, we always use a solar tracker. Different solar tracker are used as follows.

3.1 Passive trackers

The principle behind passive trackers is to make use of the solar heat to cause an imbalance, which leads to a movement in the tracker. They work on thermal expansion and commonly employ a low boiling point compressed gas fluid or shape memory alloys. For the high precision of the concentration of solar Power, the passive tracker are not always used. However, they can be employed for common flat PV systems. The passive trackers is more useful than the active tracker, however, the efficient in low temperature is less. The SMA actuator can easily be deformed even at relatively low temperatures (by tracker actuators below 70°C). It produces mechanical work by returning back to its original shape when heated above transformation temperature. The study found that the tracker worked very well in the short term field tests and the SMA actuators provided an efficiency of approximately 2% [11].

3.2 Active trackers

The mechanism of a active solar tracker is to use a motor to enable control the mobility of the tracker. These motors are usually fed by a (**Figure 3**).

The motor executed the command from a signal which have a main aims to provide magnitude and direction and incidence angle. The incidence angle is enable to change from 0° to 90°. We highlight that the active tractors made use performed accurately however, they consume more energy. They are more efficiently than the passive trackers.

3.3 Active trackers with single-axis system

To compare to a two axis systems that provide two degrees freedom, a single axis provide for only bone. Hence, a single axis consumed less energy than a two axis system. The 1A-3P sun tracker was designed to operate at only 3 different angles as shown in **Figure 4**. A simple designed tracker is combined with a DC motor to turn the system The tracker rotation is enable by a timer IC which provides the time signal to trigger the motor to turn at the turning angle. The measuring functions for tracker motion, PV generation and all the control algorithms are implemented using microcontroller PIC18F452 [12] A standalone single axis active solar tracker and presented the modeling and simulation of the photovoltaic system under a constant load using MATLAB/Simulink was designed by [13]. The different components

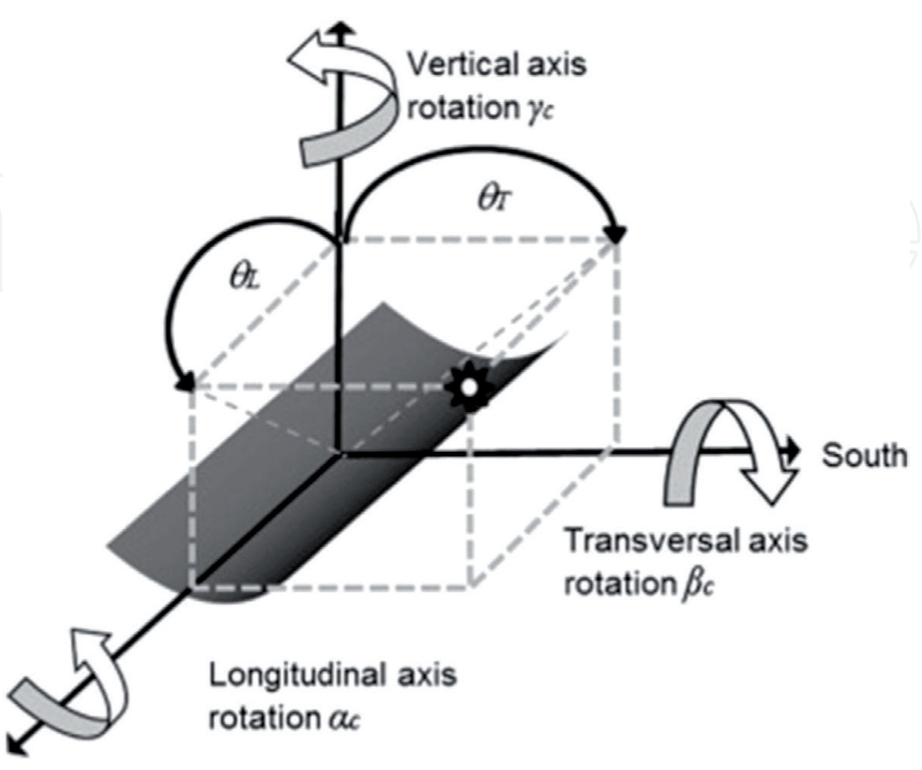

Figure 3.
Scheme of the rotation angles [11].

