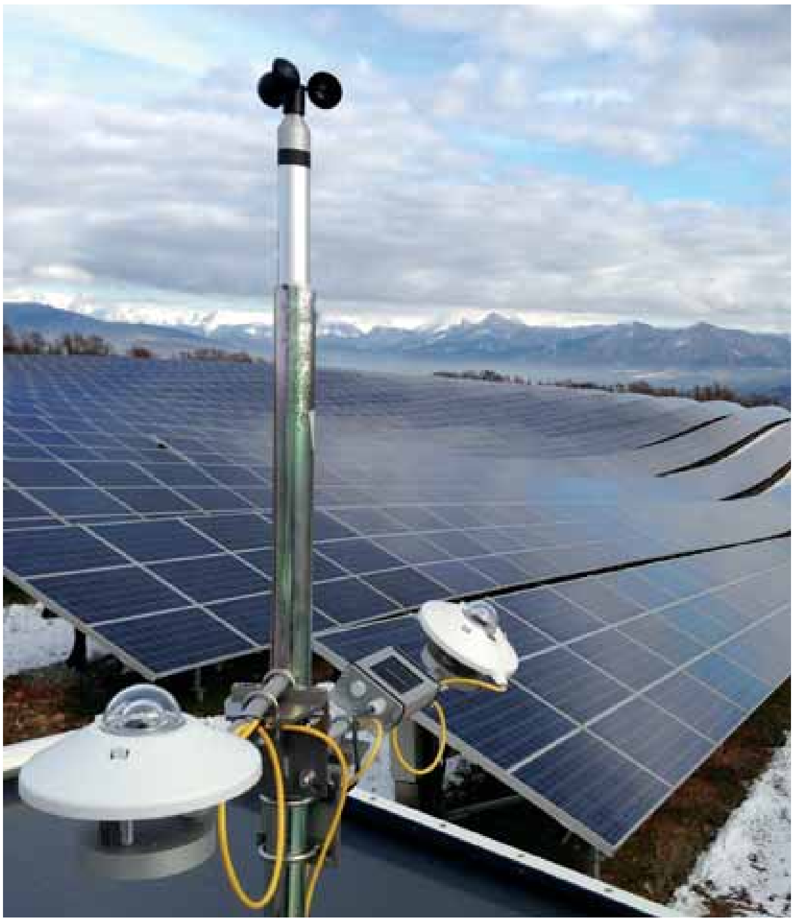
The art and science of pyranometers

Irradiance measurement | Pyranometers play a crucial role in gathering irradiance data for PV yield and performance modelling. Ben Willis explores this sometimes-overlooked piece of technology and efforts by researchers to improve our understanding of its characteristics



Source: PTS Mesures.

Pyranometers are a vital part in the planning and ongoing monitoring of PV power plants.

About the size of a dinner plate and resembling something akin to an alien spacecraft, the humble pyranometer is an understated but essential element in the design and operation of a PV power plant. While irradiance data from satellites offers a useful broad-brush assessment of the potential profitability of a proposed PV plant, it is no match for measurements taken directly from the site itself.

Pyranometers are precision instruments that measure global horizontal irradiance, the amount of electromagnetic radiation from the sun falling on a flat surface at a given location. Although it will not always be economically viable or indeed necessary to have a pyranometer installed at every prospective PV site, in the further-flung parts of the world where the data is patchy, or in areas with specific climatic conditions, they will be essential in helping make the business case for a project.

"There are some unexplored areas in the world where people cannot make use of the solar atlas, they cannot make use of solar satellite information," says Kees Hoogendijk of EKO Instruments Europe, a manufacturer of pyranometers. "Satellites are not very precise on radiation quantities. So you can say 10-15% uncertainty is normal. And for many investors it's not sufficient to plan a big project."

The power of pyranometers lies in their ability to tease out inherent uncertainties in the data derived from satellites. As explored in the previous issue of *PV Tech Power*, prevailing practices in the use of satellite data do not allow for a particularly nuanced picture of the variability of site irradiance conditions, leading to either excessively conservative or overly optimistic energy assessments. But by combining datasets – from satellites and from ground stations – some of those uncertainties can be if not eliminated then significantly reduced.

"[Combining datasets] can change the overall irradiance values up or down," says Gwen Bender, an energy assessment engineer for forecasting firm, Vaisala. "You see benefits from that because it's pretty much a one-for-one relationship between irradiance and power. So if I can raise the estimate by 2% that's 2% more power you're going to see in modelling.

