

Fast dynamic processes of solar radiation

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Abstract

This paper studies dynamic processes of fast-alternating solar radiation which are assessed by alternation of clouds. Most attention is devoted to clouds of type *Cumulus Humilis*, identified through visual recognition and/or a specially constructed automatic sensor. One second sampling period was used. Recorded data series were analyzed with regard to duration of illuminated ‘windows’ between shadows, their stochastic intervals, fronts and the magnitude of increments of solar irradiance.

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Keywords: *Cumulus Humilis*; Duration; Interval; Front and increment of solar radiation

1. Introduction

In studying the correct functioning of a PV-array in combination with a battery and inverter, attention must be given to the dynamic behavior of the energy source. Likewise, the same principle applies to solar thermal systems, which perform under conditions of alternating radiation. They are cooled down and warmed up frequently, which increases losses. Fatigue of materials depends on the same alternating thermal processes, being a result of alternating radiation. The behavior of annual, monthly, daily and hourly averages of solar radiation is known in detail. Even minute-long averages have been studied to some extent (Gansler et al., 1995; Soubdhan and Feuillard, 2005; Tomson and Mellikov, 2004; Tomson and Tamm, 2006; Tovar et al., 1998). Lack of knowledge about faster processes of solar radiation in the second-long range has inspired the experimental study presented below. Over this range, diurnal and seasonal periodical processes have no meaning and may be eliminated. Therefore, the radiation relevant to this study can be considered a purely stochastic

phenomenon. The stochastic origin of radiation is caused by clouds, which will be evaluated from the point of view of their dynamic behavior, and the classification below differs from that used in atmospheric physics.

All data used in the paper were observed or recorded at Tallinn University of Technology 59°23'N, 24°40'E during the summer season of 2008 (from May till August). The monitoring pyranometer used is a photoelectrical model from SolData Instruments (DK), which has a transient response of a millisecond or less (SolData Instruments, 2009). A recording (sampling) interval of 1 s was used. The data were stored in the data logger of a GRAPTEC Corporation ‘Midilogger’ GL200.

2. Visual recognition of clouds

Visual recognition of clouds is a rough means of assessing a situation in which fast changes of solar radiation may be expected and recorded. This method is preferred due to its simplicity as it may be used by everyone and everywhere. Unfortunately, the result is not accurate enough as we will see later.

The conditions of the cloud cover were evaluated by two independent observers every noon following the classifica-

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Table 1
Conditions of the cloud cover.

Description	Evaluation mark
Clear sky	0
High turbidity or light (sparse) upper clouds	1
Overcast or foggy	2
Mainly cloudy with some cracks between them	3
High <i>Cumulus</i> , moving slowly	4
Low <i>Cumulus Humilis</i> , moving fast	5

tions outlined in Table 1. Situations ‘0’, ‘1’ and overcast clouds ‘2’ do not induce fast changes (high increments) of solar radiation, although solar radiation does always manifest small-scale fluctuations.

Arbitrarily, we consider the global solar irradiance¹ $G(t)$ as having small-scale fluctuations if the increment of the solar irradiance is $\Delta G < 50 \text{ W m}^{-2} \text{ s}^{-1}$ for clear sky conditions and $\Delta G < 150 \text{ W m}^{-2} \text{ s}^{-1}$ (Tomson and Tamm, 2006) in overcast conditions. The increment of the solar irradiance is defined as the difference between its values in a sequence of recordings $\Delta G = G_{n+1} - G_n$. A clear sky day has a low value of ratio between the standard deviation G_{stdev} and the average value G_{aver} of irradiance $G_{\text{stdev}}/G_{\text{aver}} < 1\%$. Fig. 1 shows examples: line 1 was measured on 27 June 2008 with parameters $G_{\text{aver}} = 949.4 \text{ W m}^{-2}$; $G_{\text{stdev}} = 1.33 \text{ W m}^{-2}$ and line 2 was measured on 26 May 2008 with parameters $G_{\text{aver}} = 891.4 \text{ W m}^{-2}$; $G_{\text{stdev}} = 0.88 \text{ W m}^{-2}$. Both of them were recorded with the 45° tilted surface facing due South. Both examples exhibit high frequency fluctuations.

