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IDENTIFICATION OF DYSFUNCTIONAL MODULES WITHIN A PHOTOVOLTAIC GENERATOR

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Keywords: Photovoltaic module; By-pass diode; Photovoltaic power; Divider bridges.

This research paper presents the design and the realization of a system that can detect dysfunctions in modules constituting a photovoltaic generator, the proposed system is intended to monitor an autonomous photovoltaic generator and to discern which photovoltaic module is out of order based on the use of its characteristics such as the by-pass diode and the output voltage. This method can also be used to gain time while searching the dysfunction in the system with the auto-diagnostic algorithm, and it makes the maintenance work faster and easier than conventional, which reduces the photovoltaic power loss. The results show that through simple algorithmic calculation and divider bridges, we can know the state of the photovoltaic generator and which module is dysfunctional and then display the result to the user.

1. INTRODUCTION

According to REN21's 2017 report, more than 20 % of worldwide electrical energy is generated from renewable resources [1]; this energy is mainly obtained through wind turbines, water dams, thermal power plants (stations), biomass, and mainly photovoltaic (PV) generators [2]. It is on the maintenance of this later that we are going to focus.

A photovoltaic generator is composed of several cells (in series), the cells are less irradiated because of shading, winds of sand, raindrops, or even if they are entirely damaged; they force the well-irradiated solar cells to deliver a weak electric current, even if they can produce a higher electric current. This significantly reduces the performance of the PV module [3].

In addition, the solar cells that fail in the PV generator become inversely polarized and dissipate the energy generated by the irradiated solar cells. As a result, failed solar cells overheat, and hot spots appear on the solar cell. The solar cell will be damaged if the dissipated current exceeds the maximum power that the solar cell can withstand [4, 5]. On this issue, the manufacturers implement bypass diodes on PV modules to let the current flow in parallel with the failed module. Still, when the by-pass diodes lead, they introduce some voltage drops and consume some of the energy generated by the PV module [6].

To simplify the maintenance of solar energy devices, in particular photovoltaic panels, we have examined their characteristics and their operation to allow the detection of any problem that may occur without even having to move to the installation site. Our study aims to improve the PV system by adding an intelligent diagnostic circuit. The system allows the detection of any dysfunctional panel in the chain and informs the user via an easy-to-read display system.

This paper is organized as follows: the study of a photovoltaic generator and its characteristics are presented in the first section. In the second section, the proposed system for dysfunctional module detection is discussed and the necessary electrical measurements to size it is shown. The third section is about the programming and the practical tests. The paper ends with a conclusion of the presented work.

2. DESCRIPTION OF A STAND-ALONE PHOTOVOLTAIC SYSTEM

The role of a stand-alone photovoltaic system is to supply one or more consumers with solar energy, for this purpose, we will describe a PV chain to convert solar energy to usable electrical energy. The system comprises a PV generator, a dc/dc converter, a battery, an inverter, and a load (Fig. 1).

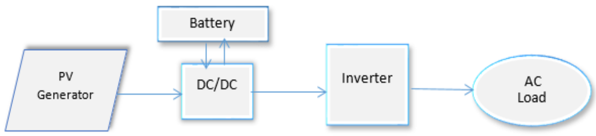

Fig. 1 – Bloc diagram of a stand-alone photovoltaic system.

The photovoltaic panel is a generator able to produce electrical energy from a direct current from solar energy, which is renewable and clean energy. The electrical energy retrieved is directed to a dc/dc converter, which manages the voltage according to the specific needs (step down / step up). The converter is connected to a battery, able to stock the electrical energy for later use, and to an inverter which transforms the direct current into an alternating current.

The PV generator is made of many modules connected in series or parallel. These modules (Fig. 2) are composed of several cells that capture the light and are generally connected in series. The cells are made of semiconductors, Silicon, its most popular shape being Crystalized Silicon. The PV generator is capable of delivering electrical energy due to a field created by the PV effect; it's due to the absorption of photons through processed Silicon that leads to the creation of electron-hole parity in the NP junction of the semiconductor. Every PV module has a reference sheet in the back that displays the standard characteristics (Fig. 3).

