★ PES ESSENTIAL

Fast response sensor for solar energy resource assessment and forecasting

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Our industry continually strives to get better, smarter energy. Research and development means there are always new innovations on the market. PES brings you the latest in fast response sensors from EKO, for measuring solar radiation due to various cloud conditions. This plays an important part in the quality of converted energy from solar devices.

Even though the solar radiation incident at the top of the Earth's atmosphere is relatively constant, the amount of solar radiation arriving at the Earth's surface is extremely variable. It depends on the location, date and time of the day, and on the atmospheric conditions.

It is well known that absorption and scattering by gases, aerosols, and water vapour present in the atmosphere have attenuating effects on the incoming radiative power. It is also well known that the attenuation of the incoming solar radiation caused by clouds is larger than any other atmospheric component.

Another atmospheric effect has gained interest recently, while being counter intuitive – clouds can also cause enhancement of the incoming solar radiation. Partially cloudy skies with broken clouds lead to multiple scattering and radiation reflection. At times this may result in increased irradiance from a portion of the sky exceeding the expected irradiance value during actual clear sky conditions.

Furthermore, during partially cloudy-sky conditions, fast passing clouds induce irradiance variations with high frequency. During such conditions, either the sun becomes covered by clouds or it doesn't, resulting in a short period with low irradiance followed by a short period of high irradiance, whereas the size of the irradiance step depends mostly on the season, time of the day, and cloud geometry.

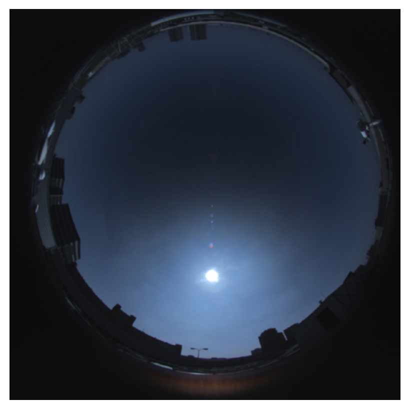
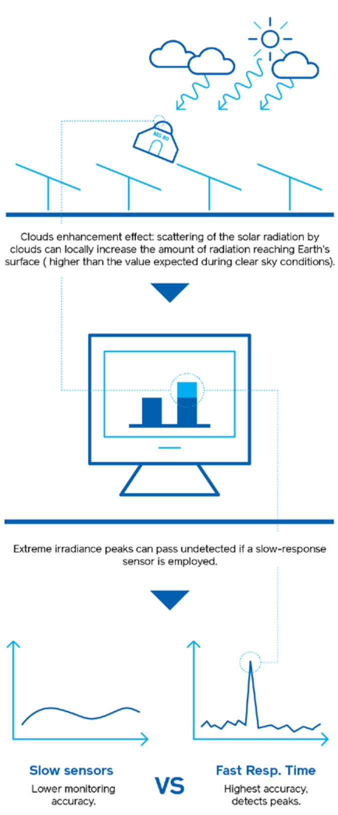


Figure 1. EKO SRF Cloud camera images acquired during solar noon for one clear sky day (top) and for one cloudy sky with broken clouds (bottom)

Fast responding to peak irradiance



These transient effects often referred to as solar radiation ramps, or power ramp rates have a big impact on the quality of the energy converted from solar devices. This effect however is very much linked to the amount of time that the device requires to react to a change in irradiance – the response time.

The impact is lower for solar thermal devices. Since these devices have a slow response time to irradiance steps, the irradiance peaks tend to be smoothed during the energy conversion.

On the other hand, solar Photovoltaic (PV) devices have an extremely fast response time to the irradiance peaks and in this case, proper attention is required. PV devices operate under the photoelectric principle, in which light is directly converted into electricity and this process can range from micro-seconds to a few milliseconds.

