How to measure albedo for bifacial PV

Hukseflux is a market leader in albedometers for bifacial PV system performance monitoring

The measurement of the albedo, or ground surface reflectance, of surfaces is gaining popularity. Bifacial PV modules generate power using both the global solar radiation and the reflected solar radiation. Downfacing pyranometers are suitable to make reflected radiation measurement, but you must carefully consider what the performance model requires as an input; the ground surface property or reflected irradiance? This note comments on instrument specifications, measurement location, and orientation.

Introduction

Albedo, also called solar reflectance, is defined as the ratio of the reflected to the global radiation. It is a dimensionless number smaller than 1. It is a property of the ground surface.

Figure 1 *in PV system performance monitoring users typically employ Plane of Array (POA) on the right, Global Horizontal Irradiance (GHI), on the left, and increasingly also Reflected Irradiance (RI), in the middle*

An albedometer is an instrument that measures both global and reflected solar radiation and, by calculation, the solar albedo, or solar reflectance for a particular ground surface. An albedometer is composed of two pyranometers, both installed horizontally, the downfacing one measuring reflected solar radiation.

In the open field, the solar albedo depends on the directional distribution of incoming radiation and on surface properties at ground level. It is usually expressed as a single number, determined by taking an average over a day. Changes of albedo are typically slow and seasonal, except when it snows. Albedos of typical surfaces range from about 4 % for fresh asphalt and 15 % for green grass to 90 % for fresh snow.

The classic application of albedometers is in meteorological energy balance studies, studying albedo variations of large area's over multiple years. With the rise in popularity of bifacial PV modules, there is an increased demand to measure the albedo at PV power plants. This is possible with pyranometers, but there are a few things to keep in mind.

Use of Albedo measurement in the PV performance model

The albedo measurement is used as input to the performance model. The performance model is agreed between the stakeholders. Stakeholders should at the same time agree:

- what "albedo" in a PV power plant means
- if it should be continuously measured, or not at all (contribution to the total yield may be small, value of a very accurate measurement may be questioned)
- and if so, how

Parameters in the performance model

About the parameters used in the performance model:

- the primary input to a PV system remains Plane of Array (POA) radiation, either measured with a pyranometer facing up mounted in the plane of array, or estimated from Global Horizontal Irradiance (GHI) with an upward facing horizontal pyranometer
- with downfacing pyranometers you measure horizontal reflected irradiance (HRI)
- it may be that the performance model asks for measurement of reflected radiation in the plane of array of the downfacing side of the bifacial panel, or plane of array reflected irradiance (POARI). Most performance models do not require this input because this

approach leads to confusion; many PV power plants do not have a single or uniform Plane of Array. Many performance models expect the albedo of the ground surface only
- some performance models ask for distributed sensors among the panels or site surveys to get a better idea of spatial variability of the albedo. Quantifying the albedo variability is a requirement of IEC for proper uncertainty evaluation of the performance test of bifacial PV systems (see site survey)

Reflected radiation between PV arrays

While albedo in the open field is simple to define as a property of the ground surface, for PV there are some complicating factors:

- the amount of reflected solar radiation between PV arrays is dominated by the shading of the ground surface by the array panels, and in second place by the reflectance of the ground surface (albedo)
- As shading dominates, albedo does not need to be known with high accuracy
- the shading and ground surface properties are not homogeneous
- for reflected yield calculation, conversion to panel backside in-plane irradiance is required
- for reflected yield calculations, spectral corrections may be required; spectral content of reflected radiation is not the same as incoming radiation. Usually this correction is treated as insignificant

At a fundamental level we can expect that reflected radiation below solar array structures, as a percentage of incoming global horizontal irradiance above the array is very variable;

- reflected solar radiation below PV arrays varies in space over a power plant, for example in the middle of a row the albedo will be different from that at the ends of a row due to different shading patterns or a different local horizon
- reflected radiation below PV arrays varies over the day depending on moving local shading patterns
- albedo of the ground surface may vary seasonally depending on vegetation properties, shading patterns soil moisture content

Common practice: performance model input

The complicated nature of the reflected radiation is the reason why most performance models suggest keeping it simple:

- enter ground surface albedo as a single number
- enter seasonal variation by month
- calculate backside POA based on a GHI measurement and model calculations
- use reflected radiation measurements, because of their local nature, as model validation, and not as critical input

One unobstructed reference station

Some performance models suggest using a measurement at a location away from the arrays, measuring HRI not suffering from any shadow effects, and determining the albedo as a ground surface property. The question then is if this location has a representative ground surface.
At the array location, the reflected radiation measurement may be realistic, but there also are many local shadow effects which gives a confusing impression of the ground surface albedo unless the GHI is also measured below the array panels. The unobstructed measurement has the advantage of simplicity. If representative, it serves as a check of the maximum albedo and as a point of reference for satellite observations.
See also: site survey.