Fig. 2 – Photovoltaic panel.

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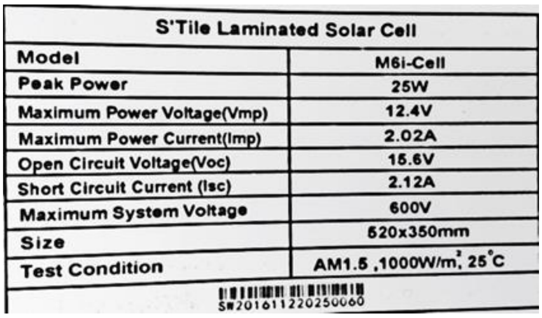

S'Tile Laminated Solar Cell	
Model	M6i-Cell
Peak Power	25W
Maximum Power Voltage(Vmp)	12.4V
Maximum Power Current(Imp)	2.02A
Open Circuit Voltage(Voc)	15.6V
Short Circuit Current (Isc)	2.12A
Maximum System Voltage	600V
Size	620x350mm
Test Condition	AM1.5 ,1000W/m², 25°C

Fig. 3 – Photovoltaic panel's nameplate.

2.1. CHARACTERISTICS OF THE PHOTOVOLTAIC SYSTEM

The photovoltaic cell is characterized by a short-circuit current I_{sc}, which is the maximum current delivered by an illuminated cell connected to itself, and an open circuit voltage V_{oc} which is produced voltage by an unconnected illuminated cell. These two characteristics are present in the $I = f(V)$ curve and the maximum power point (MPP) (Fig. 4).

The last characteristic is the shape factor which is a ratio between the MPP and the product of I_{sc} and V_{oc}, it varies between 0 to 100 %

$$FF = \frac{MPP}{I_{SC} \cdot V_{OC}} . \qquad (1)$$

The temperature and the irradiance level have a direct influence on the characteristics of the photovoltaic cell; the short circuit current varies essentially according to the irradiance, while the open circuit voltage changes with the temperature. As for the maximum power point, it is influenced by both temperature and irradiance.

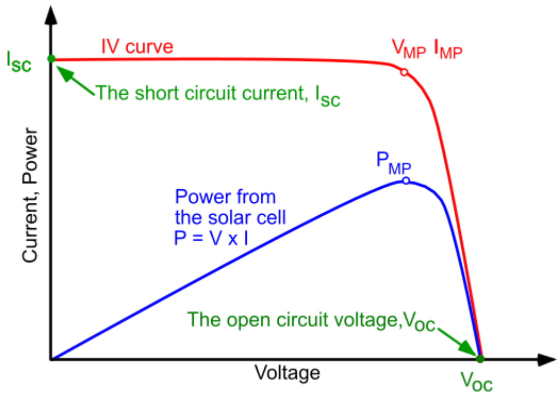

Fig. 4 – *I-V* and *P-V* curves.

2.2. BY-PASS DIODE

The photovoltaic modules need protection to prevent the destruction of the cells or any kind of damage. For this purpose, we focus on the bypass diode (Fig. 5).

These diodes are associated with the photovoltaic cells network and are implemented inside the solar panel. In case the module doesn't generate any electrical current due to damage or shading effect, the diode will short circuit the network and allows the direct current to pass through it directly.