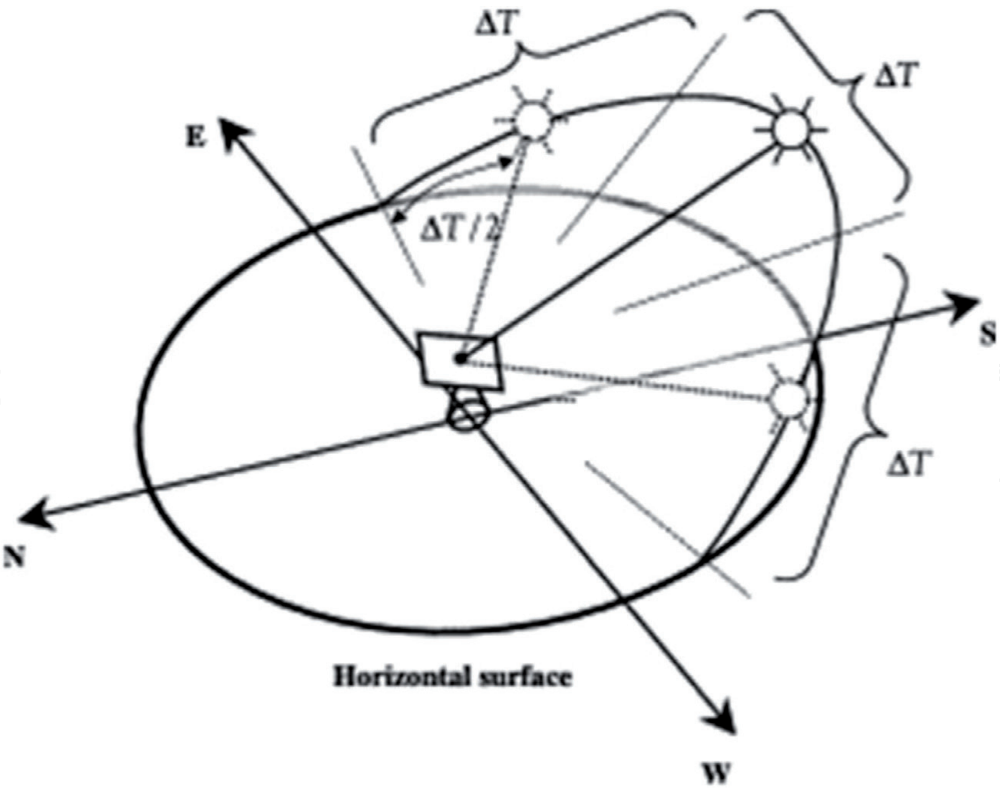

Figure 4.
Schematic diagram of azimuth three step tracking [11].

such as a servermotor, a batetery, a charger, two LDR sensors and external load and microcontroller provide the output. The aims of the tracker is to rotate in a single axis, then it's designer take into accunt of the number of axis rotation and activate the motor to had a single-axis freedom. The sunlight intensity was sensed using the LDR sensors, which would then send a signal to the microcontroller to rotate the panel using the servo motor. To control the system, a Lead Acid battery polarize the components which is controlling via a charge controller. Konar et al. designed a single axis microcontroller based automatic, position control scheme. The system is controlled by two axis, the first one is a reflector that tilted optimally across it; the second one is controlled by the tracker by changing the azimuth angle. The tracking system was designed to search for the maximum solar irradiance in the whole azimuth angle of 360° during the locking cycle, and hence the system was not constrained by the geographical location of installation. The system also employed step tracking scheme instead of continuous tracking which keeps the motors idle for a longer time to save energy [11] reported a single-axis solar tracker on a small size Parabolic-Trough Collector (PTC). To locate the azimuth of the sun, a algorithm that classified as an an open-loop is elaborate. The angular tracking error was accurately characterized using a digital inclinometer. The transversal Incidence Angle Modifier.