Figure 2 *2 x S30 spectrally flat Class A (secondary standard) pyranometer connected to a fixture plus rod, together forming an albedometer. The downfacing pyranometer is equipped with a glare screen to block solar radiation entering the lower detector at low solar angles (150° instead of 180° full field of view angle).*

Recommendations in summary

A summary of Hukseflux 'recommendations for albedo measurement for bifacials:

- keep the albedo definition simple: most models assume it is a ground surface

property with a seasonal (monthly) variability; let the model take care of corrections for shading patterns, and conversion to plane of array
- employ at least one instrument located away from the array, so that you have one unobstructed reference albedo measurement. This is under the assumption that the ground surface properties at the station are representative for those between the array
- keep logistics simple; use the same instruments for POA, GHI and RI measurements. These are typically spectrally flat Class A (secondary standard) pyranometers. You can then also use the same calibration services
- use either 2 x single pyranometers or modular instruments consisting of 2 x pyranometer, this is easier for servicing and recalibration
- consider performing surveys for site characterisation in different seasons (also relative to the unobstructed reference station) to determine ground surface properties. This is a requirement for uncertainty evaluation
- as an alternative for surveys, consider using multiple instruments between the arrays to verify model calculations of reflected irradiance and get an idea of its spatial variability; when using multiple instruments between rows, you may also employ lower accuracy (spectrally flat class B or C) instruments. Typically, these instruments are installed horizontally facing down, in some cases users choose to install in plane of array
- do not install pyranometers for RHI measurement below 1 m height; 1.5 m is a good and practical compromise
- for personnel safety, electrically insulate instrument body from PV array mounting frames
- after snowfall, do not use the values measured by an unobstructed reference albedo measurement station. An unobstructed station will not have snow patterns representative of those between arrays

Performance model, ratio and index

The new IEC 61724 "Photovoltaic system performance" series of standards is the best available source that defines parameters such as "performance ratio" and "performance index". IEC uses the following definitions:

- **performance model** gives a mathematical description of the electrical output of the PV system as a function of meteorological conditions, the system components, and the system design. This model is typically agreed upon in advance by the stakeholders of the test.
- **predicted output** is the output for a given period as calculated using the performance model based on historical weather data
- **expected output** is the output calculated using the performance model when entering measured weather data
- **rating** performance as specified by the manufacturer, usually confirmed via the name-plate on the panel, or as agreed upon by a supplier, typically under reference conditions such as Standard Test Conditions (STC)
- **performance ratio (PR)** is the ratio of measured output to expected output for a given reporting period based on the system name-plate rating
- **performance index** is the ratio of measured output to expected output for a given reporting period based on a more detailed model of system performance than the performance ratio

Site survey on a sunny day

To investigate the characteristics of the site, users may perform a site survey. During the survey you may walk around with an albedometer and measure at different locations. Under stable solar conditions you may also use a single pyranometer and invert it.
The purpose of such survey is to investigate:

- spatial variability of the (ground surface) albedo
- seasonal variability of the albedo
- correlation between a field station and the conditions at the arrays.

At the location of all POA measurements, IEC 61724-3, clause 5 requires measurement of the local albedo to verify that it is representative of the albedo of the total power plant, fits the assumptions made in modelling, and to use the measurements in the uncertainty evaluation of the performance test.

Recommendations and boundary conditions for the survey are:

- choose a sunny day, with limited cloud cover and solar elevations above 60 degrees

- you are interested to measure the ground surface properties: measure above unshaded locations with a representative ground surface / vegetation
- Measurements in shaded locations typically provide a signal level that is too low to make a good albedo estimate
- in case there is seasonal vegetation, measure at 2 to 4 moments in the year
- you may use an albedometer or under stable solar conditions you may use a single pyranometer and invert it

