RELEVANCE ANALYSIS OF ATMOSPHERIC VARIABLES IN THE PRODUCTION OF AN EXPERIMENTAL PV POWER PLANT CONSIDERING DUST DEPOSITION IN THE MEDITERRANEAN COAST

J. Alonso-Montesinos[1,2], J. Barbero[1], F. J. Batlles[1,2], F. Rodríguez-Martínez[2], G. López[3], J. Polo[4], N. Martín-Chivelet[4], M. Alonso[4], N. Vela[4], A. Marzo[5,6], P. Ferrada[5], M. Cortés[5]

[1] Department of Chemistry and Physics, University of Almería, 04120 Almería, Spain

[2] CIESOL, Joint Centre University of Almería-CIEMAT, 04120 Almería, Spain

[3] Department of Electrical and Thermal Engineering, Design and Projects, University of Huelva, 21004, Huelva, Spain

[4] Photovoltaic Solar Energy Unit (Renewable Energy Division, CIEMAT), 28040 Madrid, Spain

[5] CDEA, University of Antofagasta, 02800 Antofagasta, Chile

[6] Solar Energy Research Center (SERC-Chile), Santiago (Chile)

Abstract

Photovoltaic solar energy (PV) is the technology for electric generation that shows the highest growth since 2002, experiencing an average annual increase of 48%. The prediction of the solar resource for a PV plant, connected to the grid, is necessary to ensure optimal capture and transformation of the available solar energy and reliable power production. In addition, the accumulation of dirt on the surface of photovoltaic modules has a significant impact on the production of a photovoltaic installation. This phenomenon is related to the angle of inclination of the panel and the meteorological conditions, such as the aerosols present in the atmosphere, relative humidity, ambient temperature, pressure, etc. The fundamental objective of the present project is to develop an experimental PV plant to characterise the losses per soiling with the aim to predict in the short term, from one to three hours, the production of a photovoltaic plant.

Keywords: Solar radiation, PV forecasting, Soiling, Atmosphere.

1. Introduction

Renewable energies have the advantage of a lower impact on the environment compared to other sources of energy; however, its performance is conditioned by its variation in weather and weather conditions. Besides, contributing to reduce pollution, its implementation will reduce our energy consumption and our energy dependence on the outside, which currently exceeds 80%.

Photovoltaic (PV) plants are the technology for electricity generation that shows the highest growth since 2002 thanks to the sharp decrease in the manufacturing costs of PV panels. Most photovoltaic systems connected to the power grid employ maximum power tracking systems (MPPT) to ensure that the PV module operates at a point that produces maximum generation. However, maintaining a photovoltaic panel near your MPP is a difficult task when atmospheric conditions lead to variations in panel temperature and incident solar irradiation. Thus, given the high dependence of the output power of the system with the incident solar irradiance, the transitory phenomena (ups and downs of radiation in a short period of time) significantly alter the power output of the photovoltaic system.

One of the main problems in the operation of PV plants is to accurately predict the moment, duration and quantification of a significant drop in incident global solar radiation. Long-term predictions, such as those made 24 hours in advance, do not allow us to estimate in detail the variations in global irradiance in short time intervals of the order of a minute. The prediction of short-term solar radiation, also known as nowcasting, is a current research topic and provides predictions in a time horizon of the order of one to three hours and with a

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resolution of the order of minutes (Alonso-Montesinos and Batlles, 2015). There have been numerous researchers who have addressed the issue of short-term solar resource prediction in recent years. In addition, soiling is a factor that has a high correlation with the angle of inclination of the module and weather conditions (aerosol load, relative humidity, wind speed or precipitation).

