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# **A new method for fault detection and identification of shadows based on electrical signature of defects**

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**5.b. Solar energy systems**

**6.d. Smart grids**

Good diagnosis and monitoring of PV systems are key points to maximize PV production. The main objective of this work is focus on the development of a new tool able to detect faults of PV systems on real-time, with a particular care for the detection of shadows. The proposed detection method is based only on DC power measurements.

Keywords: Monitoring system, DC power analysis, fault detection, impact of shadows, shadows nature identification

## **1. Introduction**

With the decrease of the fossil energy reserves in the world, renewable sources have been seriously studied and developed in a large range such as photovoltaic (PV) energy. In the last few years, this source has received much attention, especially for its applications on urban buildings. In this specific application field, several PV monitoring systems have also been developed for the purpose of improving global knowledge of behaviors and then performances. Most diagnosis methods are based on the comparison of monitored data with simulation results of the PV systems [1], [2], [3]. Moreover, some fault analysis have compared predicted production data with real measured ones as described by [4], [5]. Others works are based on statistically analyzed data using learning methods [6]. A sophisticated verification method described in [7] can also check the shadows on the PV modules or detect inverter stop. But these techniques have not been optimized for fault detection analysis. Major studies presented in the literature have used simulation results without testing experimental data from actual monitoring of PV systems [8]. Furthermore, some of these approaches take into account climate sensors or meteorological data bases [9], which can quickly increase the cost.

During their working, PV arrays may be completely or partially shaded able to induce important decreasing of performances. The duration of the DC power drop is related to the type of shadow on PV module such as soiling, building environment, leaves, etc. The aim of this work is to create a real-time fault detection by analyzing the DC power output and more particularly studying the impact of shadows. This detection method is designed to minimize the use of sensors due to economic constraints. The measurement of output current and voltage of the PV array is carried out by a monitoring system. With these measurements, the method is able to detect DC power losses and identify the nature of faults on PV arrays.

This paper is organized into 3 parts. Firstly, DC power analysis is treated to study the behavior of DC power with different types of shadows. In the next part, a monitoring system, tested and established on real PV systems is presented in order to collect DC power data. In the last part, an algorithm of fault detection and identification is proposed and explained. Experimental results using this algorithm are presented through two days over one week of DC power measurements.

## **2. DC power analysis**

It exists several DC power analysis such as the study of Chouder [10] which has evaluated the power losses in a PV system. Silvestre [11] has presented a fault detection procedure using current and voltage analysis. By analyzing these works, the fault detection methods can be classed into three categories based on the comparison of :

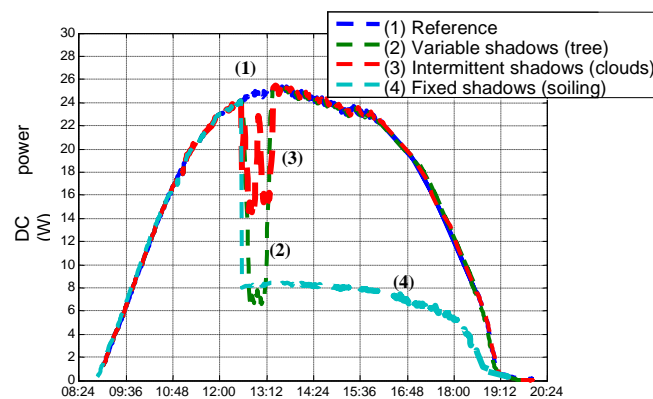
- DC power measurement with its model
- DC voltage measurement and its model
- DC current measurement and its corresponding model

This presented analysis of the effect of shadows study is only focus on the measuring of DC output power without any additional parameters of simulation. In the previous works done by El-Basri [12], experimental tests allowing numerous studies of shadows and their impacts on PV modules have been performed. Moreover, it has been shown that two kinds of shadows could be distinguished: homogenous and partial shadows. The homogeneous shadows affect the PV plant in its entirety, partial ones have more or less impacts depending of their nature and their local position.

Each type of shadow can be identified in function of its behavior on DC power output. Basically, there are 3 types of shadowing as :

- Fixed shadows caused by dust, bird droppings or leaves, with a long time impact on DC power losses.
- Variable shadows caused by trees or, electric poles in function of the position of the sun or big clouds depending on position and hour of the day.
- Intermittent shadows caused by rapid clouds or embedded obstacles which are more difficult to be predicted with an intermittent impact on losses.