(IAM) curve is determined by ray tracking simulation for all longitudinal incidence angles as well as the transversal incidence plane is showing in **Figure 4**. The proposed procedure gives a better accuracy for the tracking error than the theoretical acceptance angle [14]. derived formulae to evaluate the daily and hourly radiation incident on azimuth three step tracking system, hour angle three step tracking systems and compared the results with the radiation received by a horizontal surface. A yield tilted surface performed an a optimal angle gain 30,2% higher radiation than a horizontal surface. In comparison, a two axis azimuthal three step tracking performed better with a 72% higher radiation [15]. As shown in **Figure 5** a global illustration of the schematic digram**.** A theoretical study to analyze the performance

Figure 5.
Solar tracking system at the Cologne University of Applied Sciences.

of an east–west oriented single-axis tracking panel was done by [16] claimed the performance of a single axis tracking, the system consist of a panel fixed in a horizontal axis, in different time of the year. They compared the gain in an est-west to north-sud. The results show that the yearly gains obtained in est-west is less than the north-sud. The results show that, the correlation between the irradiation and the latitude is hight, it's 12% at the equator and 14,3% in the Arctic. To increase the efficiencies of the PV plant, a ray tracking is performed; besides, the change of the angle may have an impact of the output of the system. The mathematical formula can accurately investigate the optical performance, As make a use by [11] with a single axis in South–North, they estimate the annual radiation of the panels composed the system when using a single axis. Some of study haves been done in china, they compare single axis and dual axis and conclude that the dual axis performed 96–97% higher than the single axis. The results illustrate that in some areas, at low resources, the tracking is unsuitable. The sun tracking may perform better than the traditional fixed if both are compared over the year, the gain performance were estimated to higher than 30% with high solar irradiation, however it is less than 20% in low irradiation areas [17–19].

4. Experimental work

The outdoor system are developed and investigated. It's installed on the roof of the Technical university of Cologne. The angle of incidence starting position with orientation to the sun gradually changing the angle of inclination at a constant azimuth angle up to an angle of incidence of 90 selection of the distances between the approached angles of incidence helicopter measurement horizontal module storage (inclination = 90°) gradual change in solar tracker azimuth orientation over a total angle of 180 choice of the distance between the approached angles. The angular

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incidence effect is measured with the short circuit current which is assumed to be proportional to the light reaching the solar cell and thus the photon generation.

4.1 Isotextured solar cell

The incident angle modifier is varied for 0° to 90°. The measurement of the short circuit current of the two modules is done when the incidence angle is changing. A textured surface retains more light than a plane surface in a active area of a PV or cell. However, the advantage of the rough surface can be offset by the mechanism of the recombination at the surface of the PV module or cell textured. At the comparably low angles of incidence, the reflection is reduced to 4% [20]. A textured such as the Alberino glass will drastically lower the reflection for angles of incidence ≥50° and thus will keep the incidence angle midifier closer to unity. The texture of Alberino P is the best described as inverted and rounded pyramid. The **Table 1** shows the electrical characteristics of the Two PV plants in monocrystalline silicone.

Within the framework of this work a solar tracking device was constructed at the Cologne University of Applied Sciences (CUAS) which is capable of measuring the IAM of solar cells and whole modules, see **Figure 5**.

4.2 Global and direct irradiation

Global solar radiation on horizontal surfaces can be measured with a pyrometer or reference cell which is an instrument that measures global solar radiation from all directions. To calculatee the global solar radiation we use the formulate as follows.

Diffuse solar radiation (G_b).

Direct beam solar radiation (G_d).

Solar radiation on a horizontal surface is the sum of the horizontal direct and diffuse radiation.

$$G_H = G_d + G_b$$

The solar module is irradiated by permanently changing solar spectrum. To nevertheless be able to compare the performance of different solar cells technology, a standard spectrum with a relative air mass (AM) of 1.5 was defined:

$$\text{Irradiance} = \frac{Avarage\ value\,[W/m{}^\wedge 2] * 115{,}3\,mV}{1000\,[W/m{}^\wedge 2]} \tag{1}$$

Power (Pmax)	240
Open circuit voltage (Voc)	36,72
Short circuit current (Isc)	8,74
Voltage at maximum power (Vmp)	28,89
Current at maximum power (Imp)	8,31
Permissible system voltage	1000VDC
Maximum reverse current	
Application class	A

Table 1.
Electrical characteristics of both PV modules.

$$Isc,stc = Isc,mes + Isc0 * \left(\frac{G0}{G} - 1 \right) + \alpha * (T2 - T1) \qquad (2)$$

Where, $I_{sc,stc}$ represents the measured current which is standardized, I_{scmes} is the measured current and I_{sc0} is the short circuit current measured.