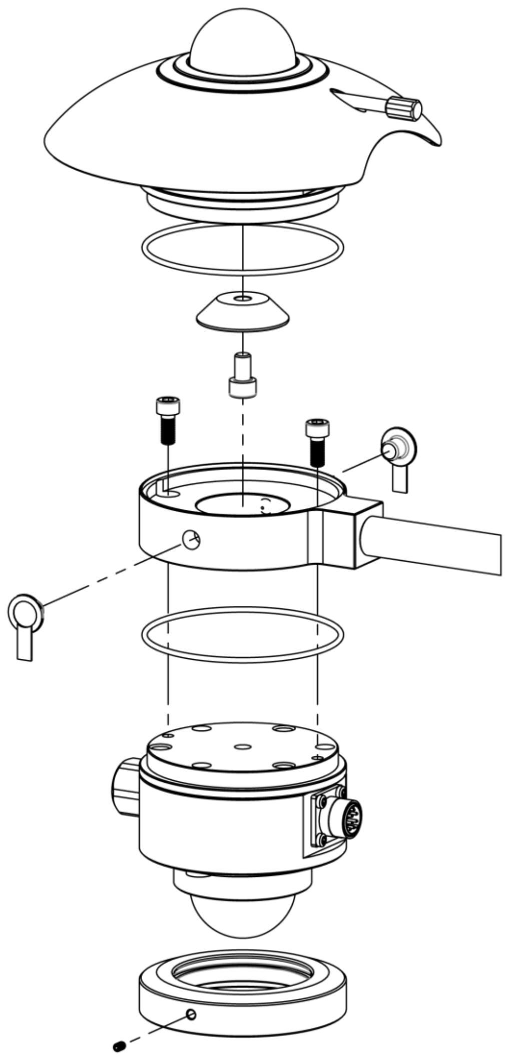

Figure 3 *how the albedometer of Figure 2 is constructed of 2 x pyranometer.*

Installation height

If the pyranometer is too close to ground surface, it will measure in a small area only and its own shadow also becomes a source of error. If it is installed too high, you can no longer inspect and clean it. A 1.5 m installation height is a good compromise.

Recalibration

We recommend re-calibrating pyranometers every 2 years. Typical indoor calibration can efficiently be done with a standard model pyranometer housing an albedometer does not fit in. This is why we prefer albedometers constructed from 2 x standard pyranometer like in Figures 1, 2, 3 and 4.

Electrical insulation and protection

For personnel safety, we recommend keeping pyranometers away from the PV array mounting frame. In case connection is unavoidable, for example when used with 1-axis trackers, make sure the connection is electrically insulating, for example using plastic mounting plates. Protect both sides, instrument and datalogger, against electrical surges.

In plane of array or not?

A pyranometer measures irradiance in the plane of its sensor surface. To directly measure the usable irradiance for the PV panel backside, the pyranometer must be aligned with the PV panel backside, so in plane of array. However, most performance models assume you measure the horizontal albedo. The model later corrects to plane of array, using at least a view factor and sometimes more advanced modelling.

Glare screen?

A glare screen limits the full field of view of the downfacing pyranometer to 150 ° (it is normally 180 °). This is useful for horizontal albedo measurements; in case you do not use a sunscreen, at sunrise and sunset the downfacing pyranometer may measure similar values as the upfacing pyranometer, suggesting albedo's larger than 1, which is physically not possible. Using a glare screen is not a requirement: Nowadays measurements suffering from glare-related errors are eliminated from the dataset by software limiting the measurement of the downfacing sensor to solar elevations > 10 °. When measuring reflected radiation in Plane of Array (POARI), using a glare screen is not good practice; you simply miss part of the incoming irradiance.

What pyranometer to use

General recommendations for choice, calibration and cleaning of pyranometers of IEC 61724-1 are summarised in a separate note.
Hukseflux pyranometer model SR30 is compatible with the requirements of Class A monitoring systems.

Hukseflux
Thermal Sensors

Figure 3 *the Tube mounts of SR30 and SR15 and SR05 can very well be used to measure global, reflected, and Plane Of Array irradiance. For downfacing instruments we typically do not use the sunscreen. See also Figure 1.*

See also

- SRA01, SRA20-D2, SRA30-D1 albedometers
- AMF and ALF mounting and levelling kits

About Hukseflux

Hukseflux Thermal Sensors makes sensors and measuring systems. Our aim is to let our customers work with the best possible data. Many of our products are used in support of energy transition and efficient use of energy. We also provide services: calibration and material characterisation. Our main area of expertise is measurement of heat transfer and thermal quantities such as solar radiation, heat flux and thermal conductivity. Hukseflux is ISO 9001 certified. Hukseflux products and services are offered worldwide via our office in Delft, the Netherlands and local distributors.

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