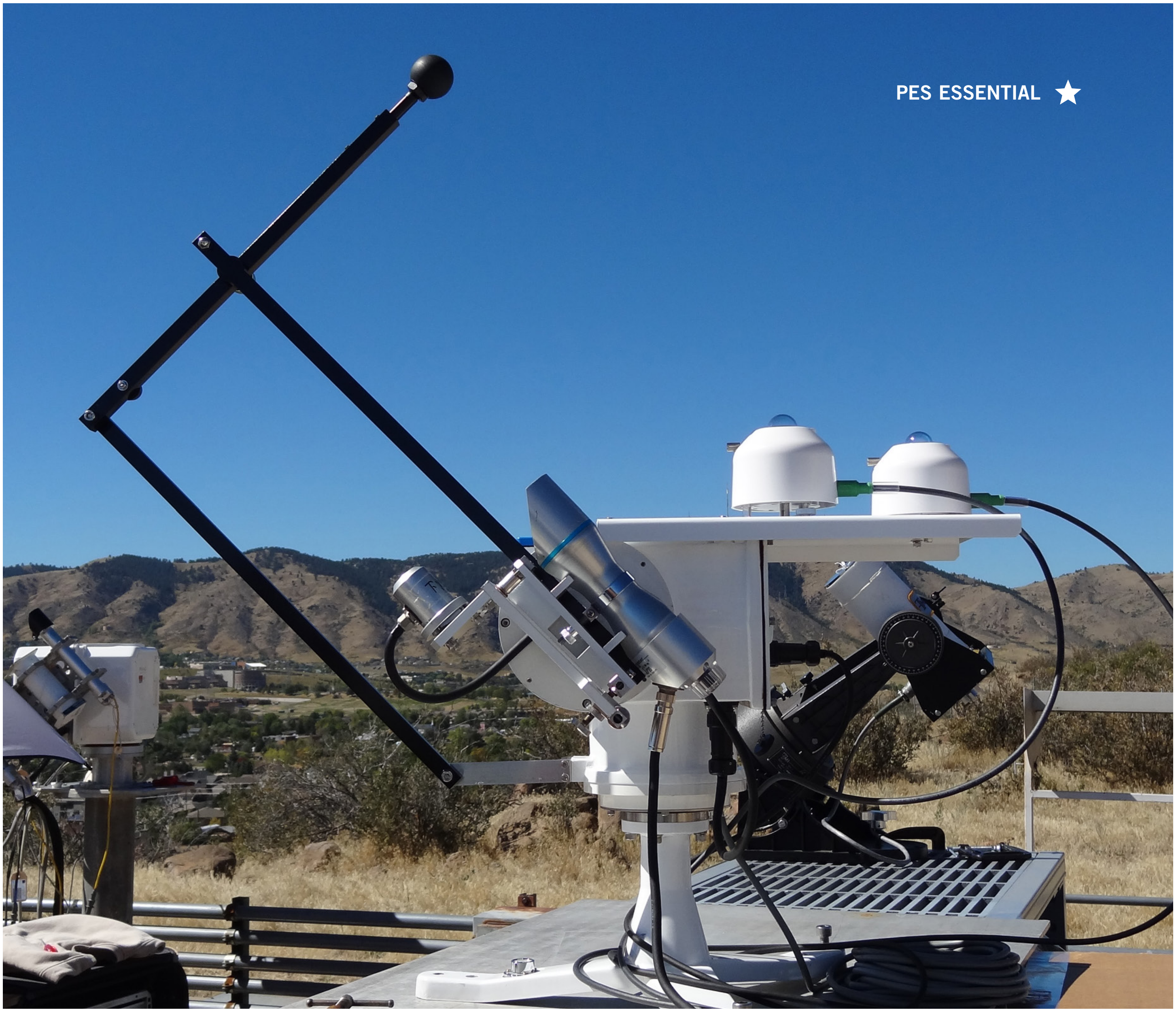
The converted electricity can be used directly, stored, or fed into the electrical grid. The different configurations require different components, which are size based on the PV modules ratings under Standard Test Conditions (STC – 1000 W/m^2 of broadband irradiance, with a spectral distribution according to the ASTM Air Mass 1.5 global spectrum and 25°C device temperature). In some extreme cases, enhancement effects may lead to irradiance values above the extra-terrestrial solar constant (approximately 1367 W/m^2, varying within ±3%).

In the past, such events were regarded as instrumentation errors, but with the improvement of tools for observation with lower uncertainty, there is a better understanding of the dynamics in the atmosphere.

