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RESEARCH ARTICLEOPEN ACCESS

DEVELOPMENT AND SET UP OF AN ARDUINO-BASED SOLAR RADIATION SENSOR USING A REFERENCE CELL

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ABSTRACT

Our work is pointed toward planning a device for estimating all out solar radiation in light of a reference photovoltaic cell. The rule of this device is chiefly founded qualities of a photovoltaic cell where sun oriented radiation is corresponding to the short circuit current, wich is estimated by a resistor.The voltage difference at these connections is measured by acquisition using a functional amplifier and then recorded into an analogue-to-digital converter for further processing. The Arduino Uno platform was chosen to process and display in real-time the solar radiation received from the reference cell surface. The affordable device has a wide range of uses, including monitoring solar radiation in both stand-alone and grid-connected photovoltaic power plants. The decision to utilize the Proteus design software environment has proven to be a key factor in the successful testing and validation of the device's performance. This integrated platform has enabled the efficient implementation and simulation of the hardware and software components, ultimately leading to the development of a cost-effective and reliable solar radiation estimation solution.

I. INTRODUCTION

The need to estimate solar radiation and its components is evident in a wide variety of applications, including agriculture, meteorology, engineering, and renewable energy. The use of Global Solar Radiation (GSR) estimations obtained from regression models based on satellite data has become a common practice for developing applications and supporting scientific research. This information is of vast interest in many areas of human activity, such as agriculture, hydrology, meteorology, civil engineering, architecture, and environmental studies. It is particularly crucial in the areas of solar thermal, photovoltaic, and solar conversions, where accurate radiation data is essential for the optimization and simulation of these systems.[1-5]

Renewable energy is increasingly vital due to the declining availability of fossil fuels, their pollution generation, and their contribution to global warming. Almost all environments are affected by contamination from the rise of greenhouse gases. Currently, the measurement of solar radiation using instruments is expensive and limits the number of measurement points due to the high cost of these instruments. The opportunity to have a primary radiation measurement source available for free is a significant advantage that renewable energy offers. Therefore, it is necessary to create a simple, robust, and economical device that provides sufficient information.[6-8]

Evaluating the performance of solar technology with precision before installation is crucial to streamline the integration of photovoltaic systems. Utilizing various radiation sensors on the market allows for the measurement of solar radiation in specific regions. Selecting the most suitable sensor based on factors such as quality, price, and compatibility with local conditions can present a challenge. The photovoltaic (PV) industry commonly employs thermopile pyrano-meters and calibrated PV Reference Devices (PVRDs) as the main tools for measuring irradiance [9]. Pyrano-meters are widely respected in the scientific community for monitoring PV systems, but the high cost of acquiring a pyrano-meter is a major barrier to its widespread adoption, especially for individuals and organizations with limited financial resources. Pyrano-meter prices usually range from 1000 to 5000 dollars,, or even higher, depending on the precision and advanced features included in the device.

Research conducted by A. Azouzoute et al, [10] compared a thermopile reference pyrano-meter and a mono-crystalline reference cell to evaluate the accuracy of the latter cell in various climatic conditions. The findings indicate that, overall, the measurements of the two sensors are in good agreement, with a correlation coefficient of 99.97%. However, during periods of elevated temperatures, the relative deviation increases to -4.8%. This deviation significantly decreases to -0.7% during the cold season. Furthermore, their results suggest that reference cells offer a cautious estimate of irradiation levels, emphasizing the importance of correcting values when using this device for resource assessment.

This work aims to solve this problem of deviation at high temperatures by designing a low-cost device with high standards by connecting the reference PV cell to an Arduino microcontroller, through which we can modify the data and correct the deviation ratio to achieve accurate results of solar radiation. Additionally, the cell tension values are amplified, and the value of radiation is displayed on an LCD screen. We use the Proteus environment for implementing this device, ensuring reliable and effective performance. The presented work is structured into five sections. Section 2 provides a detailed description of the PV model. Section 3 explains the simulation of the PV model using Proteus software. Section 4 presents the results and discussion of the findings. Finally, Section 5 summarizes the conclusions drawn from the study.

