SELECTION OF RECORDED SOLAR RADIATION

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Abstract

In this paper features of radiation are studied, which may be used selecting its alternating fragments. Among studied features are deviation and standard deviation from the moving average value of irradiance, sum of increments and difference between envelopes of the recorded dataset. The analysis has been made using EXCEL worksheets and its standard functions. Preferred feature for the selecting is deviation, which exceeds the conceded value. This approach minimizes the computation and allows selecting previously recorded datasets. Method of data selecting has been used for analysis of alternating radiation in Estonian summer in seasons 1999 –2002, which has a high share – 50% of the daytime.

Key words: solar irradiance, alternating fragments, EXCEL worksheet.

1. Introduction

Studying (fast) dynamical properties of solar radiation stable (or slowly changing) radiation is out of importance and its recording is redundant. In (Tomson, 2010) the problem has been solved by a specialized hardware. Recording is switched 'on' only then while during a 10 minutes interval increment of the radiation has twice (four times, switch able) surpassed a threshold value in regard of its moving average, assessed by a low-pass filter. This method is valid for new measurements and the hardware has to be designed. While we have no specialized hardware or have to analyze an old continuously recorded dataset, another approach has to be used. In this paper we study feature of the changing solar radiation, which can be used to select fast changing fragments of the formerly recorded datasets – for the analysis or saving in the memory. We expect that dataset has been recorded digitally. We will use the EXCEL worksheets and its standard functions as much possible. Writing a specialized program for the data selection is enabled only then while these features are assessed and rationalized. Selected features will be used to analyze dynamical properties of solar radiation in the Estonian summer season.

2. Concepts being used

Input dataset $G(t)$ of the global irradiance on the horizontal (or tilted, no sense) plane will be processed where $t \in \{...t_{i-1}, ti, t_{i+1}...\}$ are sampling instants with the sequence numbers $i \in \{1, 2...n\}$. We will use a sequence number only then, while a certain time instant has to be indicated. The global radiation, which is transformed to energy yield, is preferred. Also, it is most simple to measure.

Sampling interval (period) $\Delta t = t_{i+1} - t_i$ is a time interval between two sampling instants in sequence. Most of authors studying fast processes of solar radiation are using 1 minute sampling period (Gansler et al., 1995; Soubdhan and Feuillard, 2005; Tomson and Tamm, 2006; Tovar et al., 1998). BSRN methodology (McArthur, 2005) calculates one-minute data as average values of six measurements during the said minute. (Tomson and Hansen, 2010) shows that such methodology isn't the best considering dynamics of radiation, but it is common praxis and cannot be ignored. (Paulescu and Badescu 2010) uses Δt=15 sec long sampling interval and (Tomson, 2010) Δt=1 s sampling interval. Hardly shorter sampling intervals are required to study the dynamic processes of solar radiation.

Processing interval T is a time interval to calculate a generalized value of the process under study. A single value $G(t_i)$ may be a random number and can not considered as characteristic parameter. Therefore is suitable to operate with generalized during T values, with average value $G(T) = \Sigma(G\{t\})/n$ where n is number of instants inside the T, (simple) deviation $\delta G(t)$=$G(t) - G(T)$, standard deviation $\sigma G(T)$ and so on. Is expedient to choose $T >> \Delta t$, but this choice is not critical. Standard deviation is defined as usual (Bendat and Piersol, 2000)

$$\sigma G(t) = \sqrt{\frac{n \cdot \Sigma(\delta G(t)^2 - (\Sigma(\delta G(t))^2}{n \cdot (n-1)}} \, .$$

Radiation interval T_r is duration of sunshine between shadows of fast moving clouds *Cumulus humilis* or *Cumulus fractus*, which exists mainly in conditions of single-layer clouds. Irradiance in these intervals is assessed mainly due beam radiation $G_b(t)$.

Shade interval T_s is duration of shadows in the same conditions. Irradiance in these intervals is assessed due diffuse radiation $G_d(t)$.