Fig. 1 shows different behaviors of DC output PV power in function of type of shadow.



**Fig. 1 : Analysis of the power behavior for each case of shadows**

For the case (2), when a shadow is due to a tree or a chimney, the maximum power generated by the PV module first decreases and then can quickly return to its normal power after a few times. The case (3) represents passing clouds inducing various drops in time and in percentage of DC power. For the last case (4), where a fixed shadow is induced by leaf or soiling on PV modules, there is a significant DC power loss during a long time. Moreover, the duration of this decrease is more important than in the others cases, and the power does not go back to its reference without human intervention.

The analysis of PV characteristics gets more complicated if the PV array does not receive uniform radiation, as in partially shaded conditions, resulting in multiple power peaks. The presence of these multiple peaks reduces the effectiveness of the existing maximum power point tracking (MPPT) schemes [13] due to their inability to discriminate between local and global peaks. Before the presentation of the fault detection method, the system of monitoring developed specifically for this study will be presented and allowing a precise DC power measurement.

### 3. DC measuring box and PV system description

#### 3.1. DC measuring box

PV monitoring system is needed to collect measured data in order to diagnose the source of defects. This implies in this study that a measuring box composed of sensors must acquire in real-time each voltage and current value of the PV chain connected to the grid. Developments of various monitoring systems have been designed in some studies [14], [15]. The choice of sensors is oriented on elements which are non-invasive, plug and play in order to facilitate the connection of the monitoring system on the PV plant. The connection between the monitoring system and the PV plant is made through specific connectors to minimize its effect on the PV energy production.

Hall Effect sensors are chosen as the CSLA2CD manufactured by Honeywell for the input. An embedded web server is used to collect data to be graphed form in real time. The measuring box is developed to support a DC input voltage of 1500V and an AC input current of 30A. Fig. 2 shows schematically DC voltage and DC current measuring for just one PV module.

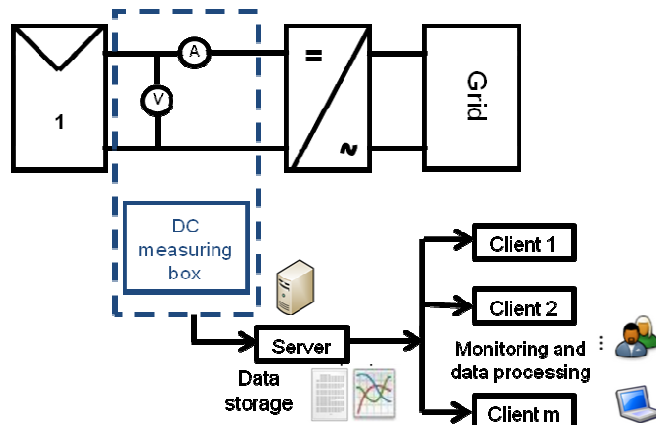


Fig. 2 :Schematic bloc of test bench to DC power measurement with measuring box

### 3.2. PV system description

In the LAAS-CNRS laboratory, at Toulouse, a building named ADREAM has a PV surface of 720m<sup>2</sup> composed of 4 PV fields of several slopes with a total power of 100kWp. The main goal of this building concerns essentially the energy management and the smart-grids (robot, cars, grid, etc). Its peak power is enough to develop a full scale demonstrator and to perform real-time validations of experimentations.

The PV module used in this work is referred *TENESOL TE2200* with a rated of 250Wp, constituted of 60 PV cells and 3 bypass diodes. Its position is in horizontal and it is situated on the roof of the ADREAM building.

The tree shown in Fig. 3, casts a shadow over the studied PV module according to the moment of the day or period of the year. Since the PV module is at an horizontal inclination, it can be shadowed by others proximate PV modules with different inclinations. The next part describes the DC power measures of the PV module under shading conditions. The fault detection algorithm is also described step by step.



Fig. 3 : Horizontal PV module and the environment able to occur shadows (tree, PV modules)

## 4. DC power fault detection around of types of shadows on PV module

The DC power fault detection proposed in this work consists in analyzing the effect of shading on the DC power output of the PV module. This method is based on the detection of the power drop and the duration of the type of shadows as explained in section 2. To validate this approach, a DC power measurement campaign has been performed in order to obtain several types of behaviors of DC power and to establish links with surrounding climate or local environment structures. In addition, simulations have been done to achieve the validation and to adapt this algorithm in the future with the addition of new impacts.