Global horizontal irradiance (GHI) values well above the solar constant have been measured and reported for several locations, for example: >1500 W/m^2 in Norway (G. H. Yordanov et al., 2013), 1533 W/m^2 in Cyprus (R. Tapakis and A.G. Charalambides, 2014), 1832 W/m^2 in Ecuador (P. Emck and M. Richter, 2008), 1891 W/m^2 in Colorado, USA (C.A. Gueymard, 2017).

Cloud induced extreme irradiance events have a stochastic nature and therefore, their duration, frequency and magnitude, are extremely variable and differs from location. In some cases, these fluctuations may lead to energy surplus higher than would be predicted by clear sky models (R. H. Inman, et al. 2016). To properly understand their short-term and long-term impact in PV devices and components, accurate measurements should be carried out.

Likewise, the uncertainty associated with the quantified solar resource will define a strong business case and the project investment risk. Since, PV devices are now being cost effectively broadly applied at utility scale,



the larger the amount of PV devices connected to the electrical energy grid, the larger the impact and concern for the utilities' operation during the passage of clouds.

Miscalculations in the PV plant performance will result in lost revenue, as well as over and underproduction penalties depending on the power purchase agreements, which are both based on the available solar resource. Such concerns have led to the need of advanced cloud detection and solar forecasting tools, by means of ground based measurements such as: cloud cameras and radiation sensors spread out and operating within a network.

Discerning short-term trends can only be detected with sensors capable of providing quality short-term data. The faster the predictions are, the faster the sensors need to be. The measured irradiance value during solar radiation ramp events is, however, strongly conditioned by the type of detector used, as well as by the data acquisition system settings. To accurately measure the actual irradiance value with reduced uncertainty, the need of proper instrumentation with faster response times, as well as data logging parameters, is frequently mentioned in the literature.

For solar irradiance monitoring, the sensors that allow measurements with the fastest response times are photodiodes and reference cells, since they both operate under the photovoltaic principle. However, such devices do not respond equally to all regions of the solar spectrum.

Furthermore, most commonly employed sensors of this type have the spectral response of silicon, resulting in the under sampling of the solar spectrum. Not to mention that silicon spectral response is not uniform, and peaks at the red and near infrared region of the spectrum, away from the green region of peak emission from the sun.

During the course of a clear sky day, the sky shifts from red to blue to red due to Rayleigh scattering, resulting in broadband irradiance measurement overestimations during sunset and sunrise and underestimations during solar noon, due to the spectral mismatch of silicon sensors (D.L. King and D.R. Myers, 1997).

During the fast passage of clouds, the spectrum will vary abruptly resulting in a higher measurement uncertainty, but still these sensor types provide the best measure of variability in time, during very fast transient irradiance measurements.

Thermopile based pyranometers, on the other hand, have a nearly flat spectral response, minimising possible spectral mismatch effects. The limitation for measurements during solar radiation ramps rests in the thermopile response time. Thermopile devices operate under the thermoelectric effect, in which a temperature variation is associated with a voltage potential. The temperature variation in the thermopile is directly proportional to a variation in irradiance, which, in turn, depending on the quality of the device, takes a few or several seconds to respond.

