Assessment of a quality control procedure of hourly solar irradiations at Fez city, Morocco

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Abstract. In order to properly dimension solar power plants, it is necessary to have long series of relevant measurements of the available solar components at the site chosen for the installation. It is, however, well known that the quality of the measurements of solar irradiations can fail from time to time. Therefore, a quality control of the recorded data must be carried out before their use. This paper describes an assessment of a quality control procedure which is implemented for the hourly horizontal global and diffuse solar irradiations. A set of four quality control tests are applied to remove the erroneous data.

1. Introduction

The knowledge of the solar irradiation received by a surface of the earth is important for the use and good management of this energy in several fields of research. The measurement of the global solar irradiation on a horizontal plane is carried out by using a pyranometer for a defined time step. Obviously, pyranometer measurements are often sensitive to errors which may be due to technical or operation and maintenance problems of the equipment [1, 2]. It is for these reasons that the quality control of solar measurements has become a concern of most researcher’s scholars who have proposed different methods to ensure good reliability of the data. In the case of data representing a time step of one hour (our case), errors due to the cosine response are more relevant [2, 3]. The ENDORSE project [4] proposed a quality control procedure (QCP) based on extreme and rare observations, considering the three components of solar irradiance: Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI) and Direct Normal Irradiance (DNI). This QCP will only be applied for solar altitude data below 7° to process the intrinsic cosine error of the pyranometers. Younes et al. [2] developed a ten-minute and hourly irradiations quality control procedure that went through four different levels of testing. They proposed physical and statistical indices to develop a semi-automated procedure based on the clearness and diffuse indexes ($K_t$ and $K_d$ respectively).
In the present work, we applied the quality control procedure of Younes et al. [2] to our solar irradiation measurements at Fez city in Morocco.

2. DATABASE
Our work consists of a quality control of the global and diffuse hourly horizontal solar irradiation measurements. These measurements are made using two identical Kip & Zonen pyranometers (model CM11) whose one is equipped with a shading ring to measure the DHI. These equipments are part of a meteorological station placed on the roof of the Faculty of Sciences and Technology of Fez (Latitude: 33°59’58”N, longitude: 4°59’22”W and altitude: 450 m). The measurement period is from 01/01/2009 00:00:00 GMT to 11/06/2015 at 12:00:00 GMT. Figure 1 shows the hourly variations of the measured GHI and DHI for the whole considered period. Given that the diffuse solar irradiance is measured by a pyranometer equipped with a shadow band, we applied the correction procedure proposed by Drummond [5] to take into account the part of diffuse component blocked by the shadow band. To calculate solar position at each instant, we use the Solar Position Algorithm (SPA) [6]. SPA is an algorithm based on precise astronomical equations allowing to calculate the solar position with a very low uncertainty, it was developed at the National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy to calculate the sun’s zenith and azimuth angles and other related parameters with unmatched low uncertainty of +/- 0.0003 degrees, in the period of years from -2000 to 6000 [7].

![Figure 1. Hourly variations of the measured GHI and DHI for the whole considered period](image_url)

Figure 1 shows that:

- There is a significant data hole in the GHI measurements due to a problem in the connection cable between the pyranometer and the acquisition chain.
- There are significant values (red color) of DHI.

The second problem is due to the fact that the solar shadow band suffers from misalignments from time to time. This can be seen in figure 2 illustrating the scatter plot of the hourly diffuse fraction $K_d$ against the clearness index $K_t$, defined as:

$$K_t = \frac{GHI}{G_{TOA}}$$  \hspace{1cm} (1)
Where $G_{TOA}$ is the horizontal solar irradiation available at the top of atmosphere.

\[ K_d = \frac{DHI}{GHI} \]  

(2)

This figure shows several anomalies, mainly several values of $K_d$ and $K_t$ are greater than 1. This phenomenon can be explained by the fact that the clouds albedo could increase the global radiation to a value greater than that of the extraterrestrial radiation, which gives a value of the clearness index greater than one [3]. To construct an accurate and reliable dataset, we must apply a check of data quality control.

### 3. Quality Control Procedure

The erroneous solar data are clearly visible in Figure 2. To solve this problem, we applied a set of four tests of quality control.

#### 3.1. The first test

Authors of references [2, 3, 8] recommended to exclude the recorded data at low sun altitudes ($h_{solar} < 7^\circ$). This is in order to process the intrinsic cosine error caused by the pyranometer. The cosine response is the response of the sensor to the angle at which the solar radiation touch the detection zone, this angle is generally important during sunrise and sunset, which introduces a higher cosine error [2]. However, by plotting the clearness index $K_t$ according to the solar altitude (Figure 3), we can see that a choice of a limit of $5^\circ$ is very plausible.

According to this illustration, it has been observed that certain values of the clearness index have exceeded 2 for solar altitudes less than $5^\circ$. Figure 4 shows the $(K_t,K_d)$ scatter plot after this test application.