There are recent works that show in a relative way the impact of some meteorological variables on the losses by soiling in several regions of the world (Bouraiou et al., 2015, Ferrada et al., 2015, Micheli and Muller, 2017, Urrejola et al., 2016). The annual losses in a photovoltaic generator due to dirtiness will depend a lot on the characteristics of the site (climatic and environmental conditions) as well as on the characteristics of the transparent cover of the module. In dry and arid climates, losses of up to 25% have been reported after three months of operation in the dry season (Stein and Farnung, 2017). After analyzing the results of different studies, it can be stated that, after irradiation and temperature, dust is the environmental parameter that most influences the performance of a photovoltaic panel (John et al., 2016). The powder is a particle less than 500 μm in diameter that has various origins, such as pollen, human and animal cells, textile fibers and, above all, organic minerals (Darwish, et al., 2015). The study of fouling in photovoltaic modules is becoming more and more important as it leads to a continuous reduction of energy production (Hegazy, 2001) decreasing their performance by up to 50% (Maghami et al., 2016; Mazumder et al., 2013). In addition, although the dirt does not lead to a degradation of the module directly, it can lead to major drawbacks such as the hot spots created by the shadows generated by the dust in the photovoltaic module, even shortening its useful life (Milanés, 2017). Studies state that characteristics such as the size of the dust grain, the type of grain, the density, the level of light transmission through the dust grain and the glazing temperature are the most important factors to study the loss of efficiency in photovoltaic solar energy (Abderrezek & Fathi, 2017; Rao et al., 2014). For example, M. Pavan et al. They found that 6.9% of losses occur with sand-type dust and 1.1% with more compact dust (Massi Pavan et al., 2011). With the appearance of dust and the drop-in performance, the need to perform spot cleaning appears. Most of these are based on water as a cleaning fluid. Some of the most used systems are natural method, electrostatic method, mechanical method and automatic nano-film method. The consequences of fouling also depend on the cleaning method that is carried out (Syafiq et al., 2016). Another cleaning system that is being implemented is based on transparent electrodynamic screens, capable of eliminating 90% of the dirt with energy produced by the own panel (Mazumder et al., 2013) thus avoiding high consumption of water, an element that , in desert areas, sometimes it is impossible to obtain.

Therefore, the main objective of this work is to determine the most significant atmospheric factors related to soiling, to be able to model them and thus have an estimate of the production of an experimental photovoltaic plant located at the Solar Energy Research Center (CIESOL) in the south east of Spain with Mediterranean climate. This determination will allow to improve the PV plant production forecasting employing different techniques and based on remote sensing devices. Therefore, given the importance of the dirt in the performance of photovoltaic installations (Trigo-González et al., 2019) and the little information relative to the characteristics and consequences of this in the Mediterranean area, in this work it is going to carry out the first of the steps necessary for the characterization of dust in the Almeria area, where the design of an experimental photovoltaic system will be carried out in order to characterize the influence of dust in this geographical area. For this, a photovoltaic installation equipped with four polycrystalline panels will be available, of which two of them will be cleaned periodically and the other two will be left to be freely soiled in order to make the pertinent comparisons.

2. Materials and methods

In this section, we will present the design of a complete experimental photovoltaic installation equipped with a metallic structure, different photovoltaic panels, measurement devices and sensors and data acquisition systems, together with those methodologies that have made it possible to achieve their objectives.

2.1 Photovoltaic modules

The panels that will be installed on the roof of CIESOL, to subsequently conduct dust studies, will be of the A-222P model of ATERSA. Four panels arranged in pairs in each row of the metal structure will be used. Of the two panels in each row, one will be cleaned periodically while the other will be left uncleaned so that the dust that may appear in the environment will progressively dirty it. Figure 1 shows a picture of the PV panel.

Figure 1.- PV panel of ATERSA manufacturer.

It should be noted that the four panels have a polycrystalline structure and the properties of each panel is presented in Table Table 1, composed of 60 cells in series each, with a power of 222W and a short-circuit current of 8.17A.

Table 1.- Main characteristics of ATERSA PV panels.