#### 4.1 Fault detection algorithm

A typical flowchart explaining the presented algorithm of fault detection is shown on Fig 4. The step (1) consists in initializing all parameters defined by this algorithm. The different previous values of DC power ( $P$ ) can be stored for example in a table format for each time. The DC power output measured ( $P$ ) at the time  $t$  is compared with the previous one measured at the time  $t-1$  and noted ( $P_0$ ). The next step (2) is the calculation of the error between  $P$  and  $P_0$ . The difficulty is to appreciate the level of the error inducing one fault or only normal variation of irradiance in particular at the beginning and the end of the day. A compromise have been done for this system. If there is a drop greater than 10% and if the Power ( $P$ ) is superior at 5W, it means that the value indicated by ( $dP$ ) is a real error. The fault parameter ( $FAULT$ ) is detected and represented by the binary value 1. On the other side, the binary value 0 represents the case of no defect. The step (3) is done if once fault is detected ( $FAULT=1$ ), the algorithm is able to identify the type of shadows in function of the duration of the DC power drop. Experimentally, it should be noticed that a shadow induced by local environment has its impact which changes progressively. This depends of the position of the sun and the surface environment around the PV plant. The speed of this impact has been estimated between 10 minutes and 60 minutes. Another case of the impact shadow concerns a fixed phenomena such as soiling or leaves deposited in the PV surface in autumn. In this case, the time is more than 60 minutes and can occur several days. This requires human intervention so that the DC power to its initial state of functioning.