5. Results and discussion

The results show that, (see **Figure 6**) and **Figure 7**. For direct irradiance, reflectance losses will also be higher than for orthogonale incidence most of time, if stationary modules are considered. There is a decrease short circuit current I_{sc} in direct irradiation from 6.95 to 2.84 for monotextured and from 7.93 to 3.12 in the incident angle from 0° to 60°. This is due to the effect of variation in the minority carrier concentration as said by [21].

The textured module shows a good performance at low irradiance there is still a high share of direct light with oblique incidence angles. So the performance of the textured module is strongly affected by the factor $K_{\tau\alpha}$ as said by (20) Nils Reihners (2018). The short circuit current for the global irradiation decrease from 9.91 to 5.80 for the monotextured and from 11.09 to 6.68 for no textured when the incidence angle increase from 0° to 60°. On top of the cosine effect, additional losses occur, particularly at incidence angles beyong 60° as showed in **Figure 7**. They provide correction factors for device short circuit current Isc for incidence angle β from 0° to 90° with respect to normal incidence of 0°. The short circuit current dependence losse angle is called incidence angle modifier. It is defined as the ratio of the short circuit current measured at an angle of incidence and the short circuit current at perpendicular incidence. The value of corrected by cosines to eliminate the cosine effect and to keep all other angular effects

$$K_{\alpha}(\beta) = \frac{I_{sc}(\beta)}{I_{sc}(0°).\cos(\beta)}$$

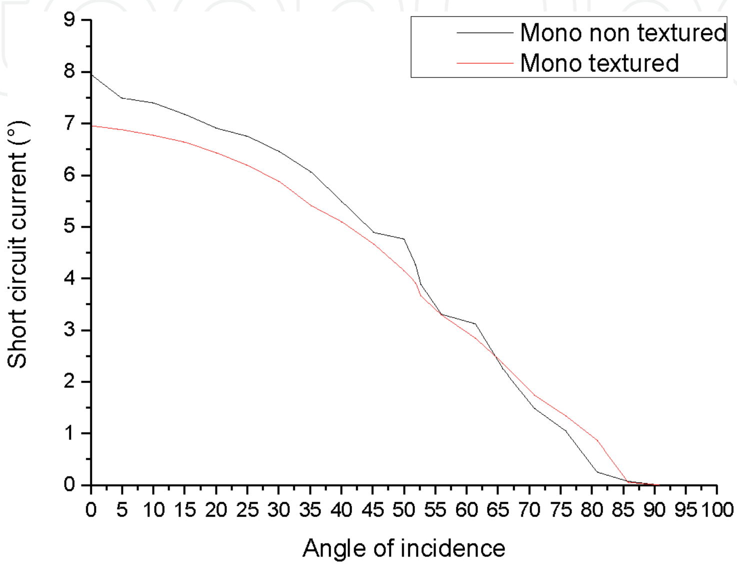

Figure 6.
Curve of direct irradiation in dependence on the angle incidence.

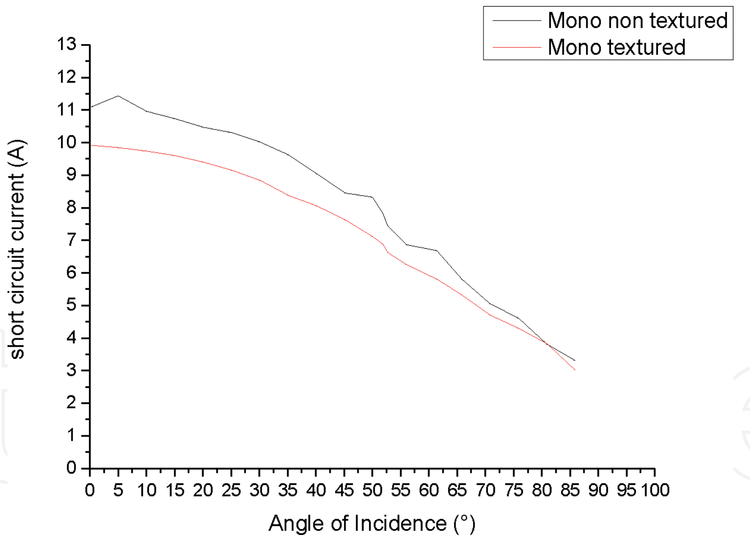

Figure 7.
Curve of global irradiation in dependence on the angle incidence.

