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Improving the performance of PV systems by faults detection using GISTEL approach

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ABSTRACT

In this paper, we present a new approach for detecting the faults in the photovoltaic systems based on the satellite image approach for estimating solar radiation data and DC output power calculations for detecting the failures. At first stage, the estimation of the hourly global horizontal solar radiation data has been evaluated by using the GISTEL (Gisement solaire par télédetection: Solar Radiation by Teledectection) model improved by the fuzzy logic technique. Thus, the results were compared with the ground solar radiation measurements. On the other hand, the comparison between the simulated and measured output DC powers was reached to find the nature of the faults in the PV array.

The results showed a good accuracy and the simple implementation of the proposed approach. The estimation of the hourly solar radiation presents an NRMSE <0.22 using GISTEL model improved by fuzzy logic comparing with the estimation without fuzzy logic with an NRMSE = 0.2885 for clear sky and NRMSE = 0.2852 comparing with NRMSE = 0.3121 for cloudy sky.

1. Introduction

Solar energy is one of the most important renewable energies for generating electricity and meeting our daily needs. However, the efficiency of the photovoltaic (PV) panels was considered low [1] due to financial and technical problems that can increase the installation cost. Hence, the methods for estimating the amount of the solar radiation and monitoring of the PV systems become very important tasks [2]. To ensure a proper monitoring of photovoltaic plants, it is necessary to adopt specific techniques related with the type and accuracy of the information provided as well as their prices [3]. The measurement of the solar irradiation is one of those techniques. To this end, different ways were proposed in the literature to estimate the solar radiation data; such as ground models [4–6] and satellite image processing models [7–10]. In addition, several studies have been carried out on the detection of different failures in PV systems [11–15].

The results from these models showed that the optimal determination of the solar radiation estimation models, and failure detection techniques lead to an efficient PV system. Drews et al. [12] developed a procedure to detect failures in grid connected PV systems based on the average hourly solar radiation satellite data using Heliosat method and PV simulation. Firth et al. [13] have used empirical models for failure detection in PV systems. However, these methods based on the average solar radiation data, where in this paper we proposed a satellite approach model to get the hourly solar radiation. In addition, Chouder and Silvestre [14] have present an automatic supervision and faults detection of PV systems based on capture losses and the analysis of several parameters such as thermal losses and miscellaneous losses that complicate the procedure and increase the calculation time. And generally, those methods used complicated algorithms and mathematical models, and sometimes provide bad results. For this purpose, we had proposed in this paper a new simple method based on the extraction of the hourly global horizontal solar radiation data from satellite images for a specific location combined with an algorithm for detecting the faults in the PV system.

The precision of the estimated solar radiation is necessary to improve the performance of the proposed model, for that, the GISTEL (Gisement Solaire par Télé detection) proposed by [16] was used. It consists of the processing of the Meteosat second generation images MSG-2. An algorithm based on a relationship between the clearness indexes determined from the Meteosat images and the global solar irradiation received on the ground under clear

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sky was used. Moreover, a hybrid model was proposed in this paper that combined the basic method of GISTEL and the fuzzy logic approach in order to obtain more precise results.

Second, for detecting the failures in the PV array, we have proposed a procedure based on the analysis of the measured and simulated DC output powers. The DC powers are used here leading to the fact that the failure detection algorithm deals only with the DC part of the PV system. The next step consists in the determination of the current and the voltage ratios that indicates the nature of the faults. Moreover, the proposed method allows the determination of the false detection of failures. The evaluation of the proposed method was reached using the root mean square error RMSE and normalized root mean square NRMSE errors.

The remaining part of this paper is organized as follows. Section 2 presented the methodology used in this work for the detection of failures in PV systems; a background of the GISTEL model has been viewed. In addition, the mechanisms of detection of the faults have also been shown. In Section 3, we had simulated the results obtained from the GISTEL model and compared them to the measured solar radiation data. Moreover, a comparison between the simulated results of the proposed approach and the obtained ones in the case of the absence of failure in the PV array has been also carried out. The last section is devoted to the conclusion and discussion of future works.

2. Methodology

The detecting of failures in PV arrays was known as an important task for optimal sizing of the PV system to get the maximum of output power [14,17]. The failures in the PV system augment the power losses in the case of the presence of faults [18]. Hence, in this work, a proposed simulation method based on the Matlab/Simulink environment has been used for detecting the faults. This method consists of two main parts. First, the GISTEL model was applied to estimate the hourly horizontal global solar radiation time series, and then the obtained results were compared to the measured ones. At the second stage, a comparison of the output power from GISTEL and the measured data were used to detect the failures. The proposed method was presented in Fig. 1.