Peak power	222 W
Cells in Series	60
Efficiency	13.63%
Current Maximum Power Point	7.57 A
Voltage Maximum Power Point	29.32 V
Open circuit current	8.17 A
Open circuit voltaje	36.42 V
Dimensions	1645 x 990 x 50 mm
Weigh	21.5 kg
Area	1.63 m^2
Temperature of working	-40 ºC to +85 ºC
Maximum voltage of the system	1000 V

2.2 Shunts 15 A / 150 mV KL.0.5

To obtain the values of the short-circuit current that occur in each photovoltaic panel, a shunt will be used in each of these. The dimensioning of the resistance added to each panel has been made following the technical specifications of the photovoltaic panel itself. Specifically, the panel has a maximum current of 8.17 A, which means that the resistance must, at least, have an equal or greater consumption. The resistance according to each panel is the one defined for 15 A / 150 mV. Therefore, to obtain the value of the short-circuit current, the voltage that falls on the resistance will be measured. Once the voltage value in this is known, the short circuit current (I_{sc}) can be known by performing the following linear conversion:

$$I_{sc} = \frac{I_{range}}{U_{range}} \cdot U_{out} \tag{1}$$

Where I_{range} is the current range (15 A), U_{range} is the voltage range (0.150 V) and U_{out} is the measured voltage. Figure 2 shows an image of the shunt where the extremes are used to connect the PV panels.

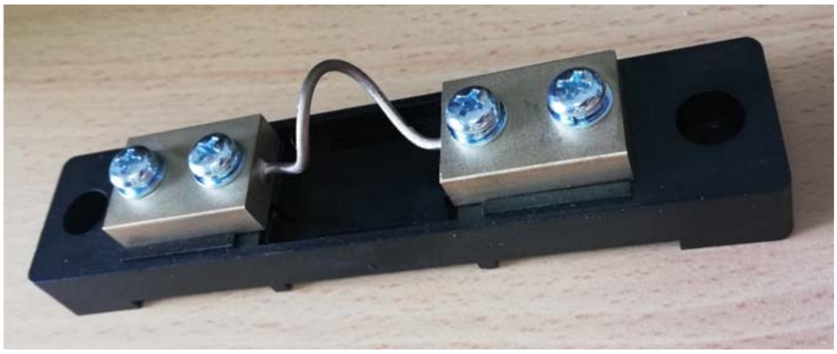

Figure 2.- Shunt 15 A / 150 mV.

2.3 Calibrated solar cells

For the measure of the global irradiance in the same array plane of PV modules, a polycrystalline solar cell encapsulated in a box in the form of a photovoltaic panel will be used. ATERSA is the manufacturer of the cells and they provide the voltage enough to cover a global irradiance from 0 to 1000 Wm-2, given as voltage in the range 0 to 65 mV. Together with each row of PV panels, two cells are placed where periodically will be cleaned one of them to compare the difference between clear and non-clear cell. Figure 3 shows the solar irradiance PV cell.

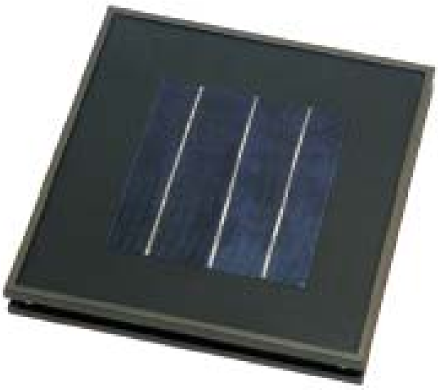

Figure 3.- ATERSA calibrated solar cell.