Period of clouds T_c is sum of both in sequence $T_c = T_r + T_s$ and a random variable. Severely we should use "period" but we will omit the quotation marks to simplify the text.

Exposition interval T_e is a time interval during which the selected data will uploaded (saved in the memory) or plotted as diagram.

3. Analysis of data in the seconds range

The analysis is based on recorded data of ten days with alternating radiation in summer 2008 at Tallinn University of Technology. We will study dynamical properties of radiation in three zones: in (longer) sunny windows, under (longer) clouds and in the time intervals with intensive large-scale fluctuations between these both. Results are presented in Table 1 and Fig. 1. Processing interval T differs because stable intervals of the radiation are short compared to fluctuating intervals.

Tab. 1.

Regime		**$G(T)$, Wm^{-2}**	**$\delta G(t)$, Wm^{-2}**	**$\sigma G(T)$, Wm^{-2}**	**$\Delta G(t)$, $Wm^{-2}s^{-1}$**	**Duration, s**
Sunny window	T=10 s	788.7	2	1.6	2	$\max T_r = 83$
Alternations	T=35 s	542.3	55.5	38.1	15.7	–
Shade	T=10 s	203.2	1.1	0.8	1.1	$\max T_s = 241$

$G(T)$, $\delta G(t)$ and $\sigma G(T)$ were defined above, $\Delta G(t) = G(t_{i+1}) - G(t_i)$ is increment of irradiance.

In Fig. 1 We can see, that most of time intervals in conditions of highlighted type of clouds stay less than 30 s. Probable maximal durations of shadows and sunny windows are of importance too as it is suitable to avoid interruptions in datasets, while general situation shows alternating radiation. Therefore is expedient to chose $T_c > T$. How much, is not critical.

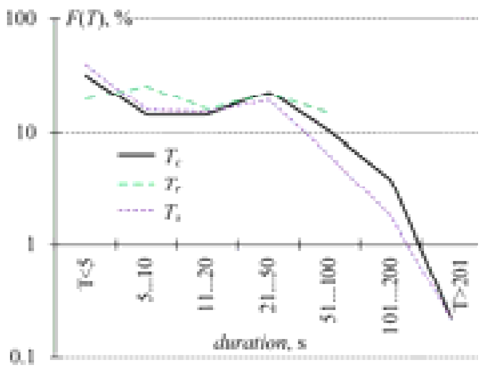

Fig. 1: Frequency distribution function of the duration of characteristic time intervals $T \in \{T_r, T_s, T_c\}$

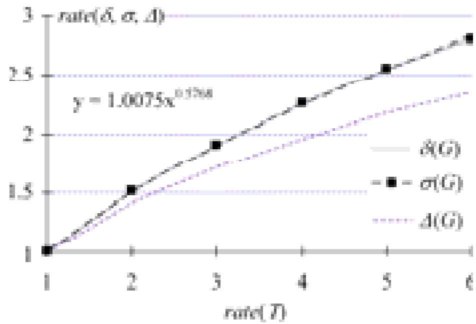

Fig. 2: Dependence of dynamic parameters of alternating radiation on relative duration of the processing interval

It is essential that all dynamical parameters $\delta G(t)$, $\sigma G(T)$ and $\Delta G(t)$ in fluctuations are dependent on the processing interval

$$\sigma/\sigma_{10s} \rightarrow = \delta/\delta_{10s} = (T/T_{10s})^{0.57} \quad \text{(eq. 1)}$$

what is shown in Fig. 2 where $\sigma_{10s}=\sigma$@10s. This dependence is weak and even recalculated values of dynamic parameters in the zone of large-scale fluctuations stay significantly larger than in zones of stable radiations. All these dynamical parameters can be used for the selection purposes.

4. Procedure statement

Flow diagram of following procedures is shown in Fig. 3.