Under light cloud cover, small-scale fluctuations have a greater magnitude and a lower frequency as shown in Fig. 2. The ratio $G_{\text{stdev}}/G_{\text{aver}}$ has a value in the range of a few per cent. Line 1 was recorded on 4 July 2008: $G_{\text{aver}} = 295.4 \text{ W m}^{-2}$; $G_{\text{stdev}} = 21.0 \text{ W m}^{-2}$; line 2 on 2 July 2008: $G_{\text{aver}} = 576.5 \text{ W m}^{-2}$; $G_{\text{stdev}} = 23.9 \text{ W m}^{-2}$.

Under heavy cloud cover (with several cloud layers), $G_{\text{aver}} < 100 \text{ W m}^{-2}$, small-scale fluctuations show a similar standard deviation as in the case of a clear sky. Large-scale increments may appear together with clouds of type ‘3’, alternating with cracks. High *Cumulus* clouds of type ‘4’ have abrupt edges and these induce large-scale increments with low (stochastic) frequency. Type ‘5’ low *Cumulus Humilis* clouds move fast and always induce high and frequent large-scale increments. The observations made during the summer season of 2008, from May till August, show a distribution of cloudiness as shown in Fig. 3.

Tallinn has a marine climate where cloudy and overcast skies prevail, but the proportion of fast alternating clouds is also significant (13%).

According to the observations (by different and independent observers), the share of days with alternating clouds (of types ‘3’, ‘4’ and ‘5’) was significantly lower (39% by

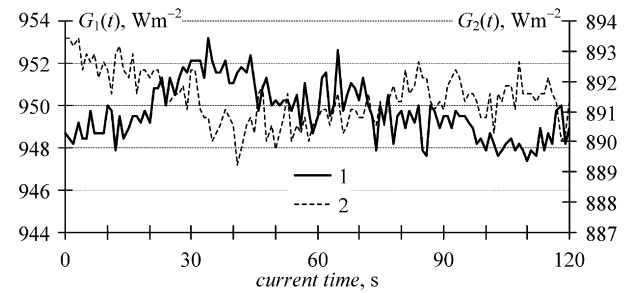


Fig. 1. Small-scale fluctuations of the solar irradiance in clear sky conditions.

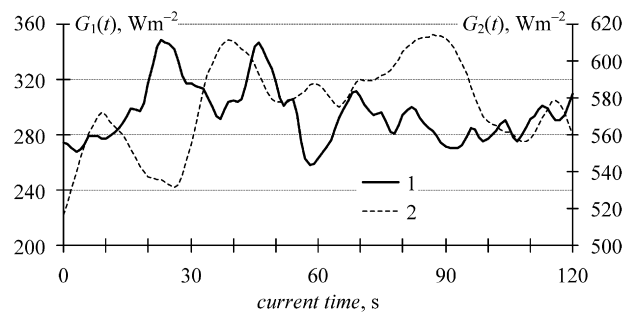


Fig. 2. Small-scale fluctuations of the solar irradiance under light cloud cover.

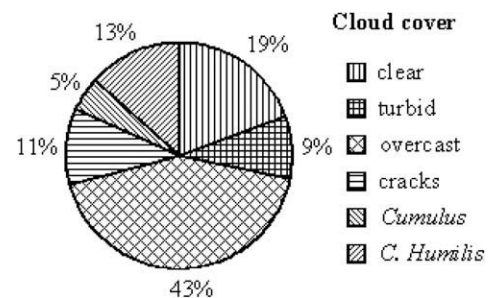


Fig. 3. Quality of clouds by observation.

the first and 7% by the second observer) than that discovered by the automatic sensor – 55%. The subjectivity of observers is high; also the frequency of observations (once per day) was too low.

As technical problems were likely to be encountered due to large-scale fluctuations, our main attention turned to clouds of type *Cumulus Humilis*, Fig. 4.

3. Automatic sensor to detect fast-alternating radiation²

To increase the reliability of analysis a special automatic sensor was constructed. Its schematic diagram is presented in Fig. 5.

¹ Here and below, we mean global solar irradiance G , unless stated otherwise.

² The author's approach to using specialized hardware is based on his former experience with designing electronic equipment. The same problem can be solved with a standard PC and continuous recording, which is extended with specialized software to delete uninteresting data.

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