2.4 DustIQ sensor

In order to control the contamination by dust that can be deposited in the environment of the installed photovoltaic plant, a new sensor will be used on the market, such as the DustIQ model of the KIPP & ZONEN brand. This sensor employs optical dirt measurement technology that provides data as much as percent of the dust losses with a frequency of one minute. Figure 4 shows the new sensor to measure the

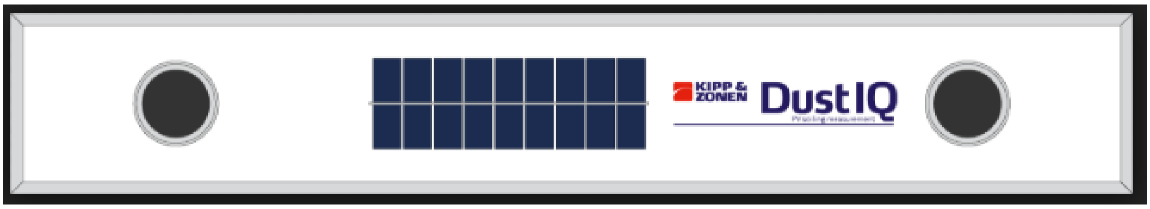

Figure 4.- DustIQ sensor.

2.5 Temperature probes (Pt100)

In order to know the temperature in each photovoltaic panel, two 4-wire Pt100 resistive temperature detectors will be placed in each one. These probes will be fixed to the back of the panel, one in its highest section and another in its lower area, to try to obtain an average representative measurement of the photovoltaic panel. By using 4 wires, the resistance is measured two to two, thus compensating for possible losses that may occur at these distances. The temperature range is -50 to + 100ºC with a resistance of 100 ohms to 0ºC. Figure 5 shows one Pt100 sensor.

Figure 5.- Temperature sensor (Pt100).

2.6 Temperature and Relative humidity sensor

To obtain the value of the ambient temperature and relative humidity in the area of the installation, the HMP60 probe of Vaisala will be used. Table 2 shows the main properties of the sensor, whereas Figure 6 shows the probe and the protection cupule of the probe.

Table 2.- Characteristics of the HMP60 Vaisala sensor.

Measuring HR range	0 – 100 %HR
Temperature range	-40 a 60 ºC
Input voltage	5 – 28 VDC
Intensity consume	1 – 5 mA
Output voltage	0 – 5 VDC

Figure 6.- HMP60 sensor and protection cupule.

2.7 Pressure sensor

To know the value of the atmospheric pressure in the environment of the installation, the contrasted barometer PTB110 of the trademark VAISALA will be used. This sensor has the capability to measure the pressure between 500 and 1100 hPa, needing a voltage supply from 10 – 30 VDC, having a voltage output between 0 and 5 VDC (Figure 7).

Figure 7.- Barómetro PTB110 de VAISALA.

2.8 Support structure of PV panels and sensors

In order to have a structure to hold the photovoltaic panels that will serve as experimentation, in addition to the rest of the elements that will be used for atmospheric measurements, the CIESOL building has been designated as the most suitable for such tasks. Specifically, the structure has been located on the roof located on the second floor of the building, on a stone pavement. The structure has been designed, as it is presented, for the array of 4 photovoltaic panels, in addition to the set of sensors described above. The dimensioning of the support structure has been made considering the dimensions of the panels and the sensors that this will support. The separation between rows was 4 m to avoid shadows throughout the year. The structure has a manual adjustment system that allows adjusting the inclination of each array of two panels, ranging from 0º to 40º. Figure 8 represents the plans of the structure for two panels

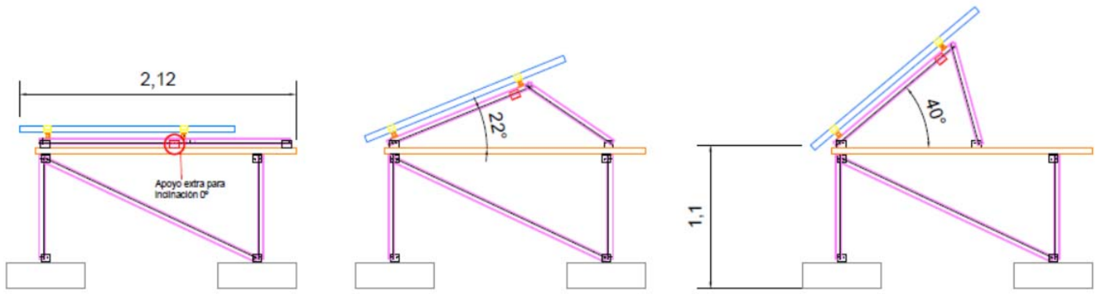

Figure 8.- Plane for the PV panel support structure.