"But the biggest impact is in the reduction of the uncertainty. So if we have a full year of observational data and the correction process goes well we can see a reduction of half or even more in the uncertainty that we could assign to the [energy assessment] model. There are very few things where you can reduce the uncertainty by half."

Cleaned up

But as with a PV power plant, which can be subject to any number of external factors, the effective operation of a ground station incorporating pyranometers requires similar care. Bender says all too often she receives datasets from ground stations where it is evident from the quality of the information being presented that the proper procedures to ensure its accuracy have not be observed.

"The care and maintenance of equipment and reviewing your own data on occasions is pretty critical to having at the end of the year a dataset you can use to materially reduce your uncertainty," Bender explains. "It is continuously surprising to me how many people never look at their data, and are then surprised at the end of a year when months of it is unusable."

Two basic practices that are not always followed are cleaning and keeping the ground station site free of vegetation. "I've seen stations where they mowed down vegetation, installed the station and then things grow back up," Bender says. "So the first couple of months are ok, then you start to get this weird shading.

"People tend sometimes to not look at the data as often as they need to. And the problem is you've spent the money but you don't have the data – or you have to wait another year because you have to catch that season again."

On cleaning, the right regime will depend on a site and its particular conditions, but the message from experts is that more rather than less is preferable. "If you talk about reference equipment it's better to clean it more frequently," says Hoogendijk. "It's really critical – like your module, your sensor instrument will also be subject to soiling and the output will be subject to that."

According to Dmytro Podolskyy, business manager at pyranometer supplier Kipp & Zonen, for a high-quality ground station, the ideal regime would be daily cleaning, particularly of the pyranometer's glass dome, on which a build up in soiling could be detrimental. But for sites in deserts or other remote locations, daily cleaning clearly becomes more complicated. In such cases, other equipment may be needed.

"What we recommend is you use a ventilation unit," Podolskyy explains. "It blows air around the dome continuously and prevents dust accumulating, and also water. It helps keep the pyranometer clean for a much longer period of time – weeks or even longer. Of course when you have dirt already there, it cannot clean it, but it keeps normal dust and pollen from accumulating."

Another approach used to mitigate the impact of soiling is to have more advanced stations that combine a number of different instruments to allow for the collection of comparative data. Typically says Podolskyy, such a station would combine two pyranometers and a pyrheliometer, which is pointed directly at the sun to measure direct radiation.

"What people do is compare the data from all these three, because they're all related to one formula. And if you compare them, if they're same, everything's fine. If it changes, then probably you've got a soiling problem and you will not get the same data from all of them," Podolskyy explains.

Whichever cleaning and maintenance regime is followed, Bender says proper recording is essential from the point of view of interpreting the data that eventually comes out of a ground station.

"Even when cleaning and maintenance are being done, they're not being recorded," she says. "So then you're looking at a data stream of two years day by day and wondering if this data is dirty or if it's just not that sunny. I would love to see better records – calibration certificates, maintenance records … if anyone goes out and touches the equipment there should be a record of it."

This is a crucial point, as without the sort of records Bender refers to, there is little to tell the data analysts what is going on in a dataset and therefore how to handle it.

"If you know a client cleans every two weeks, you'd see the peak numbers getting a little bit lower, a little bit lower, then they would jump [after the cleaning] and we'd know not to use data from the previous two or three days when the level starts to drop; removing two or three days in course of month will not have an impact on our ability to do the corrections," Bender says. "But if we don't know they've cleaned, or it's not obvious, then we're relying more on guesswork and our experience than on hard facts."

Pyranometer characterisation

Aside from the vagaries of soiling and the appropriate maintenance, as sensitive instruments, pyranometers themselves display particular characteristics that can affect the data they collect. Precisely what these are will depend on the type of instrument in question.

Broadly speaking there are three categories of instruments used to measure global irradiance – thermopile pyranometers, photodiode pyranometers and reference cells (see box). Because of the different quality of these instruments and different technologies they use, each will display sensitivities to a greater or lesser degree to certain environmental factors that will affect their performance.

For example, says Anton Driesse, founder of PV Performance Labs, a Germany and Canada-based consultancy, the angle at which the solar irradiance strikes the instruments can have an effect. "If sunlight comes in at an oblique angle to the instrument surface and some of the light is reflected, then the instrument is not going to give a true reading of the available energy. The better instruments will have smaller errors in that respect."

