

A Diagnostic Workflow and Software Platform for PV Modules

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Abstract. The aim of this paper is to propose a software platform able to process InfraRed (IR) images of PV modules. In fact, after an IR image is acquired by the thermo-camera, a processing phase is needed in order to extract information about the status (well-working/bad-working) of the cells. Moreover, the bad-working cells can be very heterogeneous, and a classification can lead to the best corrective action. The proposed software provides a comprehensive and detailed report, both in graphical and numerical terms, on each cell of the PhotoVoltaic (PV) module.

Keywords

Infrared analysis, filtering, blobs, PV cells

1. Introduction

It is well known that the PV modules have a very low efficiency. In fact, it goes from 6% to 17% for commercial PhotoVoltaic (PV) modules, depending on the used material. Then, an efficiency decrease of some per cent strongly affects its energy performance. It is also noted that the efficiency almost always has an inverse relation with the cell temperature [1]. As the PV cells are series-connected in a PV module, a bad-working cell affects the operation of the whole PV module.

The anomalies can be process-induced or material-

induced, but they appear in any case as an overtemperature [2]; for this reason, thermograph-based techniques have been proposed [3-4]. Nevertheless, sometimes it is not possible to obtain sufficient information from an IR image, because thermo-cameras have low resolution. In fact, a *high resolution* thermo-camera presents just a resolution of 640x480 pixel. Moreover, sometimes IR images are dirty, then it is not easy to understand the cause of an overheating. Because of these issues, a suitable processing of the acquired IR images has to be performed [5].

This paper proposes a diagnostic workflow for analyzing PV module, in order to extract information on each PV cell of the module. At this stage of the project, our workflow has been implemented through a Matlab-based GUI (Graphical User Interface). Here, the main components of the platform are presented, highlighting the results obtained from a tested PV module.

2. Diagnostic Platform: Workflow and GUI

Fig. 1 reports the GUI implementing the proposed diagnostic workflow for PV modules.

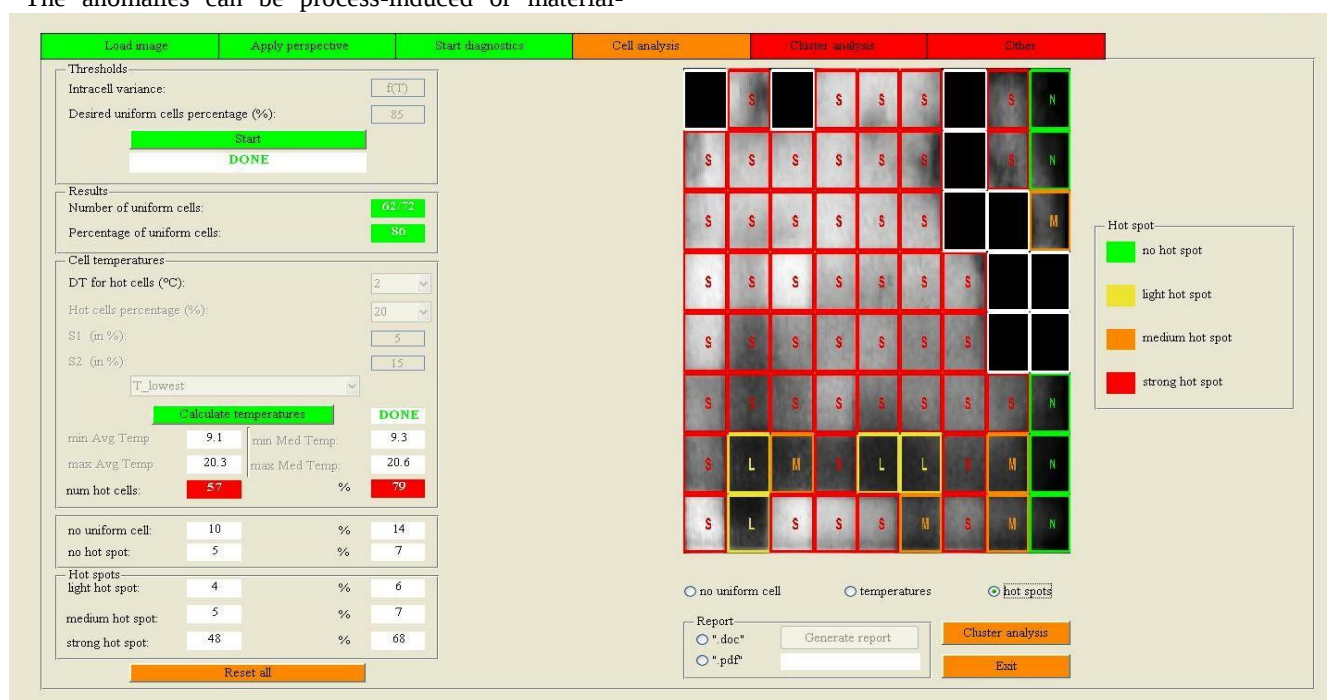


FIG. 1. SCREENSHOT OF THE GUI (HOT CELLS TAB)