2.9 Data acquisition system

For the acquisition of data, the system of the brand KeySight, model DAQ970A (Figure 9) compatible through LAN and USB interfaces will be used. There are many advantages to using this type of system, as it has great versatility compared to sensors of different types and origins, as well as having a web interface that allows controlling and configuring the instrument. It has capacity for 3 multiplexer modules, each of them with up to 22 channels. The datalogger is compatible with the SPCI programming language and has an internal DMM with a resolution of 6½ digits (22 bits) with signal conditioning.

Figure 9.- Datalogger KEYSIGHT DAQ970A.

To acquire the data of the different sensors, two multiplexer modules model Armature of 20 channels DAQM901A will be used. This model of multiplexer has 20 analog channels + 2 independently configurable digital channels and are divided into two banks of 10 channels each, with two inputs per channel, and another small bank with 2 channels and a total of 4 possible inputs. The internal circuitry of the multiplexer module is shown in the following image:

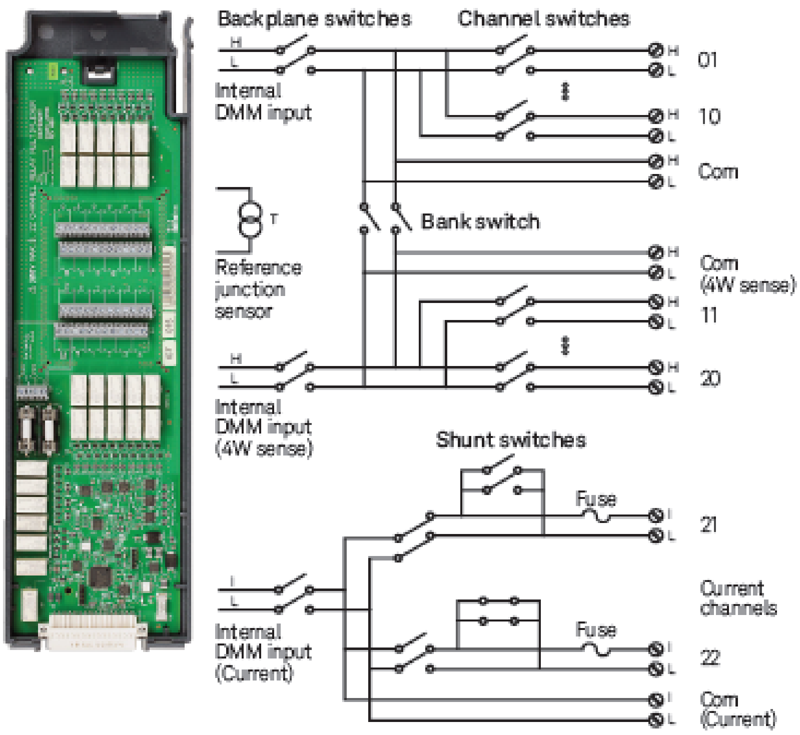

Figure 10.- Internal circuit of DAQM901A.

2.10 System connection

All sensors, except for the DustIQ dust sensor (which is connected directly in the PC), have been integrated into the datalogger. The connection of the sensors to the datalogger has been made in the two multiplexer modules. The first multiplexer has been reserved for sensors that measure the characteristics of each photovoltaic panel: module temperature and resistance (to obtain the short-circuit current). The multiplexer 2 has been used for the sensors that calculate the environmental parameters external to the panels, leaving, at this moment, a total of 13 free channels to be used in possible extensions of the installation. Figure 11 shows a schematic vision of the connections.