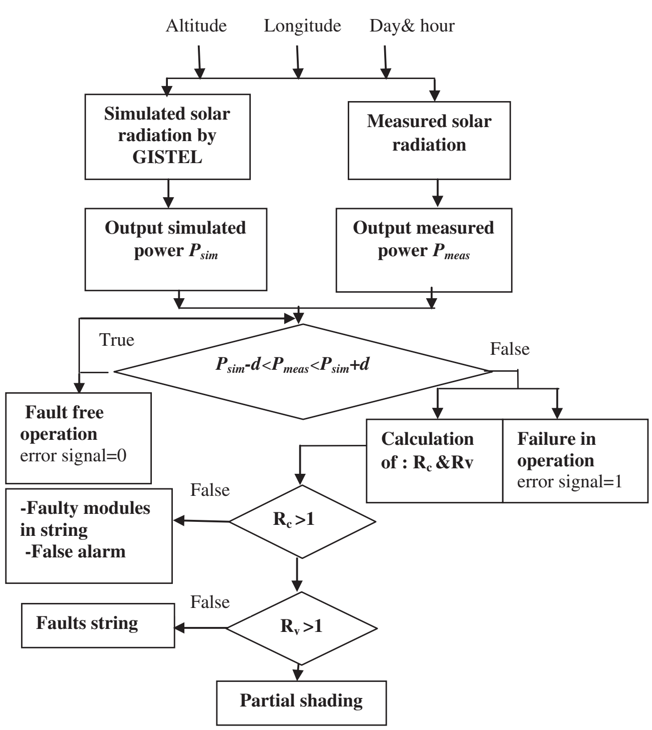

Fig. 1. Flowchart of the fault detection procedure.

2.1. GISTEL model

GISTEL is a satellite methodology based on a simple physical model. It is used to estimate global solar irradiance from Meteosat data. The adopted methodology has several steps that we have summarized by the diagram of Fig. 2.

1. For estimating the global solar radiation (*Gc*) under a clear sky, the world organization of meteorology (W.M.O.) [19] model given by Eq. (1) is used; this model depends on the solar height (*hs*) and the linked turbidity factor (*TL*) used to quantify the effect of atmospheric components of solar radiation, the *TL* values generally vary from 2 (very pure and dry sky) to 6 (polluted and humid sky).

$$G_c = cor[1300 - 57T_L](\sin(h_s))^{(36+T_L)/33} \tag{1}$$

where *cor* is the correction factor of the earth–sun distance given by Eq. (2) and *nj is* the number of the days of the year.

$$cor = 1 + 0.034\cos(0.986(nj - 3)) \tag{2}$$

2. The ground instantaneous reflection coefficients *Rib*(*x*, *y*, *d*, *h*) for each pixel (*x*, *y*) of the visible MSG image of the day *d* and the hour *h* are given by Eq. (3). Those coefficients represent the reflection of solar radiation on the surface.

$$Rib(x,y,d,h) = \frac{Bi(x,y,d,h) - Bia(x,y,d,h)}{K \cdot Gc(x,y,d,h) \cdot Ti(x,y,d,h)} \tag{3}$$

where *Bi* (*x*, *y*, *d*, *h*) represents the brightness of the (*x*, *y*) pixel, *Bia* (*x*, *y*, *d*, *h*) the atmospheric brightness recorded by the satellite above the sea by a clear sky. This brightness was considered constant, and it is equal to 12 [9]; *K* is the factor calibration of the visible channel sensor equal to 0.514. *Ti* (*x*, *y*, *d*, *h*) *is* the transmission coefficient of the direct irradiation from the ground to the satellite. It is given by Eq. (4),

$$Ti = \frac{(1390 - 31T_L)}{1367}\exp\left[-\frac{T_L}{12.6\sin(h_v + 2)}\right] \tag{4}$$

where h_v is the height angle of the satellite, given by Eq. (5).

$$h_v = \arcsin\left(\frac{1.862\cos(\varphi)\cos(\theta) - 0.274}{\sqrt{3.41 - \cos(\varphi)\cos(\theta)}}\right) \tag{5}$$

θ and φ are respectively the latitude and the longitude.

3. For determining the two clear and cloudy reference images, a sequence of images was taken over long period at 12 h UTC. Taking the minimum values of the reflection coefficients obtained from those sequence images, the clear sky reference image can be obtained. On the other hand, the cloudy sky reference image is constructed by using the greatest values of the reflection coefficient obtained using the same sequence of images.
4. The clearness index k_t is calculated for each image by comparing pixel by pixel and hour by hour the instantaneous reflection coefficients *Rib* with the two clear sky R_c and the cloudy sky R_n reflection coefficients. According to this comparison three types of skies can be observed namely clear sky, partially covered sky and completely covered sky [9], as expressed in Eq. (6)