Fractal Classification of solar Irradiances into typical days using a cumulative distribution function

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Abstract. In a view to reduce a long time series of several variables into typical days we present in this paper a method for classification of global irradiance days according to different weather classes. To do it we have used the fractal dimension as a basic criterion in the classification. The method which defines fractal dimensions thresholds using the cumulative function leads to classify the days of two Algerian sites into 3 classes: clear sky day, partially clouded sky day and clouded sky day.

Key words

Fractal dimension, classification, typical days, solar irradiances, cumulative distribution function.

1. Introduction

To electrify remote areas, the use of solar energy is the best economical and technological solution. The choice of the sites for the installation of photovoltaic systems and the analyse of their performances require the knowledge of the solar irradiation source.

To meet these requirements, we have to determine the experimental meteorological classes of the days for a given site.

Many studies have treated the problem of typical days classification [1]-[3]. Almost of these works are based on statistical methods using different meteorological parameters such as solar irradiation, temperature and wind. In this article we present a new classification method based on the fractal dimension of solar irradiances. This method defines two thresholds of the fractal dimensions using a cumulative function. This allows to determine 3 classes of days: clear sky day, partially clouded sky day and clouded sky day.

2. Experimental data collection

To carry out this work, global solar irradiance data recorded during 1992-year on a 10°-tilted surface with a time step of 10 minutes [3],[4] are used. these data are collected from the operation of two Wp photovoltaic power installations equipped with an acquisition system at Tahifet (latitude = 22° 53' north, longitude = 6° east and altitude = 1400 m) and Imehrou (latitude = 26°00' north, longitude = 08°50' east and altitude = 600 m). in the south of Algeria. Figure 1 gives representative histograms of these experimental data.

3. Classification methodology

Many studies have investigated the problem of typical days classification using statistical methods. These studies differ by the parameters used as criterion for the classification. In The present work, we propose to classify the global irradiance days into typical cases using the fractal dimension as a basic criterion.

Let us recall that the fractal dimension D measures the amount of daily solar irradiance fluctuations which are related to weather conditions and, consequently, to the state of the sky. For daily solar irradiances, the fractal dimension ranges from 1 to 2. D close to 1 describes a clear sky state without clouds while a value of D close to 2 reveals a perturbed sky state with clouds. That is why, the daily fractal dimension D is used here as criterion of daily irradiances classification. Our research reveals that some daily solar irradiances have the same fractal index but corresponding to days with different weather conditions. Indeed, a uniformly cloudy day and a sunny one have regular irradiance shapes and practically the same value for D but have daily different clearness