Step	Operation	Comments
1. Input data	$G(t)$	
2. Moving average	$G(T)$	$T\in${10 s, 30 s, 60 s…}
3. (Centered) deviation	$\sigma G(t) = (G(t - G(T))$	
4. Standard deviation	$\sigma G(t) = \text{STDEV}(\delta G(t))$	
5. Assessing exposition interval	$\text{MAX}\sigma G(T_e) > \sigma G_{lim}$ or $\text{MAX}\delta(GT_e > \delta G_{lim}$	T_e=180 s (example) σG_{lim}=20 Wm^{-2} (example) δG_{lim}=20 Wm^{-2} (example)
6. Selection of output data	$G_o(t)$ :: repeat[$\text{MAX}\sigma G(T_e)$]	User defined function (look the text)

Fig. 3: Flow diagram of procedures for data selection

Using EXCEL standard function "AVERAGE(…)" the moving average $G(T)$ is calculated using $T\in${30 s, 60 s …}. This is a new column.

The centered deviation is calculated $\delta G(t) = G(t) - G(T)$. This is a new column.

Using EXCEL standard function "STDEV(...)" the standard deviation is calculated for the centered deviation δG (t) (if this criterion will be used; otherwise this procedure is omitted). This is a new column.

Using EXCEL standard function "MAX(...)" the local moving maximum max$\sigma G(T_e)$ is calculated with the window $T_e>T$. This is a new column. $T_e\in${90 s, 120 s …}.

Using a users defined function "*repeat*(*adr,lim,val*)" the selection will made. The said function is described below. Here "*adr"* is the column of input data $G(t)$, "*lim"* is a conceded value of the dynamic parameter σG_{lim} (or δG_{lim}). This is conceded significantly larger than typical value in intervals with stable radiation (for instance σG_{lim}=20...50 Wm^{-2}). „*val*" is input data to be selected $G(t) \rightarrow G_o(t)$. This is the last column, the result of selecting.

The said users defined function "*repeat*(*adr,lim,val*)" in the Visual Basic worksheets is following: Function *repeat*(*adr, lim, val*)

If *adr* > *lim* Then

repeat = *val*

Else

repeat = 0

End if

End Function

Resulting dataset $G_o(t)$ Fig. 4 and Fig. 5 consists alternating values of $G(t)$ and zero values in the intervals with stable values of $G(t)$ an can be made denser by the "SORT" function.

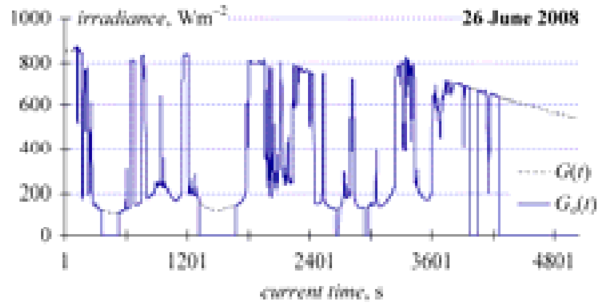

Fig. 4: Selected (1s) dataset $G_o(t)$ on the basis of standard deviation (T=30 s; T_e=180 s, σG_{lim}=20 Wm^{-2})

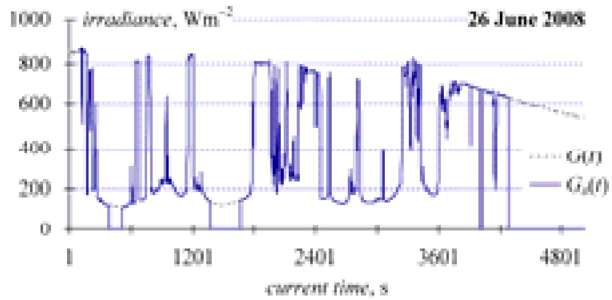

Fig. 5: Selected (1s) dataset $G_o(t)$ on the basis of deviation (T=30 s; T_e=180 s, δG_{lim}=20 Wm^{-2})

Analogous procedures have been used, while we will make the selection using other parameters.

5. Other possible features

Alternating and non-alternating fragments of the dataset can be selected also by other features.