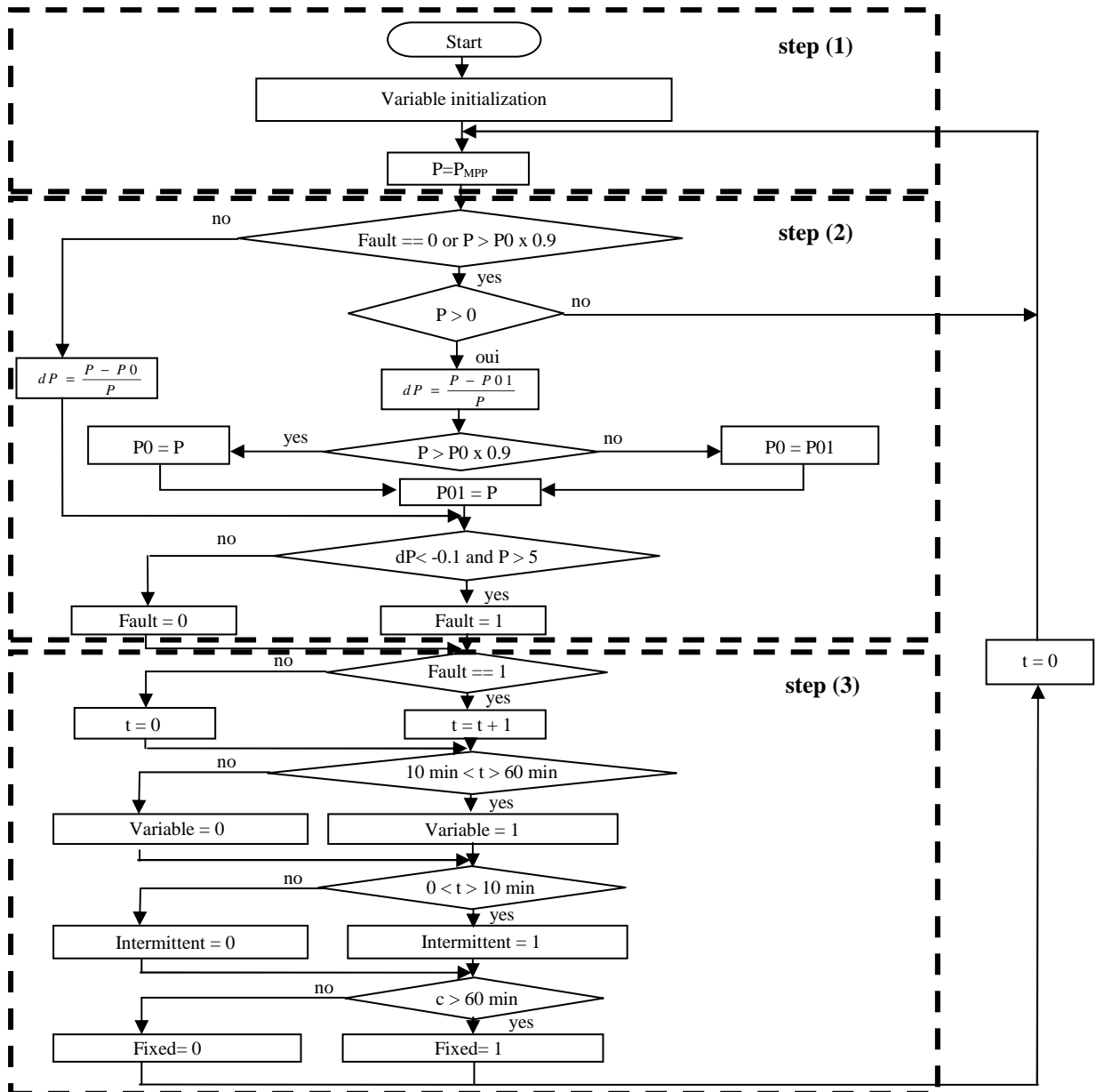
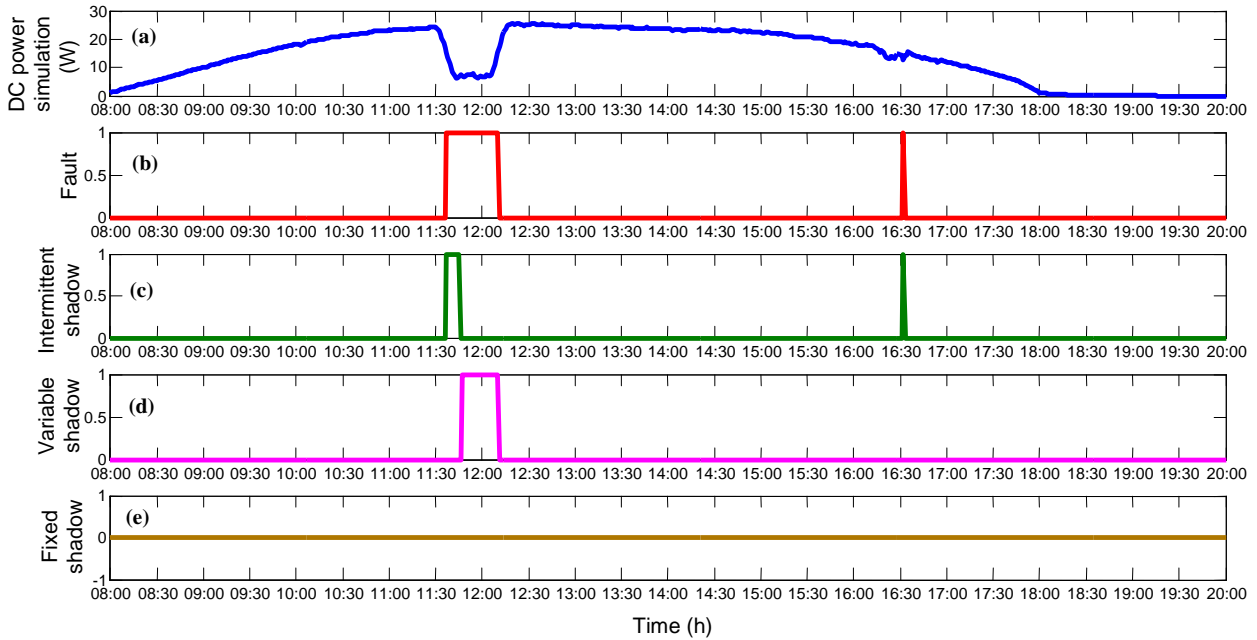


Fig. 4 Flowchart of fault detection and identification of shadows

## 4.2 Simulation results

First validations of the presented algorithm have been done by simulations in MatLab/Simulink environment. Fig. 5 shows an example of results depicting several fault detections. The binary variable FAULT (Fig 5b) is assigned to the fault detection equals at 1 when a fault is detected without distinction of type of shadow or other default. Three others variables have been defined : Intermittent shadow (fig 5c); Variable shadow (fig 5d); Fixed shadow (fig 5e).