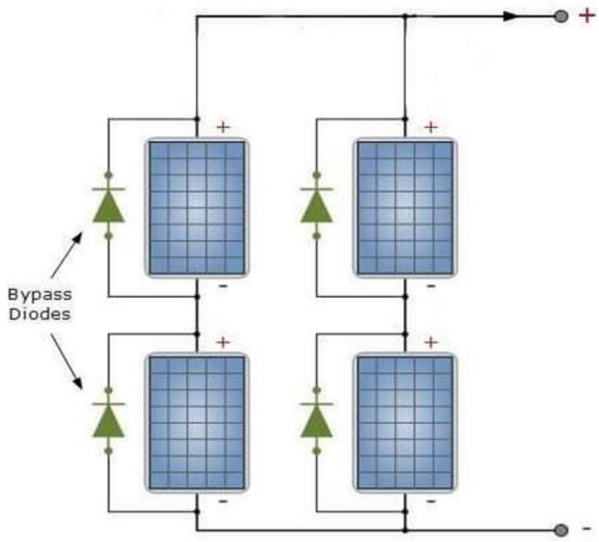

Fig. 5 – Bloc diagram of installation with by-pass diodes.

3. **THE DETECTION SYSTEM OF DYSFUNCTIONAL MODULES**

The studied system detects the dysfunctions of the photovoltaic generator and displays the state of the modules, either working or not working using a microcontroller. The generator is composed of four photovoltaic modules, when a dysfunction or damage happens to the whole generator; it is hard to pinpoint which module is affected. To solve this problem we propose a solution that requires divider bridges and a microcontroller that allows the detection of a failed module. Figure 6 and 7 illustrate the necessary connections.

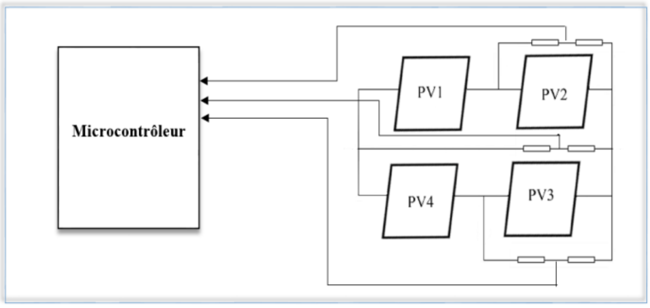

Fig. 6 – Connection of the divider bridges.

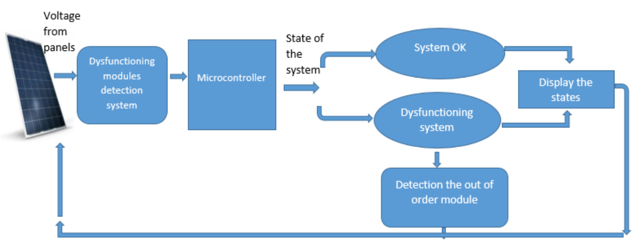

Fig. 7 – Proposed system configuration.

3.1. ELECTRICAL MEASUREMENTS ON THE PHOTOVOLTAIC GENERATOR

We start our study by measuring different parameters of the PV system illustrated below (Fig. 8). It is based on two modules in series, connected in parallel with two other modules in series.

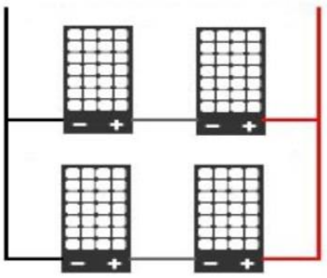

Fig. 8 – Modules connection.

To study the shading effect on the performance of the PV generator, we made the necessary measurements (Figs. 9–12). The system's output is connected to a regulator where the maximum PV output voltage is 28.8 V. The system's output is close to this value with or without shading because it depends on the regulator's input. For each measurement, we will hide one or two modules to see the differences.

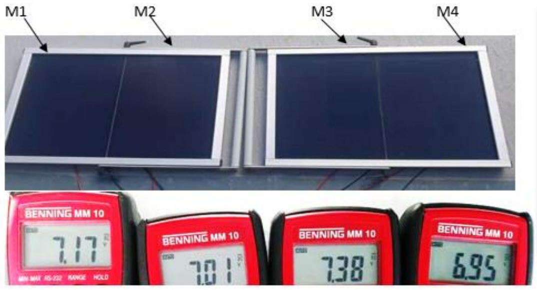

Fig. 9 – No shading.