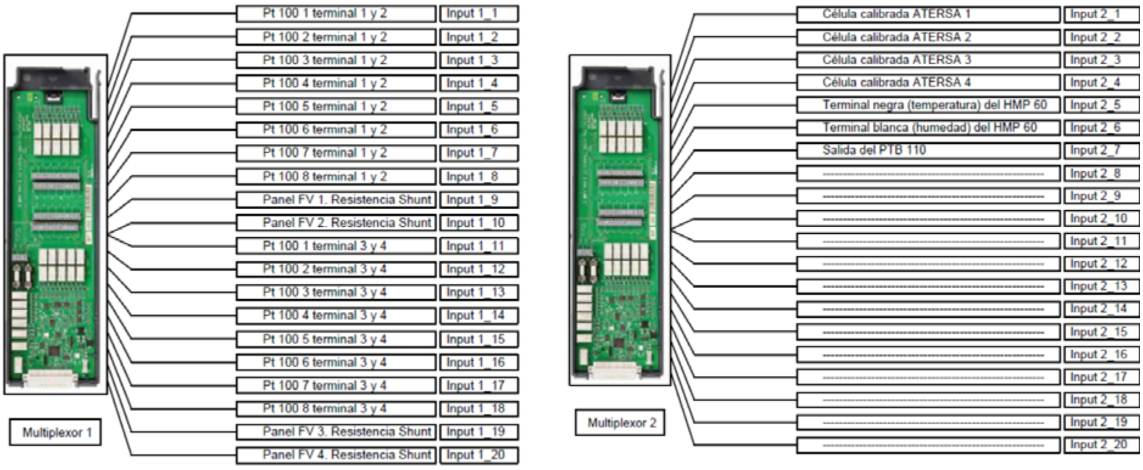

Figure 11.- Connection of sensors in multiplexers 1 and 2.

The first multiplexer has been reserved for sensors that measure the characteristics of each photovoltaic panel: module temperature and resistance (to obtain the short-circuit current). The multiplexer 2 has been used for the sensors that calculate the environmental parameters external to the panels, leaving, at this moment, a total of 13 free channels to be used in possible extensions of the installation.

3. Results for the PV installation to measure the relevance analysis of atmospheric variables in the PV production

In this section, we will present the main results of the design and installation of the experimental photovoltaic plant together with the sensors to measure the properties of the panels and atmospheric variables to obtain a representation of the losses due to dirtiness due to the dust in suspension. Figure 12 shows the result of installing two photovoltaic panels in the metallic structure together with the DustIQ dust sensor and two calibrated cells. In addition, the temperature and relative humidity sensor can be seen behind the panels. The height of the structure has been equal to that of the wall to avoid shading.

Figure 12.- PV array, DustIQ, calibrated cells and Temperature/HR sensor.

Figure 13 shows the other installed array, with two photovoltaic panels and two global irradiance sensors in the same array plane.

Figure 13.- PV array together with two calibrated cells.

Figure 14 shows the back of two panels, where you can see the installed Pt100 (in red), as well as two central boxes where the shunts are located (one for each panel). All cables have been protected by a weather pipe and are arranged to reach the Datalogger located in a room next to the installation, where the pressure sensor is located.