Another issue is so-called non-linearity, where the strength of the signal coming out of the pyranometer becomes disproportionate to the signal coming in. "The [thermopile] pyranometer is a thermal instrument: it measures the rise in temperature of a black surface in response to sunlight. But you have heat losses in various directions, and within the glass dome you can even have air currents because of the small temperature differences," Driesse explains.

"Such effects can lead to an instrument becoming non-linear. So if at full sun you were to get a reading from one of these instruments saying you've got 1,000W/sq metre, at half that intensity you would expect to have a signal that says 500, but if the instrument is non-linear, it might say 490 or 510."

Indeed, Driesse says that even a gust of cold wind on an instrument can impact its output, even if the irradiance falling on it does not change. "Designing a pyranometer is a bit of an art as well as a science"' he says. "Fortunately we have companies that have been at it for a very long time and developed both aspects, and as a result we do have very good instruments available. But they're not perfect."

Understanding these imperfections and how they affect the performance of different instruments is an entirely new field of study into which Driesse is leading the way. He says that although manufacturers are aware their instruments demonstrate different characteristics and provide customers with some data on this to help them compensate, this information is incomplete.

"People are aware there are different quality instruments available. But if you look at the [manufacturers'] specifications, you can't really get a sense from those of what's going to be your margin of error, or uncertainty, when you use this instrument to assess your PV system. It's very hard to make that link," Driesse explains.

"So if you have a bit of budget, you tend to go for the best because you can't do any better. And otherwise you rely on what the supplier tells you about their instrument choices. But it's very hard to put your finger right on what the trade off will be in terms of percentage of uncertainty."

Driesse has embarked on a major study of some of the main brands of irradiance sensors on the market today in an attempt to amass some hard data on their relative characteristics. About half are thermopile pyranometers and the others are photodiode pyranometers and reference cells. He has already carried out one round of indoor tests at the European Commission's Joint Research Centre in Ispra, Italy, and is working with Sandia National Laboratories in the USA for a round of outdoor testing. After that the instruments will be deployed side by side and carefully monitored for at least a year – half of them at Sandia in the USA, and the other half back in Europe.

The result of this will of course be a huge amount of data. Driesse says he is collaborating with his testing partners to analyse this data and will try to publish results and observations as they become available rather than wait until the last round is completed. He is convinced that the findings from the study will be beneficial to the solar industry and will "help people select instruments and understand where their vulnerabilities are and understand the nature of the uncertainties".

Unsurprisingly Driesse senses there's a "keen interest" among instrument manufacturers "to know what I find out". He hopes that rather than serving companies' marketing objectives, this information will be used by them to improve their products and thereby the accuracy of PV yield and performance assessment.

And with investors becoming ever more discerning in the quality of the data they are looking for, that can only be beneficial to the wider solar industry. ■

Irradiance instruments

Thermopile pyranometers These contain an element that warms in response to solar irradiance, producing a proportionate voltage signal. Thermopile pyranometers are sub-divided into different quality classes, with 'secondary standard' offering the best data and fewest imperfections, followed by first or second class.

Reference cell These are essentially photovoltaic cells that are used to measure irradiance. As they are less sensitive to the full spectrum than thermal pyranometers, reference cells are better suited to measuring available irradiance than overall "broadband" meteorological irradiance. This makes them better suited to characterising PV system performance as they behave in a similar way to a PV cell.

Photodiode pyranometer A mix of the two, containing a tiny photocell internally, but designed to behave as much as possible like thermal instruments.

Source: Kipp & Zonen.

A major study is underway to characterise some of the main brands of irradiance sensor on the market.

Irradiance sensors being tested in the PV Performance Labs characterisation study.

Manufacturer	Secondary Standard Pyranometer	First or Second Class Pyranometer	Photodiode Pyranometer	Reference Cell
The Eppley Laboratory	PSP SPP GPP			
Hukseflux Thermal Sensors	SR20	LP02 SR03		
Eko Instruments	MS-802	MS-602	ML-01	
Kipp & Zonen	CMP 10	CMP 3	SP Lite2	
Apogee Instruments			SP-110	
LI-COR			LI-200	
Skye Instruments			SKS-1110	
Energy Environmental Technical Services				RC01
Fraunhofer ISE				11311102.00
Ingenieurbüro Mencke & Tegtmeyer				SiS-02-Pt100 Si-02-Pt100 Si-02-Pt100-x
NES - Mess- und Meldesysteme				SOZ-03
Total	**6**	**4**	**5**	**6**