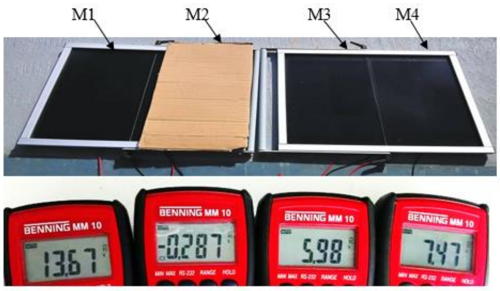

Fig. 10 – M2 shaded.

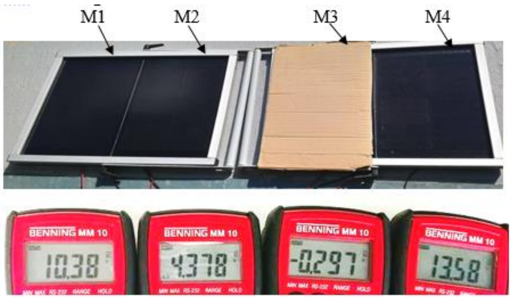

Fig. 11 – M3 shaded.

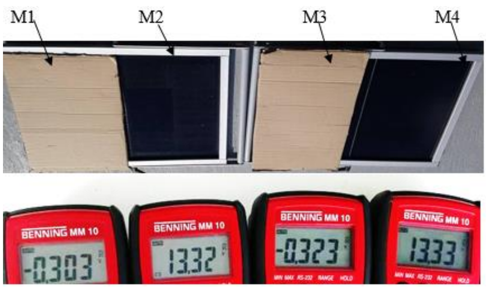

Fig. 12 – M1-M3 shaded.

The notation is as follows: M1: module 1; M2: module 2; M3: module 3; M4: module 4.

Table 1

Obtained voltage measurements under different conditions

Module voltage	No shading	Shading M2	Shading M3	Shading M1- M3
M1	7.17 V	13.67 V	10.38 V	-0.303 V
M2	7.01V	- 0.287 V	4.378 V	13.32 V
M3	7.38 V	5.98 V	-0.297 V	-0.323 V
M4	6.95 V	7.47 V	13.58 V	13.33 V

When a module is shaded, the obtained voltage is negative and close to zero, it's due to the bypass diode operation (Table 1). We conclude that the illumination strongly correlates with the delivered voltage at the output of our generator, which confirms our study.

We can outline, through the table results, that at the shadowing of one photovoltaic module, its voltage is zero, however, there's still a current circulating, which is due to the functioning of the by-pass diode.

3.2. PROPOSED CONFIGURATION

Previously, we've sketched our detection system composed of divider bridges, photovoltaic modules, and a microcontroller (Fig. 13). Now we will detail our study. The maximal delivered voltage is 31.2 V, and the maximum delivered voltage by one module is 15.6 V. The divider bridges will reduce the maximum voltage to 5 V, which will guarantee the protection of the microcontroller analog inputs.

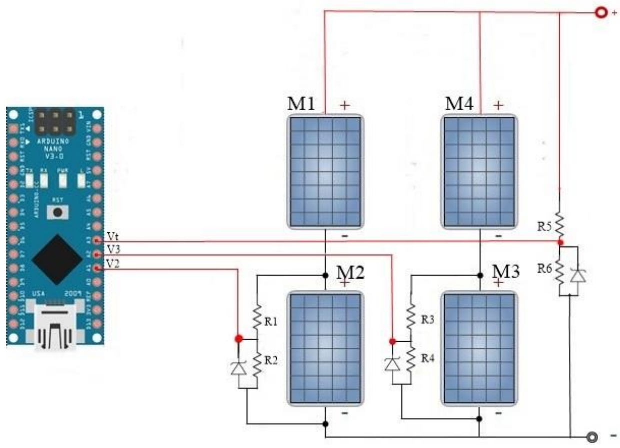

Fig. 13 – Proposed connection to the microcontroller.