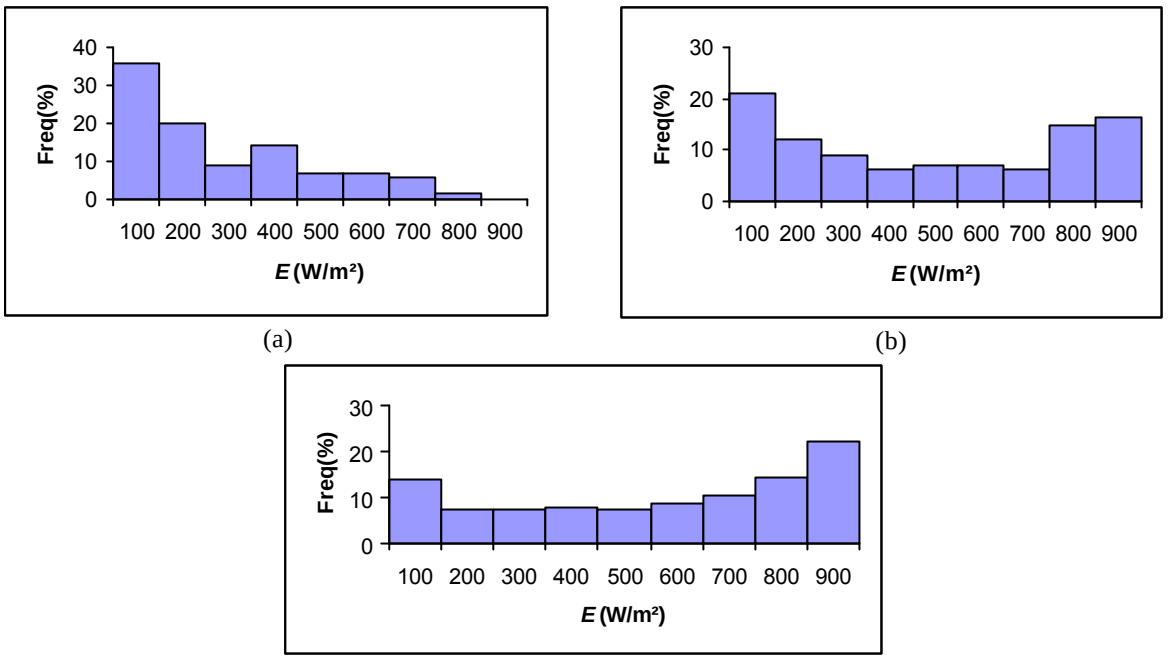


Fig. 1. Examples of irradiance histograms -a) Day of March 20, -b) Day of November 28, -c) Day of 20, 1992

indexes. This is due to the fact that the amount of global irradiation available is not related to fractal dimension. Thus, this is not sufficient as a robust classification criterion. That is why the daily clearness index *KT* is calculated along with *D* as a second criterion in the classification algorithm, which is based on *D* and *KT* thresholds. as a second criterion in the classification algorithm which is based on *D* and *KT* thresholds.

Most of statistical methods use Euclidian distance to compute the difference between samples, this is can not be used in our method because of the fact that a rainy day and a sunny day could have regular irradiance shapes and so the same value of *D*. That is why our classification method uses thresholds for *D* and *KT* to sort daily irradiances into three classes according the following classification:

Class I: Clear sky day

$$1 \le D \le D_1 \quad \text{and} \quad KT \ge 0.5$$

Class II: Partially cloudy sky

$$D_1 < D \le D_2 \quad \text{and} \quad KT \ge 0.5$$

Class III: Completely cloudy sky

$$\begin{cases} D > D_2 \\ \text{or} \\ D \le D_2 \quad \text{and} \quad KT < 0.5 \end{cases}$$

In a previous work, the thresholds of the fractal dimension D_1 and D_2 have been determined using a heuristic approach consisting in analyzing all daily solar irradiances shapes and their corresponding fractal dimension [3],[4]. I the present work, to determine the thresholds D_1 and D_2 which allows to sort daily irradiances into the three classes we have used The cumulative distribution function (CDF).

This latter is the probability that the variable takes a value less than or equal to *x*. Thus, the two thresholds of *D* are determined from the CDF of the fractal dimensions. They correspond respectively to the fractal dimension giving the following values of the cumulative distribution function *F(x)*:

$$F(x)=\frac{Max-Min}{3} \quad \text{and} \quad F(x)=\frac{2(Max-Min)}{3}$$

Max and *Min* are the maximum and the minimum values of *F(x)* respectively.

4. Results and Discussion

The methodology described above has been applied to each site presented in section 2. From the experimental data recorded in these two sites, the fractal dimensions *D* and the clearness index *KT* of all daily global irradiances have been measured. To compute the fractal dimension of a curve, many algorithms and methods exist [5],[6]. In this article the fractal dimension of daily global irradiances have been measured using a method elaborated in our previous works [3],[4]. This method is based on covering the irradiance signal by rectangles at different scales. To classify solar irradiances of the studied sites into three typical classes according the algorithm established in section 3 we have determined the thresholds D_1 and D_2 of the fractal dimension using the cumulative distribution function (CDF) method and the heuristic approach. Table 1 resumes the thresholds values of *D* obtained from the two methods.

TABLE I. - Fractal dimension thresholds obtained from 2 approaches, the cumulative method and the heuristic method

SITE	TAHIFET		IMEHROU	
D thresholds	D_1	D_2	D_1	D_2
CDF method	1.13	1.32	1.12	1.28
Heuristic approach	1.10	1.25	1.10	1.25

Table 1 shows that the thresholds given by the two methods are nearly equal. In our classification algorithm we have used the CDF method thresholds because of the fact that this method is more accurate and more practice to use than the heuristic one.

Table 2 gives the distribution of the probability of occurrence of daily solar irradiances for each class obtained from our classification.

TABLE II. - Probability of occurrence of daily solar irradiance shapes of each class

SITE	CLASS 1	CLASS 2	CLASS 3
Tahifet	0.57	0.20	0.23
Imehrou	0.63	0.19	0.18

Daily irradiances of class 1 have the largest probability of occurrence as compared to irradiances of the two other classes. These results confirm the pre-eminence of days with clear sky for the two sites, this is due to the climate of the south Algerian which is characterized by irradiances rarely fluctuated.