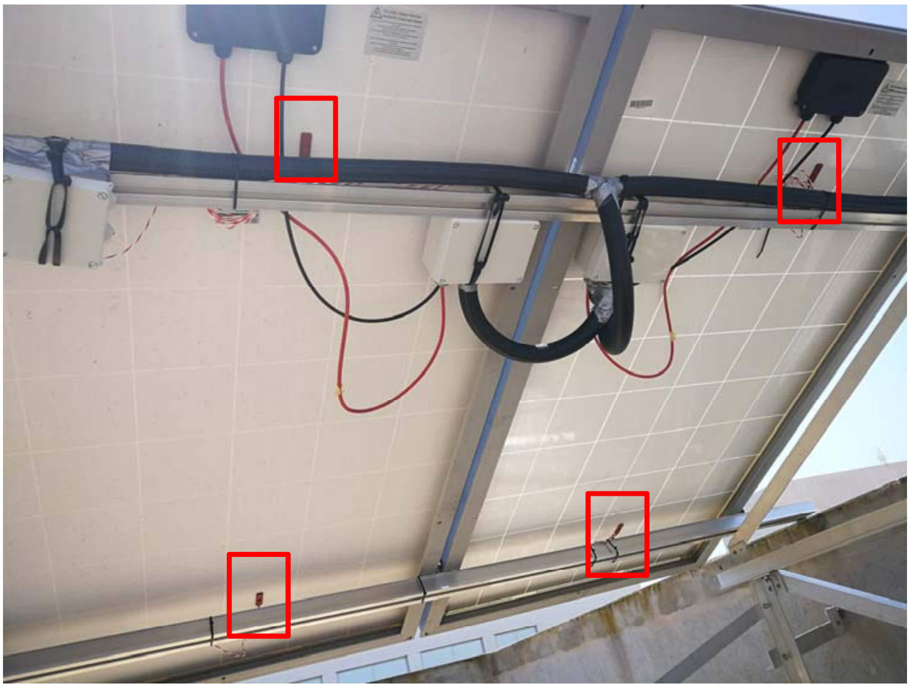

Figure 14.- Rear view of photovoltaic panels with the identification of the Pt100 sensors.

Once the communication has been effective, following the previous diagrams and annotations, it has been necessary to select different modes of operation of the datalogger, such as the determination of the communication between the acquisition system and the data server PC. This has been through the LAN interface. In order to select this type of connection, the Keysight Connection Expert application has been used.

The DAQ970A has the advantage of being able to perform a remote operations control through the web interface. To access it, simply enter the IP address of the datalogger in the web browser, where the values that the sensors are measuring in each channel are displayed. With this, you can work with the datalogger remotely through established LAN communication. Figure 15 shows an example of the measurement of the temperature sensor Pt100 nº3, located on channels 03 and 13 and where the result is a temperature value after the correct connection of the four wires.

