SYSTEMATIC ANALYSIS OF METEOROLOGICAL IRRADIATION EFFECTS

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ABSTRACT: Since installation in 1997, the weather profiles as well as the performance of a 1 MW PV system in Munich have been recorded in second intervals and have shown effects of unexpectedly high irradiances. This study investigates this phenomenon, which is the effect of cloud enhancement. Cloud enhancement refers to increased solar irradiation values due to cloud reflection. The sharply defined edges of cumulus clouds lead to reflections and thus to cloud enhancement effects. Monitored irradiance and temperature profiles clearly demonstrate this effect and its correlations. The systematic analysis of these profiles in high resolution meteorological data records indicate on the basis of time period, frequency and energy yield the importance of the review of these weather characteristics. Spectral distribution recordings of the entire courses of cloud enhancement incidents display the influence on the wave lengths. Up to now cloud enhancements effects in PV are largely underestimated and should be incorporated in system sizing and design to ensure optimal performance.

Keywords: Modelling, Irradiation Effects, Solar Radiation, Spectroscopy

1 GOALS AND MOTIVATION

In 1997 a 1 MW large photovoltaic (PV) system was installed in Munich. Since then, the environmental profile and the PV system's performance have been measured and recorded in one second intervals using Simatic WinCC[1] data logging solution. This paper delves into a very essential meteorological observation for PV systems within these data records: the effect of cloud enhancement and its correlations. Cloud enhancements refer solar irradiation values which are increased with respect to what is the theoretical maximum based on the solar position. This happens due to cloud reflections.

High resolution meteorological data records of Munich [4] [5], Kassel [6], Oldenburg [7] and Loughborough [8] have been analysed to illustrate the characteristics and importance of the cloud enhancement effect. Recordings of the spectral distribution show the course of this effect and its influence on the wave lengths. These short bursts of high power are associated with low temperatures, which means a PV system will see very high voltages,which might be in the range of the design voltages.

2 BACKGROUND AND MODELLING

Increased irradiation values are mainly caused by reflection on cumulus clouds (cloud enhancements, CE). Cumulus clouds form when warm air rises to altitudes up to 2 km where the moisture in the air condenses. Since these clouds mainly consist of tiny water droplets, their contour is sharply defined. They are isolated and opaque. Parts of the cloud that are exposed to sunlight glow deep white while the bottom area looks dark, due to the clouds own shading. Cumulus clouds can form in less than 10 min., dwell for up to 30 min. and dissolve as quickly as they came into being. It is impossible to forecast the exact amount and location of cumulus clouds, only a probability for their formation can be given. The sharply defined edges lead to reflections and thus to cloud enhancement effects. Typical irradiation profiles, their specific characteristics concerning clear sky as well as cloud enhancements can be modeled using libRadtran.

3 CLOUD ENHANCEMENT IN DAILY PROFILES

The effects of cloud enhancements are characterised in Figure 1. Diagrammed are two exemplary daily profiles of insolation values on a clear (27 July 2009, in red) and on a cloudy (8 July 2009, in blue) day. Regularly occurring spikes are visible in the blue curve. These spikes signify occurrences in which solar insolation values equal and even exceed those of the solar constant.

The fluctuating behavior also means that module and ambient air temperatures over the occurrence follow very different patterns as shown in Figure 2 for the two days shown in Figure 1. In red visible is a characteristic hysteresis curve of the module temperature upon a clear sky day. The run oft the blue curve displays the module temperature on a day with fluctuating irradiation. Increased irradiation values are also associated with decreased module temperatures due to cloud shadows between the cloud enhancement peaks.

[1] Simatic WinCC is a process visualisation and control system from Siemens AG

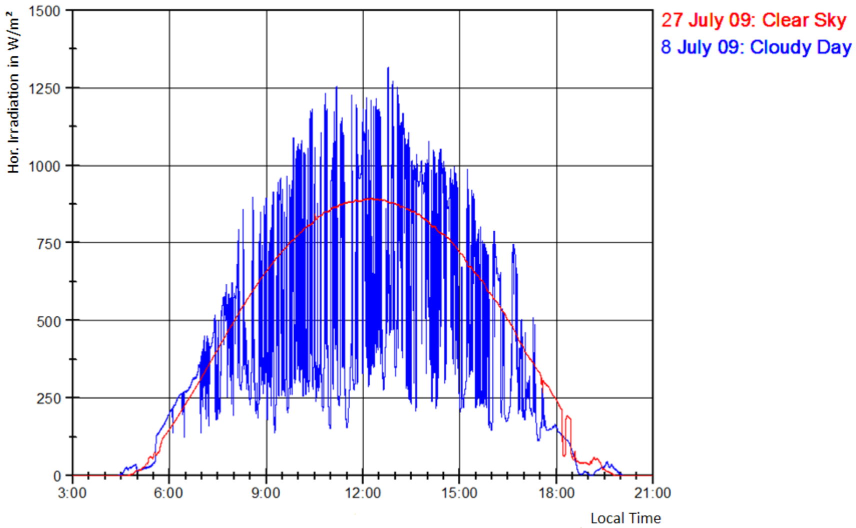

Figure 1: The chart depicts daily insolation values on a clear (red) and cloudy (blue) day. Measurements were taken at the horizontal using the CMP 21 from Kipp & Zonen.