II. PV MODEL DESCRIPTION

A photovoltaic (PV) panel is a device capable of converting solar energy into direct current (DC) electricity through the utilization of semiconducting materials that exhibit the photovoltaic effect [11]. The equivalent circuit of a PV panel is shown in the figure below. It consists of a current source, a diode, a series resistance, and a shunt resistance. [12]

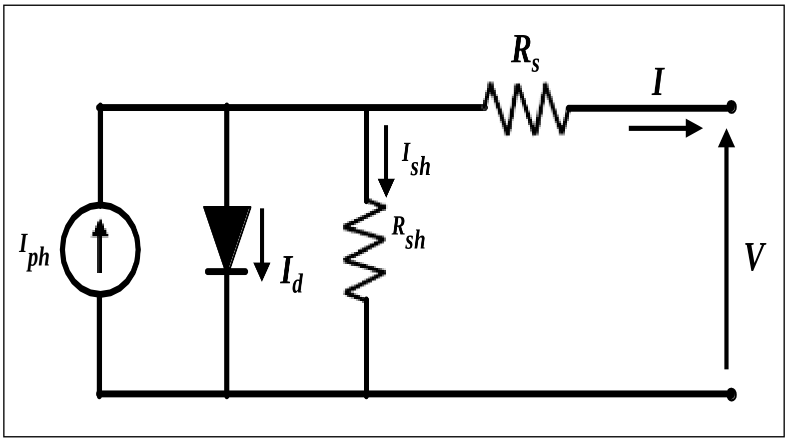

Figure 1: PV cell equivalent circuit.
Source: [11]

The PV output current is defined as:

$$I_{pv} = I_{ph} - I_d - I_{sh} \tag{1}$$

$$I_{sh} R_{sh} = I_{pv} R_s + V_{pv} \tag{2}$$

So :

$$I_{sh} = \frac{V_{pv} + I_{pv} R_s}{R_{sh}} \tag{3}$$

$$I_{pv} = I_{ph} - I_s \left(e^{\frac{V_{pv} + I_{pv} R_s}{n V_t}} - 1\right) - \frac{V_{pv} + I_{pv} R_s}{R_{sh}} \tag{4}$$

III. PROTEUS PV MODEL SIMULATION

In order to create a comprehensive model of a PV panel in Proteus software, it is essential to incorporate the one-diode model equivalent circuit. This circuit should include a striped current source to accurately depict the photocurrent source, a one-diode component with modified spice code, as well as series and parallel resistances.

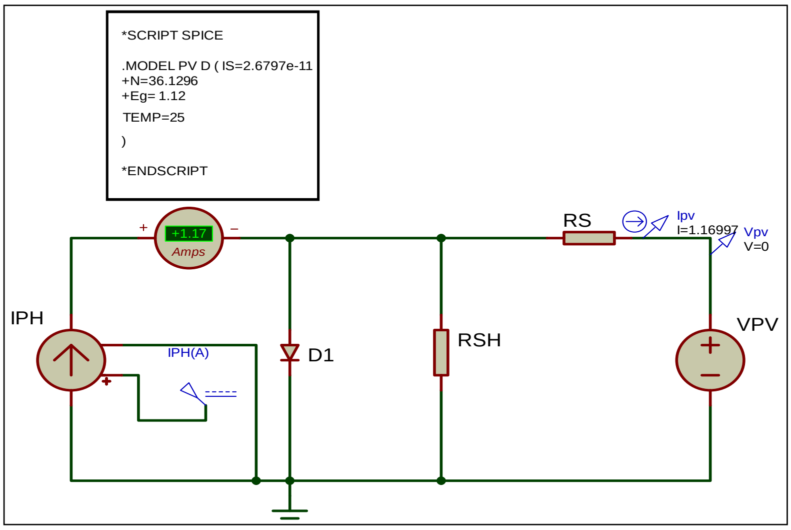

Figure 2: The circuit model of the one-diode panel in Proteus.
Source: Authors, (2025).

Figure 3 and 4shows the I–V and P-V characteristics obtained by our model atdeffrent values of irradiation and same temperature.