In Fig 1 the GUI of the platform is shown. On its top, several tabs are available, each one devoted to a step of the workflow, starting from the left. The color of each tab denotes its status: red before starting, orange during the processing, and green when completed. In particular, Fig. 1 has been captured while steps *Load image*, *Apply perspective*, and *Start diagnostics* have been completed, step *Cell analysis* is active, and *Cluster analysis* and *Other* have to be run yet.

Firstly, the workflow defines a lookup table “pixel color-temperature” and partitions the PV module in PV cells. For this aim: a) the IR image of the PV module under diagnosis is loaded; b) maximum and minimum values of temperatures are imposed; c) the four vertices of the PV module, are detected onto the IR image; d) the markers delimiting the PV cells are automatically posed (Fig. 2). If the obtained mesh is validated by the user, the selected part of the IR image is extracted from the original image and considered as ROI (Region Of Interest) by all the incoming analyses, which –from now on- will regard only this portion of the image, representing the PV module; otherwise, a *clear markers* action can be done (orange button on the left), and a new supervised procedure, for selecting the mesh of the PV cells, is run.

After that, a geometric transformation is applied (*Apply perspective*) which maps the previously extracted ROI into a reference system (having a correct perspective) in order to provide the successive steps on a non-distorted and more significant image.

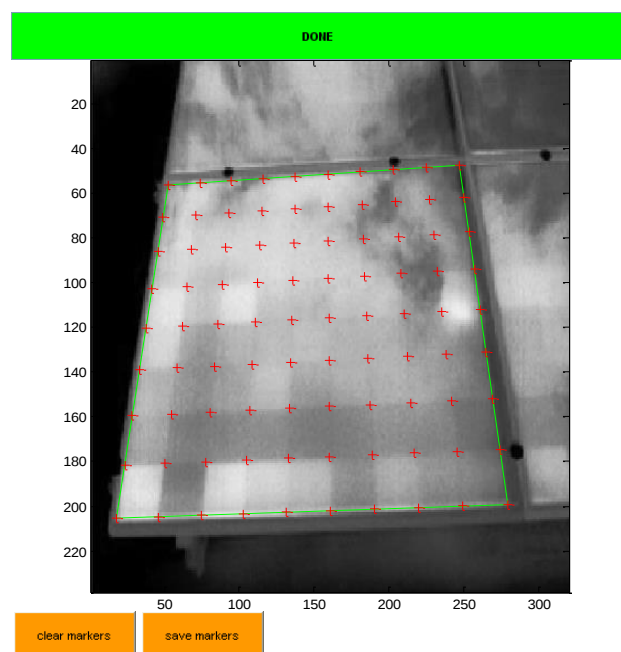


FIG. 2. MARKERS ONTO THE IR IMAGE, AS IT IS JUST CAPTURED

Now, the diagnostic can effectively begin inputting environmental parameters, such as the temperature and the radiance registered while the IR image was captured. The diagnostic consists of several analyses: firstly, a classification between uniform and not uniform cells is done, based on the value of the intra-cell variance. PV cells having an intra-cell variance higher than 2%, are considered non-uniform and, from this moment on, they will not be further analyzed (black PV cells, squared in white, see Fig. 1). The workflow neglects them, since the cause generating the non-uniformity may depend on external factors as dirt, or dust, etc. Thus, a first output is produced regarding the number and the percentage of both uniform and non-uniform PV cells.

The next step consists of setting two thresholds, in order to define the level of the hot-spots: light, medium and strong. This leads to calculate the number and the percentage of PV cells belonging to each level. Fig. 1 shows as strong hot cells are squared in red and marked by a letter S, medium hot cells in orange and letter M, light hot cell are in yellow and letter L. Conversely, well-working cells are squared in green, and marked by a letter N. As these evaluations are based on the average temperature of each PV cell, the GUI provides a diagram of the average temperature in each PV cell (Fig. 3), that is automatically saved into the report file in .doc or .pdf format. This file contains all the input and output data, too.