#### 3.2. The second test

This test is based on physical limits of clearness index $K_t$ and diffuse fraction $K_d$:
0 < \( K_t \) < 1 \hspace{1cm} (3)

0 < \( K_d \) < 1 \hspace{1cm} (4)

Results of this test are illustrated in figure 5.

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3.3. The third test

In this test, GHI and DHI are limited by their values which correspond respectively to a clear sky (figure 6) and a cloudy sky.

\[ GHI < GHI_{\text{clear sky}} \hspace{1cm} (5) \]

\[ DHI_{\text{clear sky}} < DHI < DHI_{\text{cover sky}} \hspace{1cm} (6) \]

To calculate these limits, the Page model [9] is used to determine the direct and diffuse hourly irradiations under clear and overcast sky conditions. This model was also validated by Younes et al [2] in 11 locations in the northern hemisphere from England to Japan. Figure 7 illustrates the \((K_t, K_d)\) scatter plot after the application of the third test.

3.4. The fourth test

This test is based on a statistical analysis which consists in:

- Dividing the [0, 1] interval of the clearness index \( K_t \) in twenty equally spaced intervals.
- Calculating for each interval the average of the diffuse fraction \( K_d \) (\( K_{dm} \)) and its standard deviation \((\sigma_d)\).
- Retaining only values which respect the following range:
\[ K_{dm} - 2 \sigma_d \leq K_d \leq K_{dm} + 2 \sigma_d \]  \hspace{1cm} (7)

Figure 8 represents the scatter plot after the application of this test.

4. Results

![Figure 4](image_url1)

**Figure 4.** The scatter plot of the diffuse solar fraction according to the clarity index after the first test of quality control for the hourly solar data between 2009 and 2015. The grey dots are the values that passed the test, the black dots are the values that didn’t pass the test.

![Figure 5](image_url2)

**Figure 5.** The scatter plot of the diffuse solar fraction according to the clarity index after the second test of quality control for the hourly solar data between 2009 and 2015. The grey dots are the values that passed the test, the black dots are the values that didn’t pass the test.

![Figure 6](image_url3)

**Figure 6.** Comparison between GHI after the third test of quality control and GHI under clear sky conditions for the hourly solar data between 2009 and 2015.

![Figure 7](image_url4)

**Figure 7.** The scatter plot of the diffuse solar fraction according to the clarity index after the third test of quality control for the hourly solar data between 2009 and 2015. The grey dots are the values that passed the test, the black dots are the values that didn’t pass the test.
5. Conclusion

The hourly measurements of solar irradiations are often subject to different measurement errors. The aim of this work is to monitor the quality of these data in order to serve better scientific research. A quality control procedure was applied to the hourly solar data measured at Fez city for a period defined between the year 2009 and 2015. A set of four tests were applied and we noted that 1938 measures were eliminated by the first test, 2582 by the second, 1814 by the third and 562 by the fourth test. At the end, we have 21458 hourly measures that passed all tests successfully.

References:

[1] Moradi I 2009 Quality control of global solar radiation using sunshine duration hours *Energy* **34**, 1-6.
[2] Younes S, Claywell R and Muneer T 2005 Quality control of solar radiation data: present status and proposed new approaches *Energy* **30**, 1533–49.
[3] Ruiz-Arias J.A., Alsamamra H., Tovar-Pescador J and Pozo-Vazquez D 2010 Proposal of a regressive model for the hourly diffuse solar radiation under all sky conditions *Energy Convers Manag*, **51**, 881–893.
[4] Espinar B, Wald L, Blanc P, Hoyer-Klick C, Schroeder-Homscheidt M and Wanderer T 2011 Report on the Harmonization and Qualification of Meteorological Data: Project ENDORSE—*Energy Downstream Service*: Providing Energy Components for GMES—Grant Agreement No. 262892. *Paris, France: Armines. Accessed November, 11, 2014.*
[5] Drummond A.J. 1964 Comments on “sky radiation measurement and a.corrections”, *J Appl Meteorol* **3**, 810–811.
[6] Reda I. and Andreas A. 2003 Solar position algorithm for solar radiation applications: Technical Report, National Renewable Energy Laboratory, Golden, Co, USA. Revised version: January 2008.

[7] Blanc P and Wald L 2012 The SG2 algorithm for a fast and accurate computation of the position of the Sun for multi-decadal time period. Solar Energy, 86(10) 3072-3083.

[8] Ihya B, Mechaqrane A, Tadili R and Bargach M N 2014 Prediction of hourly and daily diffuse solar fraction in the city of Fez (Morocco), Theoretical and Applied Climatology, 1-13.

[9] Greif, J, Scharmer, K, Dogniaux, R. and Page J 2000 ESRA, European Solar Radiation Atlas. Including CD-ROM (fourth ed.), Presses de L’ecole des Mines de Paris, Paris, France.