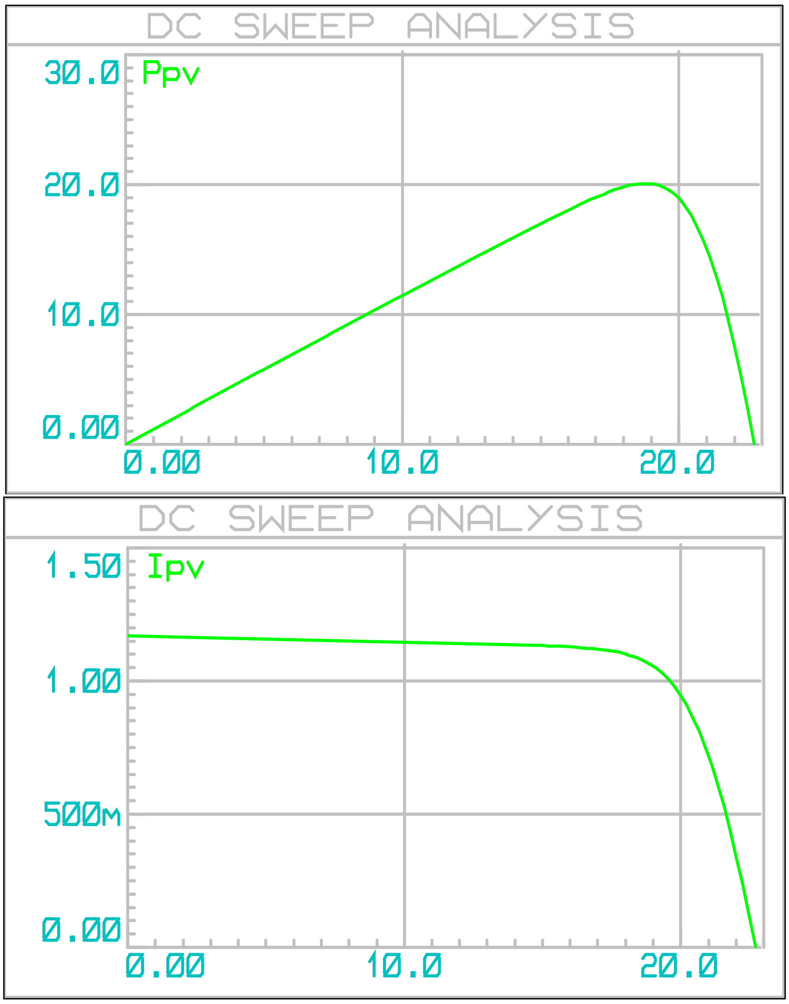

Figure 3: Voltage-Current characteristics of the PV panel model at 1000W/m^2 and 25°C.
Source: Authors, (2025).