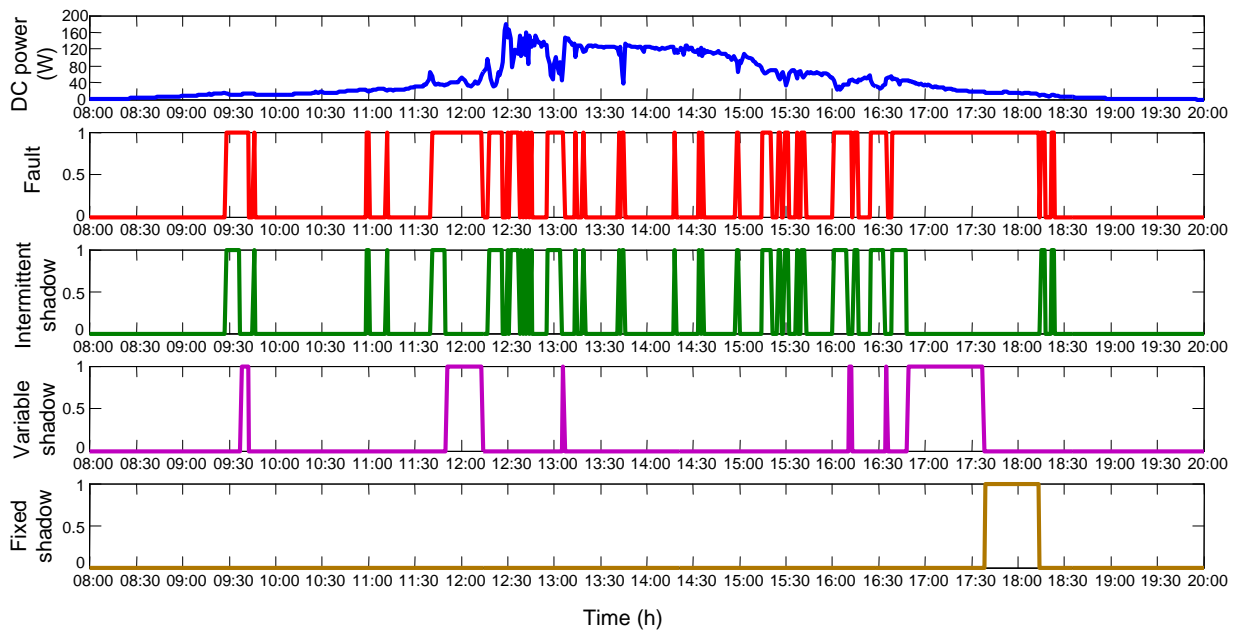


**Fig. 5 : First example of DC power drop analysis validated by simulations**

In this example, two kinds of fault are simulated. In Fig. 5 (a), a significant drop of the DC power occurs at 11h36. The algorithm detects a fault without identifying its nature as shown in Fig. 5 (b). This algorithm considers that the shadow is intermittent, as a portion of cloud with a short time (as the intermittent shadow value shown in Fig. 5 (c)). If the duration of this fault is longer than 10 minutes, the shadow is identified as another type of shadow named “variable shadow” (Fig. 5 (d)). The result can be stored to measure global performances or used in others algorithms in order to manage this type of intermittences. Once the shadow disappears, the algorithm clears its detection and then it is able to detect another one. In the second fault of the shadow scenario occurring at 16h30, the duration and the drop of this new fault are much shorter. It is detected only as an “intermittent shadow”. To validate in real cases, we have used the experimental measurements protocol in several real conditions as described in the next part.