The maximum voltage on bridge outputs V_2 and V_3, connected to the dividers, is 2.5 V, which is half of V_{max}. For a voltage inferior to 1 V, the by-pass diode may start working, so the minimum voltage will be considered as V_{min}= 1 V.

The data used are V = 31.2 V; V_{max} = 5 V; V_{3max} = V_{2max} = = 2.5 V; V_{min}= 1 V. The resistors: according to the divider bridge law $V_{t\_max} = \dfrac{V \cdot R_6}{R_5 + R_6}$ which yields to $R_5 = \dfrac{R_6 V - R_6 V_{t\_max}}{V}$. We set R_6 = 6.8 kΩ, which means R_5 = 33 kΩ.

The modules are all similar, with identical characteristics, the chosen resistors will be as follows: R_2 = = R_4 = R_6 = 6.8 kΩ and R_1 = R_3= R_5 = 33 kΩ, respectively.

To ensure the protection of the microcontroller, we connect Zener diodes to each divider bridge, for our prototype, we used Zener diodes 5.1 V, ref: 1N4733A.

We suggest a system enabling us to know the state of our photovoltaic generator by connecting it to a microcontroller. As it can be seen in Fig. 14, the divider bridges are connected to an Arduino Nano, which is our microcontroller, two witnesses LED, red and green, give a first glance at the state of our system, then an LCD screen displays the parameters of our PV generator and the different cases of modules' dysfunctions.

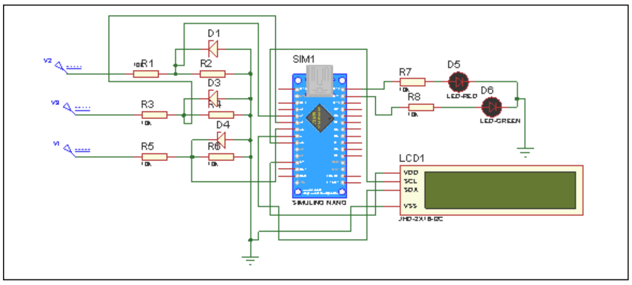

Fig. 14 – Dysfunctional modules detection circuit.

4. PROGRAMMING AND PRACTICAL RESULTS

Arduino Nano reads the output voltages of the divider bridges to know if the modules are working. The microcontroller works according to the next algorithm (Fig. 15).