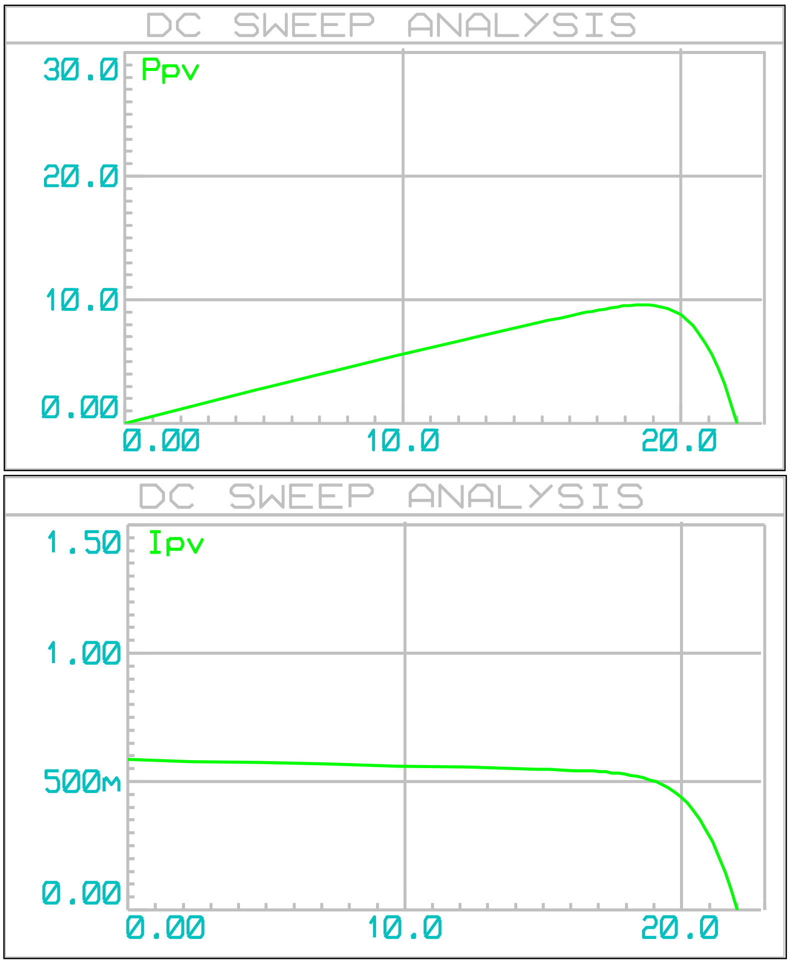

Figure 4: Voltage-Current characteristics of the PV panel model at 500W/m^2 and 25°C.
Source: Authors, (2025).

III.1 LM741 INVERTER

The LM741, also known as the Op-Amp IC 741, is a widely utilized integrated circuit for operational amplifiers. It is commonly employed for mathematical computations and signal amplification. In our experiment, we utilized this particular chip to double the minimum output voltage values produced by the inverter assembly, resulting in positive voltage levels.

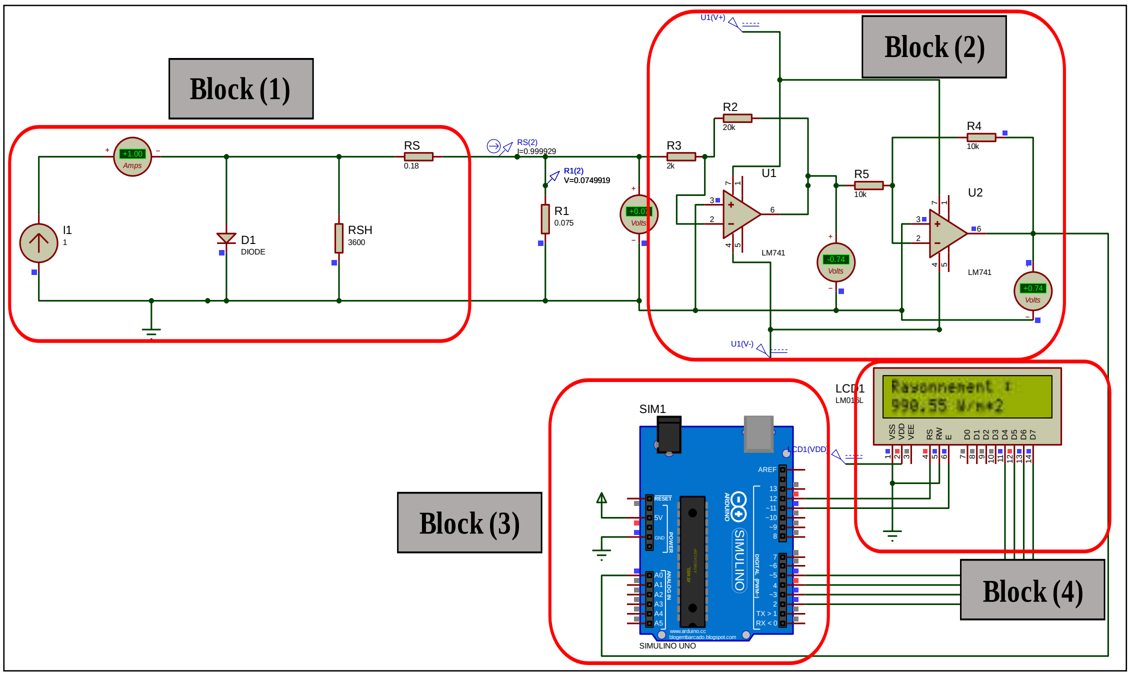

Figure 5: Circuit of the LM741 inverter.
Source: Authors, (2025).

Table 1: The values used of the resistance of the LM741 inverter in our work.

Resistance	Value
R_1	2Ω
R_2	20 Ω
R_3	10 Ω
R_4	10 Ω

Source: Authors, (2025).

III.2 DESIGNING A PV SYSTEM USING PROTEUS SOFTWARE

Figure 6 presents the PV system design created in Proteus.