Fig. 3 shows also that PV cells with the same average temperature may be posed either close together or far apart. These PV cells can be considered as a family called *cluster*. Then, the next step of the diagnostic workflow groups one or more PV cells into clusters, and compares the average temperatures of the clusters. Each cluster contains PV cells whose average temperatures differ less than a threshold set by the user. Obviously, higher the threshold, less the number of clusters, and vice versa. As an example, in Fig. 4, a threshold equal to five gives three clusters, in the tested PV module. The scheme at the right-hand side represents a cluster, constituted by two blobs (a blob is a group of contiguous PV cells): the former blob constituted by 4 PV cells, the latter one by 14 PV cells. Through a scrolling tool, the other clusters can be displayed. Moreover, cluster representation can also be labeled as homogeneous and inhomogeneous, depending on the difference between the temperature of each cluster and the temperature of the reference cluster. Also this step, similarly to the previous one, allows to generate a comprehensive report file, including the information derived in the cluster analysis.

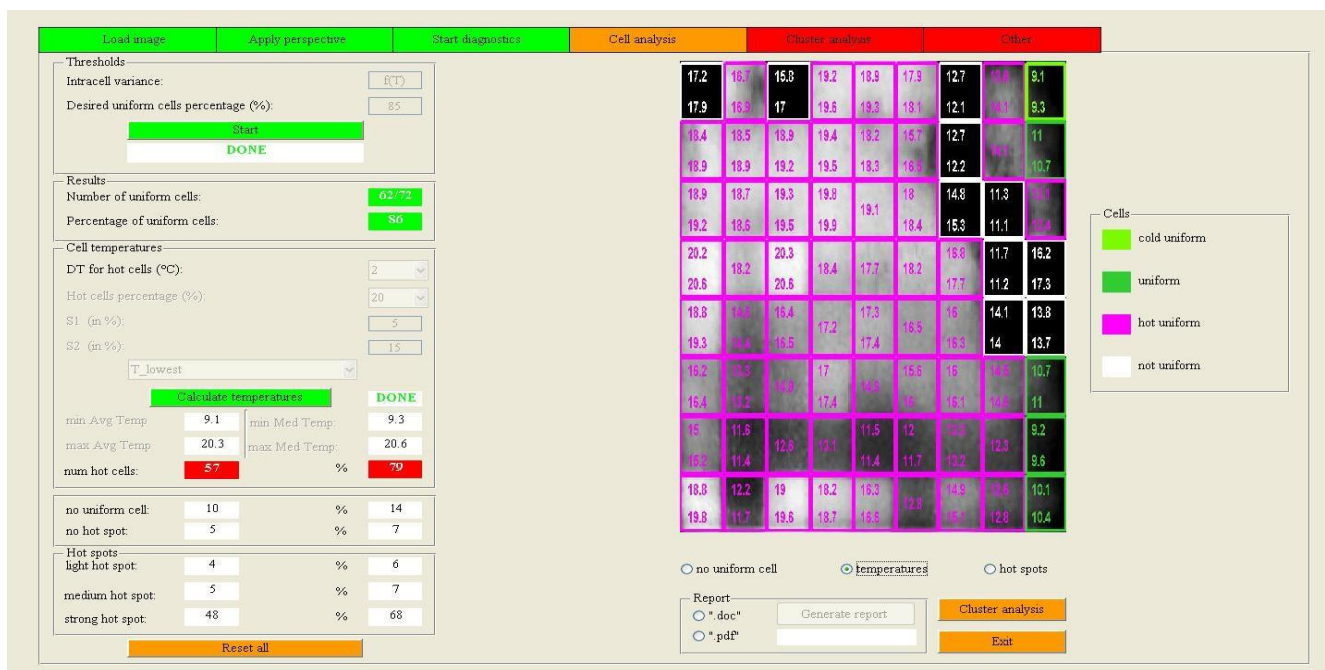


FIG. 3. SCREENSHOT OF THE GUI (CELL TEMPERATURES TAB)