1. For instance due sum of (absolute values) of increments during the processing interval, which have to be larger than a conceded control value $\Sigma|\Delta G(T)| > \Delta G_{lim}$. Fig. 6 shows the result of the selection. In this case steps 2, 3 and 4 are omitted and exchanged

With calculation of increment $\Delta G(t)$ and sum of its absolute values $\Sigma|\Delta G(t)|>\Delta G_{lim}$.

2. For instance due difference of envelopes

$\Delta G(T) = \max G(t,T) - \min G(t,T) < \Delta G_{lim}$,

where $\max G(t,T)$ is the maximal value of $G(t)$ inside the mowing processing interval. Correspondingly $\min G(t,T)$ is the minimal value of that. The result is shown in Fig. 7.Here T_e=T to demonstrate the necessity of T_e>T: output dataset $G_o(t)$ has frequent interruptions.

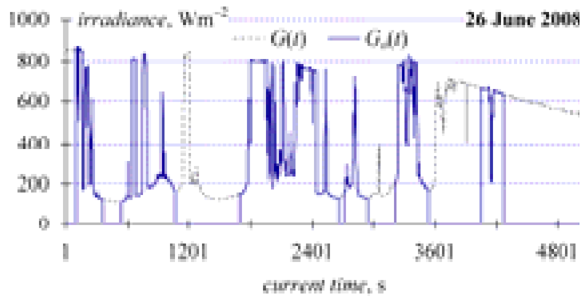

Fig. 6: Selected (1s) dataset $G_o(t)$ on the basis of the sum of increments (T=30 s; T_e=180 s, ΔG_{lim}=1000 Wm^{-2})

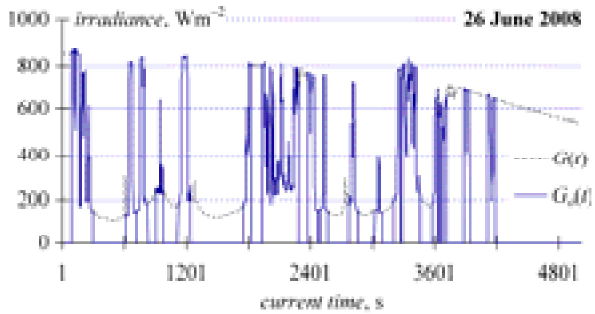

Fig. 7: Selected (1s) dataset $G_o(t)$ on the basis of the difference of envelopes (T=30 s; T_e=30 s, ΔG_{lim}=200 Wm^{-2})

Interruptions should be suppressed using long $T = T_e \approx 1 \ldots 3$ min.

Comparison of diagrams Fig. 4 – Fig. 7 shows that all explained procedures results nearly the same. Therefore the selection on the basis of deviations $\delta G(t)$ is most rational as it requires minimum of computation.

6. Analysis of the minutes range

Considerable amount of radiative information is recorded by the BSRN methodology (McArthur, 2005) as average values over 1 minute sampling interval (six averaged values). Although this methodology isn't the best considering dynamic processes (Tomson and Hansen, 2010), it is common and unified. Therefore we will analyze recorded at Tartu-Tõravere Meteorological Station (= Tartu Observatory, TO[1]) datasets in summer seasons 1999 – 2002 using designed selection tool. On the basis of five selected day (with partly stable and partly alternating radiation) generalized features Table 2 of dynamic parameters were assessed.

Tab. 2.

Regime		**$G(T)$, Wm^{-2}**	**$\delta G(t)$, Wm^{-2}**	**$\sigma G(T)$, Wm^{-2}**	**Duration, min**
Sunny window	T=10 min	752.9	2..5	2.1	max T_r=34
Alternation	T=30 min	585.5	143.9	93.2	–
Shade	T=10 min	189	12.6	9	max T_s= 41

[1] Detail description of TO is published in Russak,V and Kallis, A. Handbook of Estonian solar radiation climate.(2003). Ed. by Tooming, H, EMHI, Tallinn. In Estonian, but illustrations, diagrams and data tables in English.

"Duration" is defined for a window or shadow inside an interval of generally alternating radiation. Outside of such sunny interval (or shadow) may last several hours. Considering Table 2 the exposition interval is conceded $T_e = 3T = 90$ min (1.5 h). An example is shown Fig. 8.