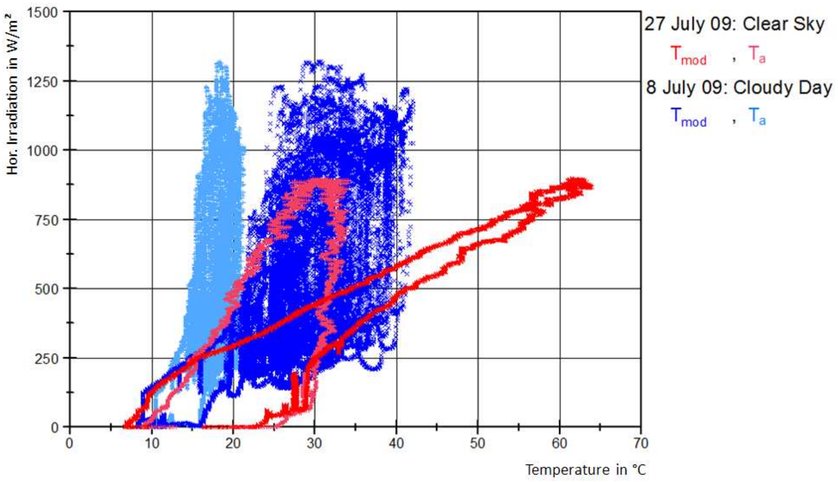

Figure 2: Module temperatures corresponding to the daily energy yield profile as in figure 1. The lighter shades of each colour represent ambient air temperature values. These were recorded using well ventilated air temperature sensors from Thies Klima. Module temperatures were determined by using reference modules containing PT100 sensors.

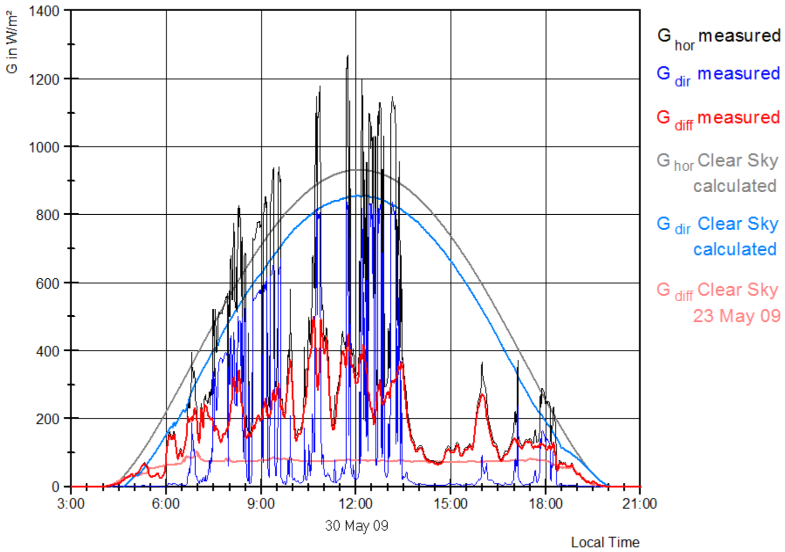

Figure 3: The black curve illustrates the daily profile of the global irradiation (30 May 2009). Visible in light grey (in light blue) is the computed (rectified) profile of the clear-sky day. The corrected clear-sky profile is also envelope for the direct radiation fraction (in dark blue). The cloud enhancement peaks become visibly in the measured values of the diffuse radiation (in red).

These peaks imply an intensive but limited irradiation input during coincidentally low ambient temperature. The inert thermal mass of the modules thus prevents a major increase of the module temperature.

Figure 3 displays another exemplary daily profile of the global irradiation (30 May 2009, in black). In light grey visible is the computed profile (libRadtrans [3]) of the clear sky for this day. The light blue curve shows a corrected profile of the clear sky day, which is also the envelope for the direct radiation fraction (in dark blue). Cloud enhancement peaks become visible in the measured values of the diffuse radiation (in red).