## 4.3 Experimental results

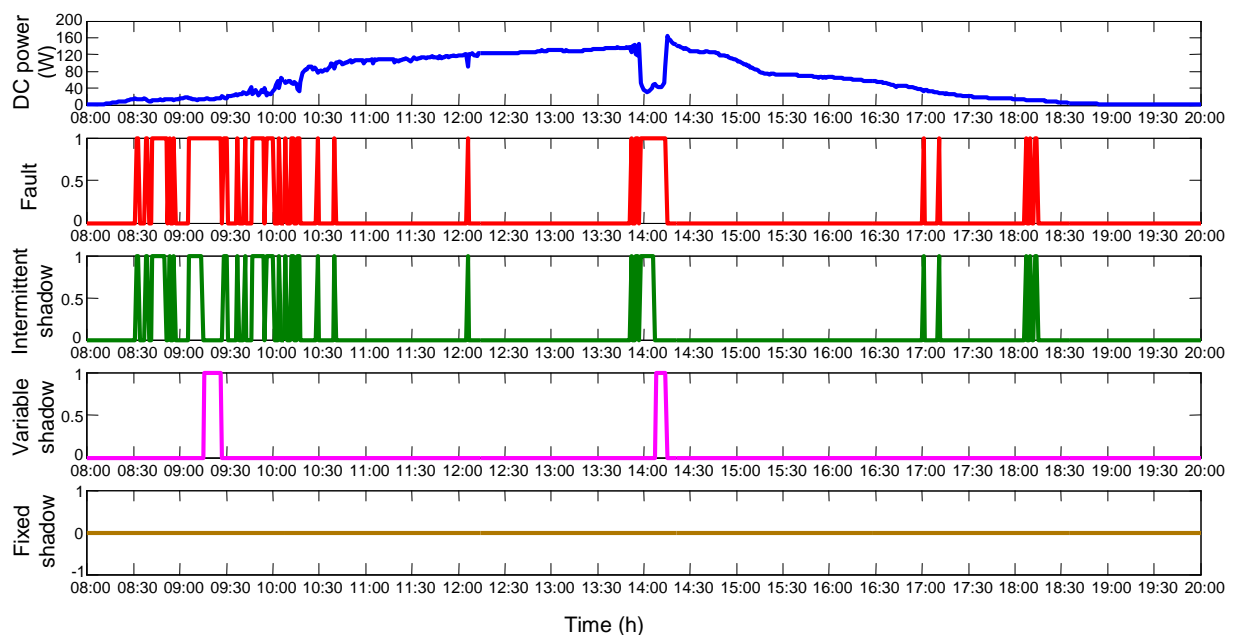
A measurement campaign of the PV module power output was performed during one week in October 2014. Two days of this week have been reported in this paper because of their typical weather context. The first day, the weather was partially cloudy and the second day it was clear sky. The results obtained are shown respectively in Fig.6 and in Fig.7.



**Fig. 6 : Drop DC power output measurements and fault detection analysis for cloudy weather (10/11/2014)**

In Fig. 6, the fault detection algorithm is tested with a cloudy sky in order to study its behavior in the presence of severe intermittency of PV production. Electrical production starts at 8:00 AM with DC power which increases slowly. Around 9:30 AM, the algorithm detects a drop of the power. At first, the cause of this drop is related to a passing cloud, but its long duration classifies it as a variable shadow as in the simulation results (Fig 5). After analysis, this shadow is caused by the tree situated near the building (Fig 3). At 12:30 PM, there is a sudden peak of PV production at 180W. But just after, an important drop appears presaging in this case, a passing cloud.

The other example of measurement concerns a sunny day as shown in Fig.7. At early 14:00 PM, there is a significant drop of the power caused by a variable shadow verified by the algorithm and the fault detection results are represented in Fig.7. This variable shadow is created artificially. During 15 minutes, an object is placed near PV modules to create a structural environment shadow like a chimney.



**Fig. 7 : DC power output measurements and fault detection analysis for a clean sky (10/08/2014)**

As shown for the first day (Fig. 6), the tree causes a significant DC power drop between 9:15 AM and 9:35 AM. Without surprise, during all the week of this measuring campaign, this type of shadow appears each day with a little variation of time impact (function of seasons). Then, the PV module production increases over time despite of a passing cloud around 12:15 PM. At 14:00 PM, PV production decreases during some time related to variable shadow moving on PV module. The algorithm detects the failure and identifies a variable shadow causing by the object.

As expected with simulation results, experimental results have been validated. This algorithm is able to detect shadows making identifications function of its nature and its duration. We can observe that this algorithm is robust and accurate enough for the case of fault detection. This fault detection method is also pertinent when the sky is not scattered by the atmosphere.

## 4. Conclusion

A new method of fault detection based on DC power measurements is presented in this paper. Photovoltaic facilities are most affected by shadows, especially in urban areas. As a result, shadows may be caused by antennas, chimneys, trees, clouds or mobile shadows moving on PV module during the day impacting the PV production. A method of detecting, locating and identifying several types of shadows is given to DC power output analysis which allows accurately and timely maintenance of solar field. This method could inform PV users or PV manufacturers of the robustness of PV modules against presence of shadows despite diodes protection included in the PV modules

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