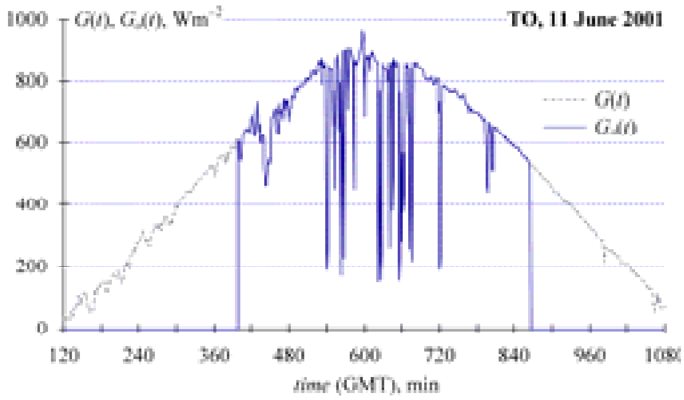

Fig. 8: Selected data $G_o(t)$ on the basis of deviation (T=30 min; T_e=90 min, δG_{lim}=100 Wm^{-2})

7. Analysis of the solar radiation in estonian summer season

Using the designed selection tool quality of solar radiation, affected by alternating clouds was investigated in the summer seasons 1999 – 2002 during May, June, July and August which are the most productive (solar energy in mind). Generalized results are presented in Table 3.

Tab. 3.

	1999	2000	2001	2002	average	σG %
G, Wm^{-2}	396.9	326.5	369.9	402.3	373.9	9.3
k_A	0.49	0.49	0.54	0.456	0.50	7.2
$E(d)$, kWhm^{-2}	5.563	4.572	5.090	5.640	5.22	9.5
Q_G, kWhm^{-2}	3.888	3.122	3.389	4.095	3.62	12.3

In the table 3 G is average irradiance during season, k_A is relative duration of alternating radiation between 5:00 – 19:00 local time (EET – Eastern European Time) and $E(d)$ – average energy per day. The last row Q_G is a formal parameter trying to evaluate the quality of radiation:

$$Q_G = E(d)/(1 + k_A)$$

(eq. 2)

Evident, that higher daily energy production increases the quality of the radiation and its alternation reduces it. In clear days $Q_G = E(d)$, which is the maximum. There are few clear days Tab. 4, but absolutely overcast days ($k_A = 0$) are even less.

Tab. 4.

	Clear days, $k_A = 0$	Overcast days, $k_A = 0$
1999	10	1
2000	6	6
2001	6	2
2002	15	0

Relative duration of the alternating radiation $k_A = 0$ characterizes both sunny and overcast days. Last column of the table 3 shows standard deviation of each variable from year-to-year. Ironically alternating radiation (alternating clouds) is the most stable quality of the radiation climate here. There exists a negative correlation between duration of cloudiness and daily energy yield Fig. 9, what is normal.

Some unexplained anomaly can be found for the years 1999 and 2000 – at the equal k_A their daily energies are different. In these years cloudiness does not differ considering daily or monthly distribution. Although in 1999 was realized 81% of potential energy at the $k_A = 0.492$ and in 2000 realized 66% at $k_A = 0.495$. Reason of that anomaly is not clear.

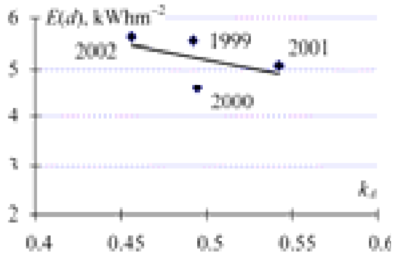

Fig. 9: Daily produced energy *E*(*d*) has negative correlation with amount of clouds

Daily distribution of alternating radiation (cloudiness) F_A should be of interest Fig. 10.