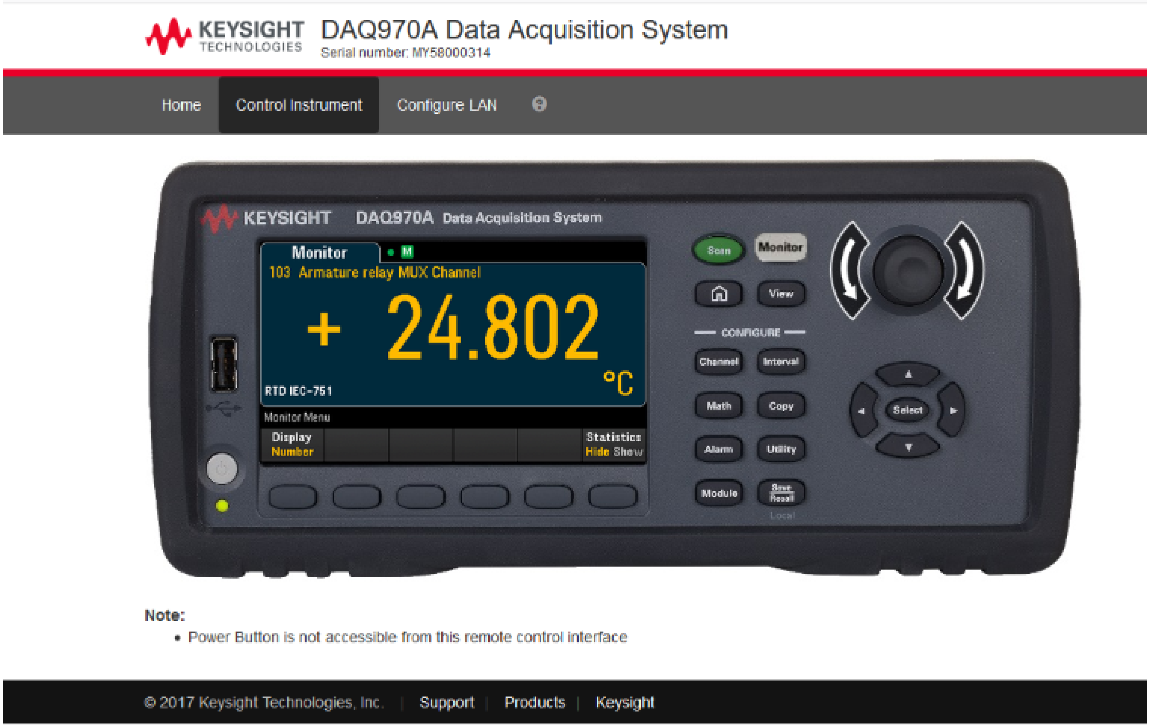

Figure 15.- Interface Web of Datalogger system.

Therefore, with the verification phase of the results it can be confirmed that the system guarantees a set of reliable measurements that enable the study of the fouling of photovoltaic panels, the influence of meteorological variables on the causes that affect soiling and, therefore, the factors that affect the performance of a photovoltaic experimental plant

4. Conclusions

In this work, the design of an experimental installation has been presented to characterize the influence of dust fouling on photovoltaic panels and how it affects their performance. In total, 4 panels have been used, each equipped with 60 polycrystalline silicon cells and with a maximum power of 222 Wp.
To be able to hold the panels, two metallic structures (in aluminum) with a capacity to hold up to a total of 4 panels have been installed. In addition, the structure has enough space to install different atmospheric sensors related to the meteorological variables that affect the photovoltaic plant.
The effect of the dust is usually more representative in the short-circuit current, when a drop in the intensity occurs whenever there is dirt by dust. For this, shunts of 15 A / 150 mV of the commercial mark KAYNOS have been installed, which will determine at any time what the open circuit current is. Weatherproof boxes have been created to protect the shunts and have been installed under the panels themselves attached to the metal structure.
The temperature of the photovoltaic panels has been measured thanks to two 4-wire Pt100 sensors of the RS PRO brand connected on the top and bottom of the back of each panel. With this temperature, it will be possible to obtain the average temperature of each panel in real time.
A total of 4 calibrated cells of the ATERSA brand have been installed, capable of measuring the global radiation at any time through a voltage output of 0 to 65 mV without the need for an auxiliary power supply. The experimental plant has been equipped with a dust measuring system of the brand KIPP & ZONEN, model DustIQ, to measure the dust deposited on the surface of the device. This measure will be correlated with the photovoltaic panels to relate the level of dust with the fall of production of the same.
The installation has been equipped with an ambient temperature and relative humidity sensor of the VAISALA brand, model HMP60. In addition, to control the possible oscillations of atmospheric pressure, a pressure sensor of the brand VAISALA, model PTB110 has also been installed within the general scheme of the installation. All the sensors have been connected and configured in a datalogger of the manufacturer KEYSIGH, model

DAQ970A, through a total of two multiplexer cabinets model DAQM901A. This configuration, with capacity for 40 analog and 4 digital channels, has been configured, with the corresponding scale backgrounds, to recover data every minute from the sensors. The software has been installed on a server computer with Windows 10 Pro to capture data in real time, and it has been possible to verify that all the data is recovered correctly.
With this installation, a very important process has been completed dedicated to the study of the factors that affect the production of photovoltaic plants, thus having a reference system that can be used to extract valuable information demanded by the energy sector, and with the that it is intended to export the knowledge to larger sized commercial plants for an improvement of the yield and the use of the solar resource.

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