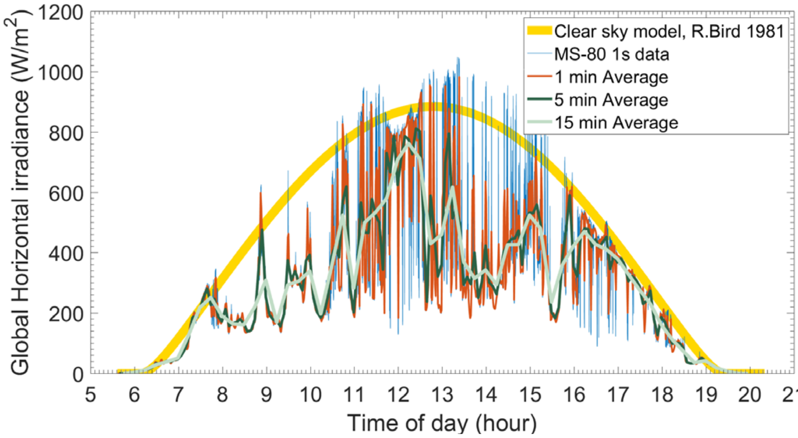


Figure 2. Effect of different averages and cloudy with clear sky model

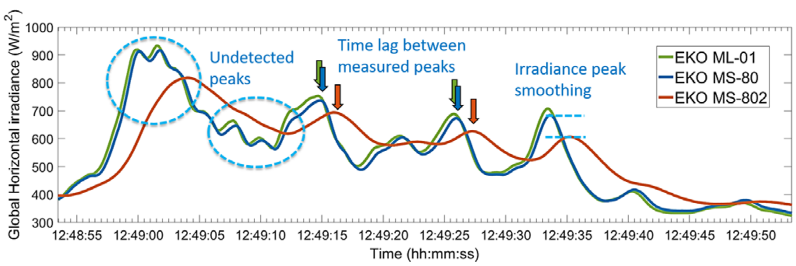


Figure 3. Data sampled at 100ms for the different sensors during solar radiation ramps

The international standard ISO 9060:1990, classifies the instruments for measuring the hemispherical and direct solar radiation. Performance required by pyranometers and pyrheliometers under this standard are well established, as are the instrument classes, according to several parameters that characterise the sensor performance.

The time to reach 95% full response is one of these parameters and the corresponding classes from best to worst measurement uncertainty are as follows: Secondary standard < 15 s, First class < 30 s, Second class < 60 s.

Meanwhile the fastest significant short-lived irradiance peaks are in the order of a few seconds. Consequently, to measure fast irradiance variations simply complying with the standard is not enough.

Recently, EKO introduced several Secondary standard thermopile detectors with response times below 1 s. The EKO MS-80 pyranometer (< 0.5 s response time) and, MS-56 (< 1 s) and MS-57 (< 0.2 s) pyrheliometers are the thermopile sensors with the fastest response time available in the market.

Incorporating a fast thermopile detector inside the sensor body, rather than on the surface, is a new concept in solar radiation sensors. It allows not only for very fast sampling rates, but also lower thermal offsets and a better long-term responsive stability.

However, novel sensors with 10 times faster response times require revised data acquisition sampling criteria, which if not complied may lead to measurement discrepancies when comparing with other slower, secondary standard sensors.

Case study: Effects of averaging and outdoor validation of MS-80 fast response time

Measurements performed at the EKO Instruments Europe outdoor test facilities, in The Hague, The Netherlands, are used as examples of the following discussion.

Firstly, a case study that explores sampling parameters and the effect of averaging is shown. In Figure 2 we plot 1s data acquired for the new MS-80 pyranometer during a partially cloudy day. In the same figure, we also provide an estimate of the GHI under a cloudless sky for that same day, calculated by a simplified clear sky model (R. Bird, 1981).

Here we can observe small spikes over the clear sky conditions that correspond to cloud enhancement after short lived peaks. Additionally, we perform 1 min, 5 min, and 15 min averages on this data, to exemplify the information loss due to low temporal resolution of data logging parameters. As expected, the longer the average time interval is, the lower the retrieved irradiance detail is. What is also interesting to see is that, depending on the applied average interval, the irradiance peaks may shift in time.

Next, to validate the measurements of our new fast response thermopile pyranometer, we present data acquired during the same day for 3 different sensors at 100ms sampling rate: one secondary standard thermopile pyranometer MS-802 (< 5 s response time), the recently developed MS-80 fast thermopile pyranometer (< 0.5 s response time) and one ML-01 photodiode sensor (< 1 ms response time). The photodiode is used as a measure of irradiance variability.

While the MS-802 lags within 3.8s to 4s, the MS-80 thermopile pyranometer follows the fastest sensor really well, lagging only 0.4s to 0.5s from the ML-01 photodiode sensor.

It is also possible to observe that the traditional secondary standard pyranometer smooths the rapid variations, resulting in an underestimation of the irradiance value during the short-lived peaks, the variations bellow 4s are barely perceived by the slowest sensor. This effect is of course scalable to sensors with slower response times.

To measure the true value of the peak irradiance and keep the uncertainty levels as low as possible, high-end ground based solar irradiance measurements should be carried out on site, together with fast sampling rates.

Time is of the essence for solar irradiance prospection and reliable fast sensors, with faster sampling parameters, will permit gap reduction in-between forecasts, which in turn will provide accurate measurements, to unlock the potential of accurate tools for short term solar irradiance forecast and solar resource assessment.

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