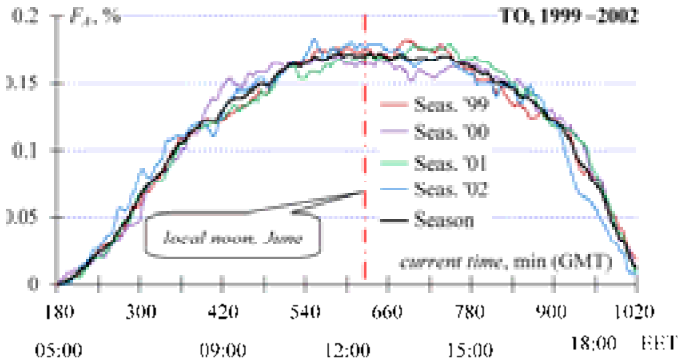

Fig. 10: Daily distribution of the frequency F_A of alternating radiation

This distribution is not symmetrical considering noon: F_A(AM) = 47.6% and F_A(PM) = 52.4.6%. Early in the morning and late in the evening no alternating radiation is available, but it results from the low altitude of the sun and low value of the global radiation on the horizontal plane. To control this hypothesis summer season 2002 was analyzed in parallel concerning global radiation G(02) and its beam component G_b(02) Fig 11.

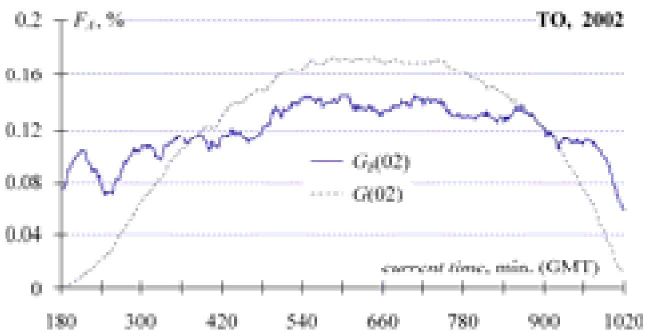

Fig. 11: Frequency of (fast)alternating clouds assessed by global radiation *G*(02) and its beam fraction G_b(02)

Analyzing beam radiation clouds are distributed much uniform during the day. This analysis did turn the attenuation on the fact that changes of the radiation are more deep and crucial when using beam radiation. This property is shown in Fig. 12, where a two hour long of recording is shown for the global radiation $G(t)$ and its beam component $G_b(t)$. Bold lines $MG(t)$ and $MG_b(t)$ are the magnitudes of springs between upper envelope max$G(t)$ and lower envelope min$G(t)$. Correspondingly between max$G_b(t)$ and min$G_b(t)$.

For the global radiation the magnitudes are assessed as differences between maximum and the diffuse radiation level, for the beam component between maximum and zero level. In the example

$MG_b(t)/MG(t) = 1.32$, which is a considerable value. Usage of concentrating and tracked collectors in the conditions of alternating radiation (clouds) may involve additional problems due dynamics of PV-electricity generation.

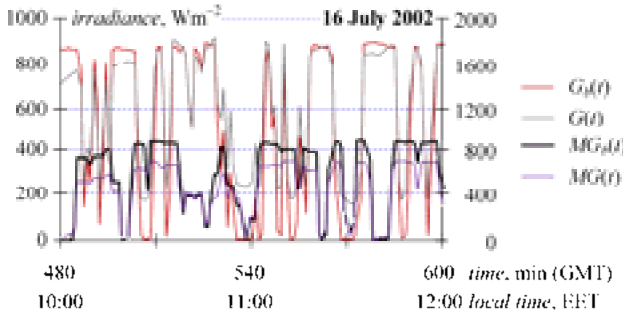

Fig. 12: Behavior of irradiance at alternating radiation: $G(t)$ is the global radiation and $G_b(t)$ its beam component

8. Conclusions

Preferred feature for the selecting of alternating fragments of recordings is deviation, which exceeds the conceded value. This approach minimizes the computation and allows selecting previously recorded datasets. Summer seasons in Estonia have high share of (fast) alternating radiation. Usage of concentrating and tracked collectors in the conditions of alternating radiation (clouds) cannot be recommended.

9. References

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