4 CLOUD ENHANCEMENT EFFECTS IN ANNUAL PRIFILES AND FOR VARIOUS LOCATIONS

The isolines in figure 4 show the calculated daily irradiation values (libRadtrans [3]) of clear sky days for Munich. This graph is superposed with measured incidents where the irradiation values lie above 900 W/m². These incidents are marked with a red colour gradient and mapped against the time of day. Thus the frequency, the duration and the intensity of the cloud enhancement effects for the year 2009 get displayed. The graph of these effects for the year 2008 lookssimilar.

Figure 5 displays insolation values above 900 W/m² classified according to the duration. This shows the energy yield of these classes for the locations Munich, Kassel, Oldenburg and Loughborough. If available, data sets of the years 2008 and 2009 were taken. Other than the coastal Oldenburg, Munich benefits from lower wind speeds, resulting in more incidents lasting longer than 300 sec. In Germany there seems to be a gradient from south to north, resulting in fewer long-lasting cloud enhancement effects in the north due to several reasons including different wind speeds. Loughborough benefits from lots of cloud enhancements but like Oldenburg has higher wind speeds than Munich. The cumulative values over the duration classes for each location indicate the importance of the consideration of this effect.

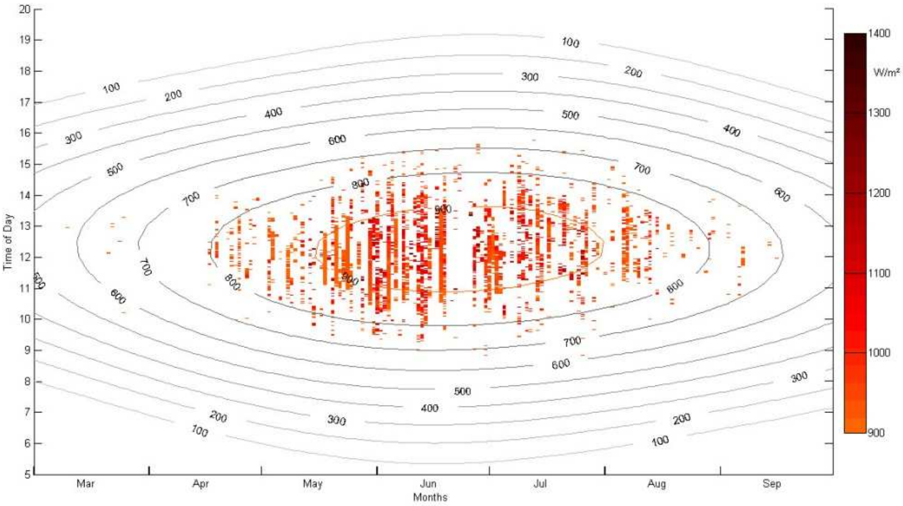

Figure 4: The isolines display the calculated daily irradiation values of clear sky days for Munich. This graph is superposed with the measured cloud enhancement incidents with irradiation values above 900 W/m² in 2009. The incidents are visible with a red colour gradient and are mapped against the time of day (showing frequency, duration and intensity of the effects).

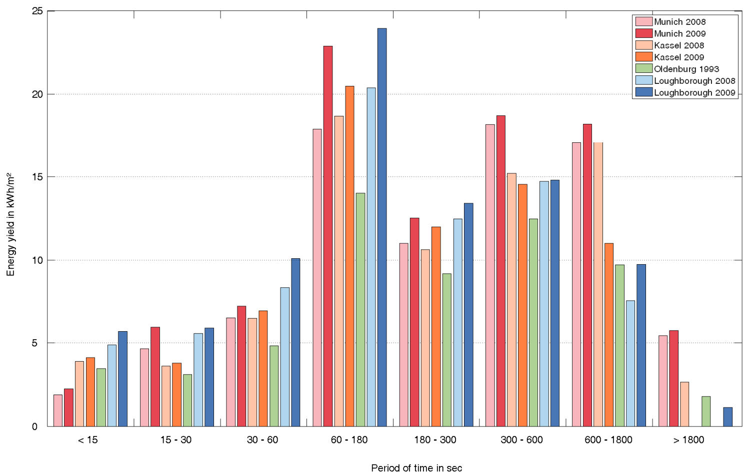

Figure 5: Insolation values above 900 W/m² classified according to the duration, showing the energy yield of these classes at multiple locations. If available, data sets of the according years 2008 and 2009 were taken. Other than the coastal Oldenburg, Munich benefits from lower wind speeds, resulting in more incidents lasting longer than 300 sec. In Germany there seems to be a gradient from south to north, resulting in fewer long-lasting cloud enhancement effects in the north due to several reasons including different wind speeds.