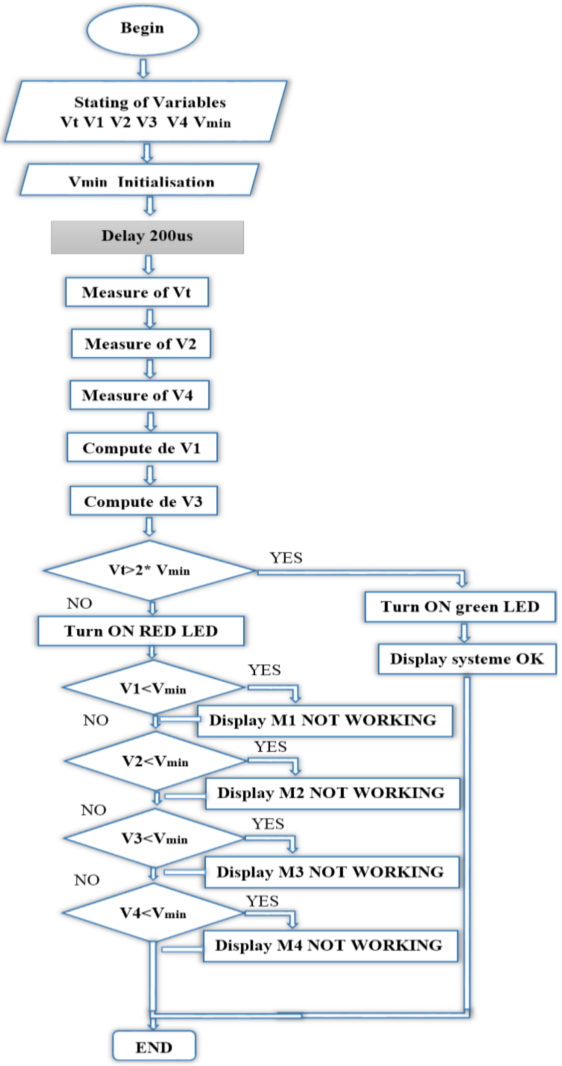

Fig. 15 – Main algorithm.

The notation is: V_t: total bridge voltage, V_{min}: minimum working voltage, V_1: M1 bridge voltage, V_2: M2 bridge voltage, V_3: M3 bridge voltage, V_4: M4 bridge voltage.

Figure 16 shows an electronic board prototype of the proposed circuit.

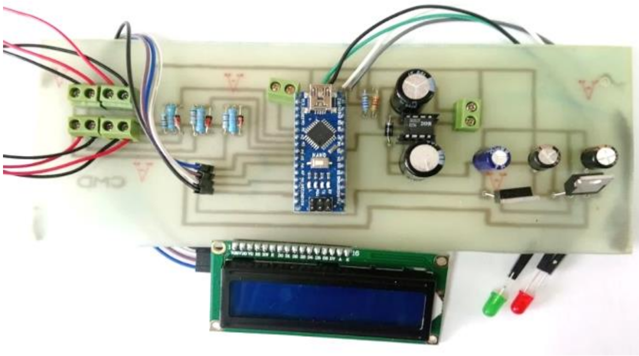

Fig. 16 – Electronic board prototype.

Different tests were made on the electronic board, which is connected to the previously PV generator studied system. The conducted tests are outlined in the next Table 2.

Table 2

Obtained results under different test conditions

Shaded modules	LCD Display	LED witness
No module	System OK	Green
M1 and M3	M1 M3 Not working	Red
M2 and M4	M2 M4 Not working	Red
M2 and M3	M2 M3 Not working	Red
M1 and M4	M1 M4 Not working	Red

In these tests, we can see the state of our system as previously mentioned, for each shaded or dysfunctional module, the LCD screen will display the name and the state of the module (Figs. 17 and 18).

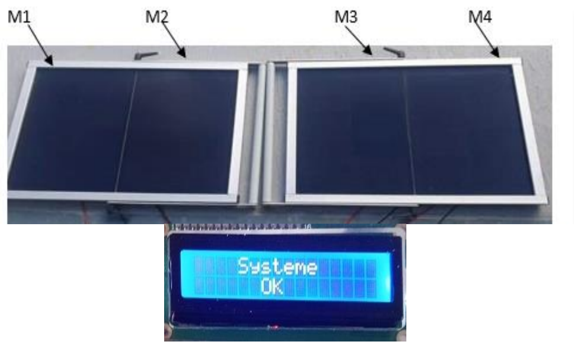

Fig. 17 – No module is shaded.

Fig. 18 – Modules 1 and 3 shaded.

5. **CONCLUSIONS**

The idea of the work presented in this paper was to make a system that allows localizing possible dysfunctions in photovoltaic modules; the proposed circuit is administered by a microcontroller to know easily which module is out of order in a photovoltaic field without even being in the installation site.

At the output of the photovoltaic generator, the voltage passing across the divider bridges links directly to the microcontroller, this voltage is tested to detect the dysfunctional modules. This test can be done on the condition that all the modules are equipped with bypass diodes. The realized prototype is adaptable to several photovoltaic systems, whether industrial or domestic.

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