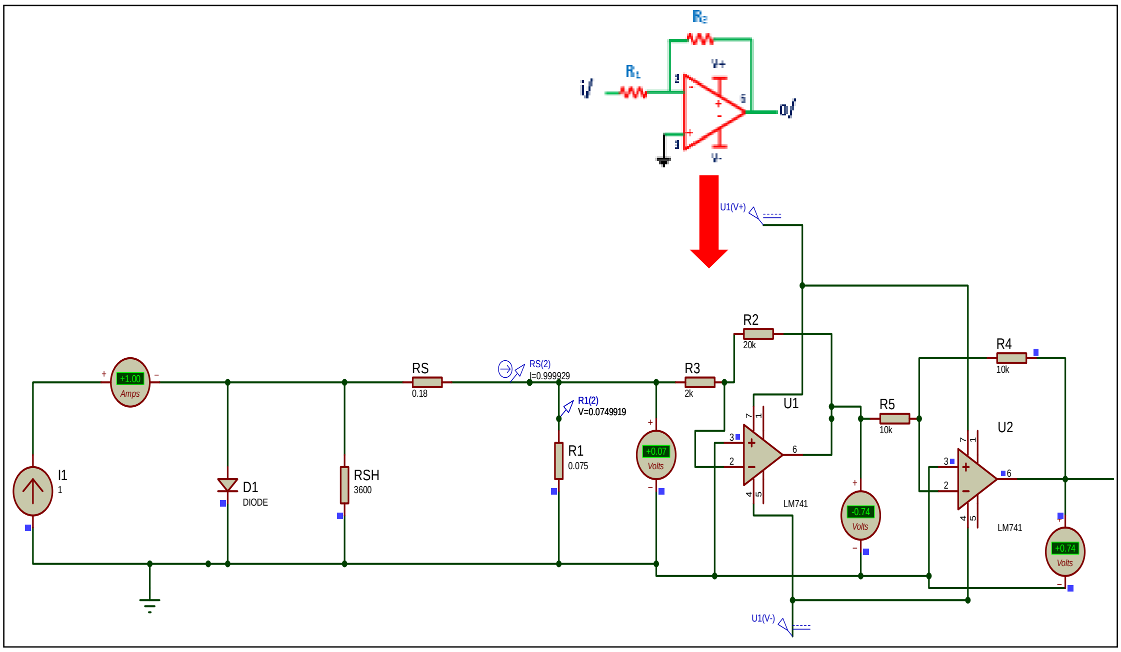

Figure 6: Schematic of device design in Proteus software.
Source: Authors, (2025).

As shown, this PV system can be divided into four blocks:

- Block (1) represents the sub-circuit of the PV panel model,
- Block (2) represents the implementation circuit of the LM741.
- Block (3) represents the embedded board (Arduino Uno). In this simulation, a specific code has been utilized. When this system is applied to the Arduino, it will calculate the short circuit current values based on the program used. This program determines the short circuit current by utilizing Ohm's law in relation to the PV voltage. The value of the luminous flux or radiation E is obtained from the equation of the current generated by the PV model when the short circuit condition is met.

$$I_{pv} = I_{ph} - I_s\left(e^{\frac{V_{pv}+I_{pv}R_s}{nV_t}} - 1\right) - \frac{V_{pv} + I_{pv}R_s}{R_{sh}} \quad (5)$$

$$I_{ph} = I_{ph0}\left(\frac{E}{E_0}\right)(1 + \Delta T) \quad (6)$$

$$I_{ph} \cong I_s \quad (7)$$

$$I_{sc} = I_{sc0}\left(\frac{E}{E_0}\right)(1 + \Delta T) \quad (8)$$

By eliminating the temperature effect: « In Low temperatures »

$$I_{sc} = I_{sc0}\left(\frac{E}{E_0}\right) \quad (9)$$

So the equation of the solar radiation E is defined:

$$E = E_0\left(\frac{I_{sc}}{I_{sc0}}\right) \quad (10)$$

- Block (4) presents the LCD screen, which is used to display the value of PV radiation.