Figure 8 exemplifies an arbitrarily chosen entire course of a cloud enhancement incident on basis of spectral distribution on the 27th August 2010. Using the AgroSpec (by tec5) the spectrum from 305 nm to 1640 nm was captured. The first measurement (in yellow) shows clear sky conditions with an irradiation performance of 899 W/m², the last measurement (in red) was taken with the sun being covered by a cloud at 430 W/m². The colour gradient represents several snapshots that were sequentially taken in between. The movement of the cloud is observable in the varying course of the spectral distribution. In the sequence of this cloud enhancement incident one line drops beneath the clear sky curve with 757 W/m² due to shading by the cloud (in orange). This exemplary incident has a maximum cumulative value of irradiation performance at 1181 W/m². As the cloud draws closer to the sun especially the short wave part of the spectrum starts to rise.

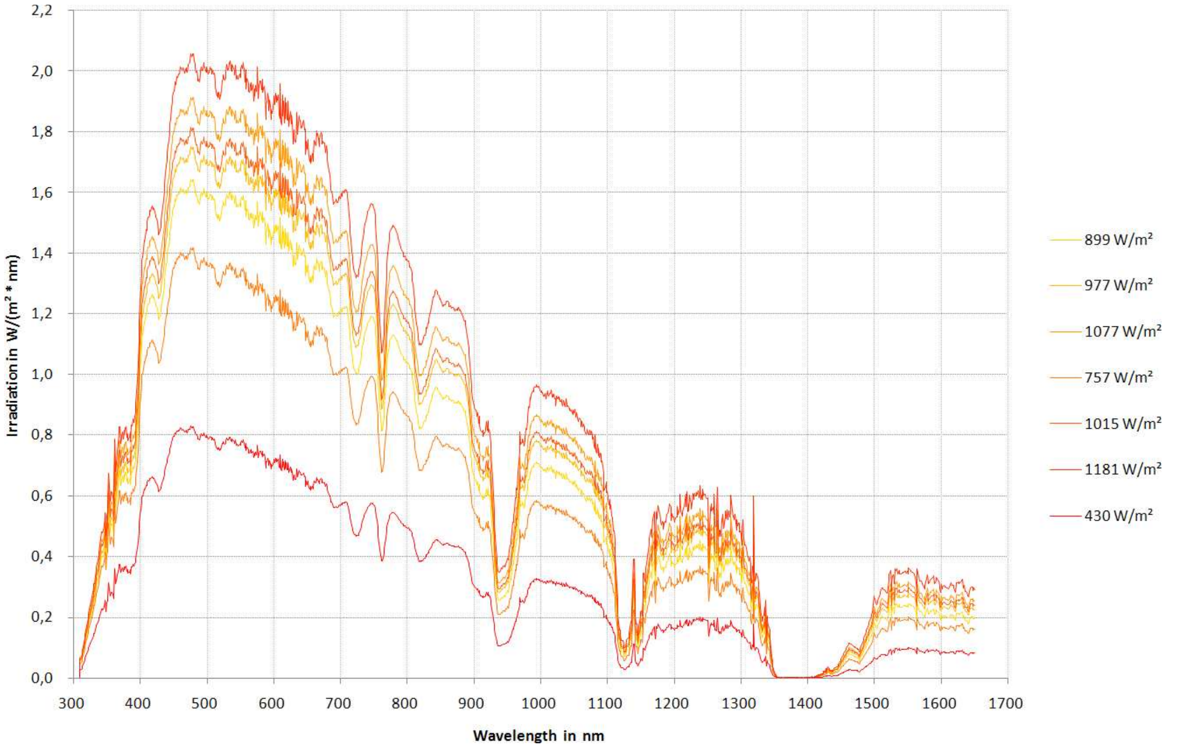

Figure 8: Using the AgroSpec (by tec5) the spectrum from 305 nm to 1640 nm was captured during an exemplary cloud enhancement incident. The first measurement (yellow) shows clear sky conditions, the last measurement (red) was taken with the sun being covered by a cloud. The color gradient represents several snapshots that were sequentially taken in between. As the cloud draws nearer to the sun especially the short-wave part of the spectrum starts to rise (orange). The diagram also shows that the peaks caused by cloud enhancement incidents mainly affect the short-wave range of the spectrum.

5 SUMMARY AND OUTLOOK

Cloud enhancements are an underestimated effect in the field of photovoltaic. Accurate evaluation and analysis of its profiles allow identification of its impact. These irradiation enhancements usually correlate with low module temperature. This is caused by reflections at low hanging and sharply defined clouds. Cloud enhancement effects should be incorporated in PV system design for optimal performance.

The next step of this project is to assure the previous results by evaluating additional locations on the European level. Therefore we are looking for further site data sets with highly resoluted energy meteorological data to extend this research, in order to give the results another validity and significance.

6 REFERENCES

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