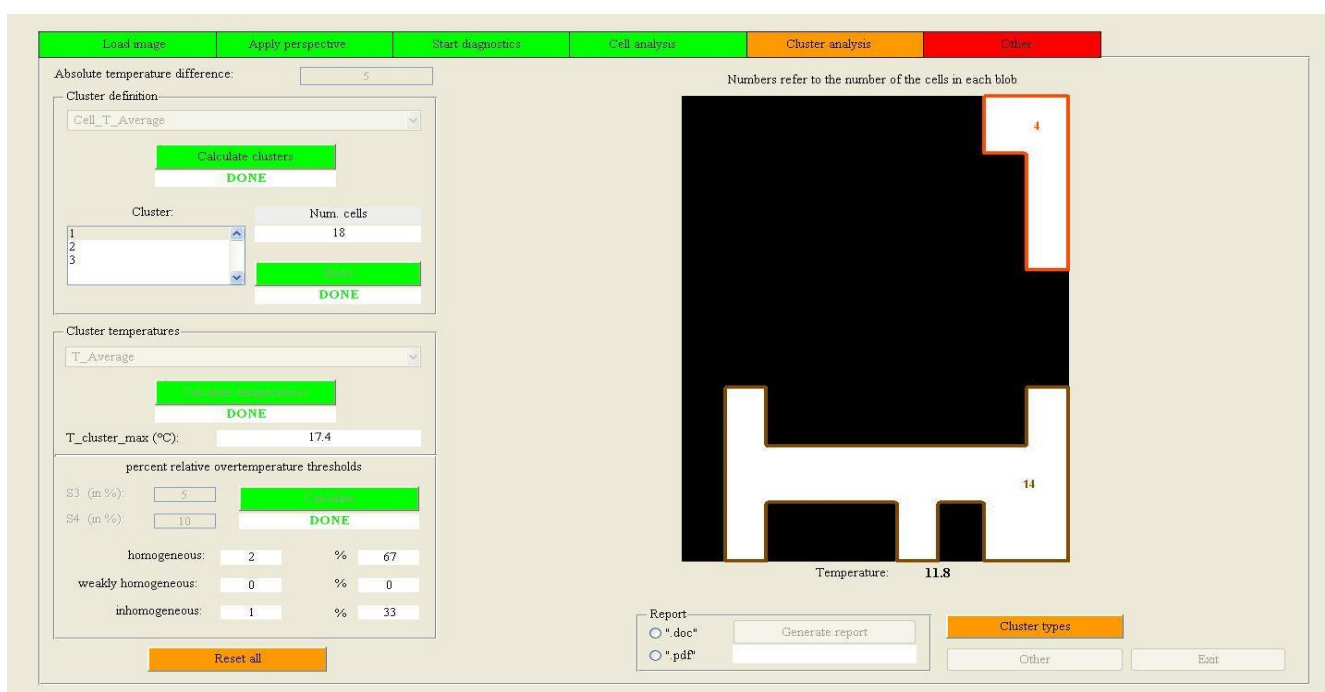


FIG. 4. SCREENSHOT OF THE GUI (CLUSTER ANALYSIS TAB)

3. Conclusions

The paper proposes a workflow for processing IR images of a PV module, in order to automatically generate a diagnostic report. The workflow has been implemented into a software platform that provides detailed information on each PV cell of the analyzed module, either in numerical form or in qualitative form. Moreover, the information is related both at the cell level, and to the cluster level.

The proposed analysis can help not only the manufacturers to improve their production process, but

also the end user to check and understand the real state of health of a single PV module, thus constituting a valid support for the maintenance, because it allows to evaluate the trend of ageing.

Obviously, the software cannot give strong directions on replacing or less the PV module from a PV plant. In fact the final decision depends on several factors: age of the PV module, financial implications if the energy produced by the PV module is supported by the government incentives, trend of the ageing of the PV module, and so on. Moreover, it is needed to know if the PV module under test is a component of a small PV plant

(rated power lower than 3 kWp) rather than a component of a very large PV plant (rated power higher than 100 kWp or higher than 1 MWp and so on); in fact the number of PV modules similarly defected can be very different, and so, the substitution costs. Moreover, it is needed also to know how many PV modules are connected to the array containing the defected PV module: in fact, a short array (i.e. array with few PV modules) will have a per cent reduction of the produced energy less than that one incurring in a long array.

In our opinion, the final decision on replacing or less the PV module should be taken after evaluating all the financial-technical implications. Nevertheless, our software platform, of course, represents a valid tool as support to the technician for these important choices.

Future works will be devoted to better characterize non-uniform cells and diagnostic related problems. This task is not trivial since different silicon-based PV modules assume different behavior, when excited by the same radiance (in the same environmental conditions).

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