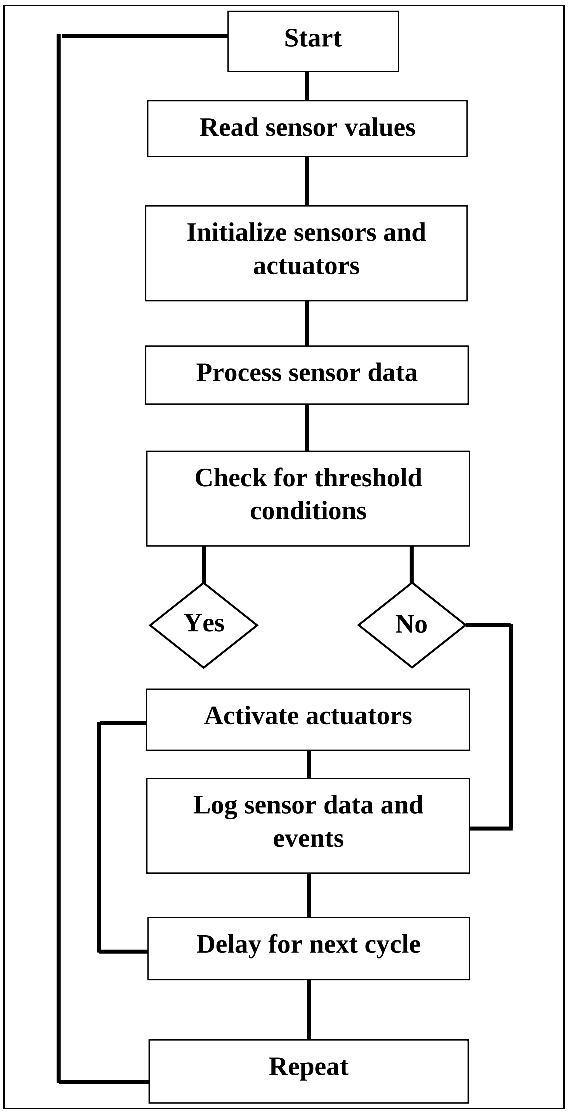

Figure **7:** The flowchart of the Arduino code.
Source: Authors, (2025).

IV. RESULT AND DISCUSSION

The simulation of our device, which is an instrument to measure solar radiation using a reference cell connected to an Arduino UNO, is presented using Proteus simulation software. In this work, we use a specific program in two cases, "low and high temperature". In the first case, the Arduino microcontroller calculates the short circuit current values based on the programmed instructions, which involve using Ohm's law with the PV voltage to determine the short circuit current. The luminous flux or radiation E value is determined from the equation representing the current produced by the PV model.

In the second case, we added a modification to the program to extract the real value of radiation while accounting for the percentage of error caused by the photovoltaic cells being affected by high temperatures. With these results, it can be argued that the device is much more cost-effective than a pyrano-meter while still providing dependable results.

V. CONCLUSION

In this paper, we propose a device developed using Proteus that can measure global solar radiation with the ability to correct the potential error ratios due to high temperatures affecting cell characteristics. The current setup consists of a reference cell, an operational amplifier, an LCD screen, and an Arduino UNO board. The device was successfully tested after its implementation in the Proteus environment. The basic concept behind this device is based on the external characteristics of the photovoltaic cell, where solar radiation is directly related to the short circuit current.

By leveraging the linear relationship between radiation and the short circuit current of the photovoltaic cell, we have successfully developed and operated a practical instrument to measure solar radiation that can mitigate the deviation caused by high temperatures. The resulting device is more cost-effective than a pyrano-meter and provides highly reliable results. From the standpoint of this study, the device can be integrated into actual systems, and its external design can be developed for application in scientific research by students and in photovoltaic installations. Additionally, it can be modified for domestic, commercial, and industrial use.

Table 3: Nomenclatures & Abbreviations.

PV	Photovoltaic
I_{pv}	Output current of PV panel (A)
I_{ph}	Photo-current (A)
I_D	PV panel diode current (A)
I_{sh}	Shunt resistance current (A)
I_s	Saturation current (A)
I_{sc}	Short circuit current (A)
V_{pv}	Output voltage of PV panel (V)
R_s	Series resistance (Ω)
R_{sh}	Shunt resistance (Ω)
E	Radiation (Ω)
	Radiation in Standard test condition (STC) ($W.m^{-2}$)
	Short Circuit Reference (A)
	Temperatureeffect (°C)
	Direct current
	Diode
	Diode constant
	Thermal voltage of PV diode
	Liquid Global Display
	Global Solar radiation
	PV Reference Devices

Source: Authors, (2025).

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