To validate the classification results, the average fractal dimension $\langle D \rangle$ and its standard deviation σ have also been computed for each class. They are summarised by table 3.

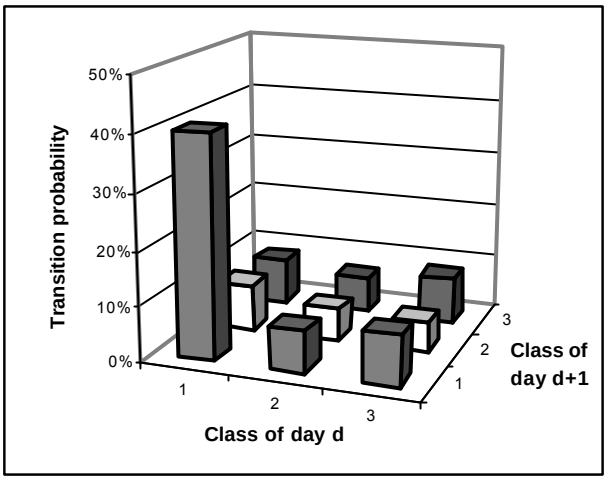
TABLE III. - Mean value and standard deviation of fractal dimension for the different classes of days

SITE	CLASS 1		CLASS 2		CLASS 3	
Tahifet	$\langle D \rangle$	σ	$\langle D \rangle$	σ	$\langle D \rangle$	σ
	1.03	0.03	1.23	0.05	1.42	0.10
Imehrou	$\langle D \rangle$	σ	$\langle D \rangle$	σ	$\langle D \rangle$	σ
	1.03	0.03	1.19	0.05	1.41	1.10

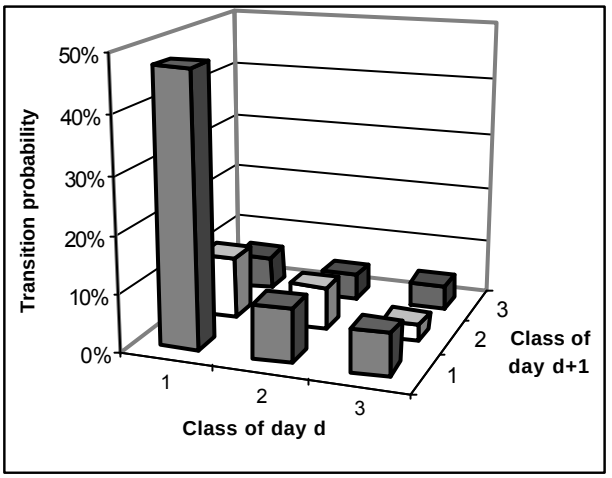
These statistical properties show that for the class 1 and 2 the fractal dimension of the days are not different since the standard deviation is low (3%) whereas for the days of the class 3, the standard deviation is more important (10%), this is due to the rainy days which posses regular irradiances shapes so their fractal dimensions are close to 1, but they belong to the class 3. These results show that the three classes contain days which are homogenous.

In another hand, to synthesize the typical day sequences we have determined the transition probabilities between the typical classes. Figure 2 presents for Tahifet and Imehrou, the transition probability, so called conditional probability *i/j* of a class *j* at a day *d+1*, when at a day *d* the class was *i*.

We remark that the persistence effect is dominant since the sum of the transition probabilities of classes *I/I, II/II* and *III/III* for the two sites are majority.



(a)



(b)

Fig. 2. Transition probability between days *d* and *d+1* a- Tahifet b- Imehrou

5. Conclusion

A new method has been proposed to classify the daily global irradiances into typical days using the fractal dimension as a basic criterion since it allows to quantify the irradiance fluctuations. This method defines fractal dimension thresholds using the cumulative distribution function. The application of this method to two south Algerian sites showed that the thresholds obtained from the cumulative distribution function (CDF) and those from the heuristic approach are nearly equal. In the other hand, it is also shown that it is possible to realize daily solar irradiances classification using the *D* thresholds obtained from the CDF method, since the statistical properties of the fractal dimension for each class have shown that the three classes contain homogenous days. This has been confirmed by the transition probability

between days *d* and *d+1* which show that the persistence effect is dominant.

The typical days obtained from the classification are with a great interest in reducing the costs involved in analytical monitoring in view of performance analysis of PV systems. Therefore, the interesting results presented in this paper need further investigations in view of their validation, for this it is necessary to apply the proposed method to other sites especially those characterized by the fluctuated climate.

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