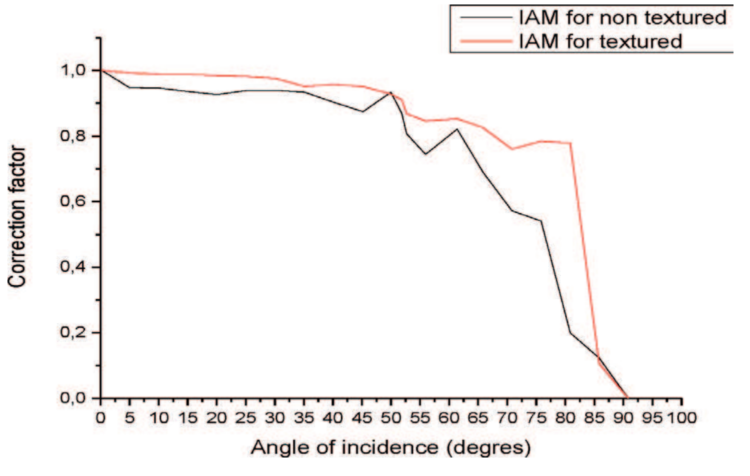

Figure 8.
IAM with direct radiance comparison between textured to no texture. Correction factor $K_{\alpha\tau}$ for flat glass and a pyramidal textured surface.

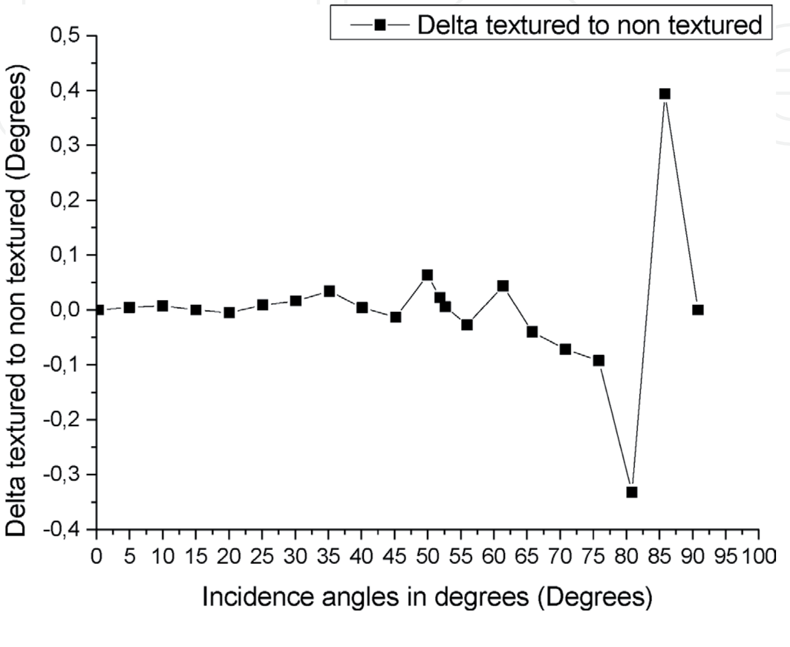

Figure 9.
IAM between delta textured to non-textured in global irradiation.

To include the influence of a changing solar spectrum, it is common to derive a correction factor, which depends on the air mass that the light needs to traverse before hitting the module.

The **Figure 8** shows the IAM comparison between textured and no textured module.

To better understand the IAM of the textured and non-textured module, we introduce the difference between the textured and no textured as showed in **Figure 9.**

6. Conclusion

Angle dependence can be a major loss mechanism in photovoltaic. Our approach enables the measurement the solar irradiation and the angle dependence for modules spectrally resolved. We evaluated the measurement uncertainty of our setup according to calibration standards and measured textured and no textured PV modules. This effort is needed to quantify in reel outdoor exposed the effects of cell textured and the incidence angle modifier. The results show that, the textured PV module performs better than the flat PV module in global irradiance and diffuse irradiance.

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