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Preliminary Design of a "Soparometer": Instrument to Measure the Rated Peak Power of a Solar Panel

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Abstract

The main determinant of the cost price of a solar panel in the market is the rated peak power as measured under standard laboratory conditions (cell temperature of 25˚C, solar irradiance of 1000 W/m^2 and an air mass of 1.5). An indirect method (considered indirect since the measurement is done under nonstandard laboratory conditions) is adopted here in order to approximate with some degree of certainty the rated peak power of a solar panel. It involves the use of a characterized solar module of known peak power for comparison to the solar panel under measurement when both are subjected to the same ambient conditions. Two electronic loads are used to drive both the test module and solar panel at their respective maximum power points in order to determine by how much in magnitude the power of the solar panel surpasses that of the module. The peak power of the solar panel is obtained using the assumption that the magnitude by which its peak power surpasses that of the module remains constant provided they are subjected to the same ambient conditions. Using this method, multiple measurements were conducted on two solar panels rated at 100 W and 50 W by the manufacturer and the results obtained were 85.73 W and 43.26 W respectively depicting a 14 percent and 13 percent discrepancy. It therefore remains a promising method of measurement if enhanced and fine-tuned.

Subject Areas

Solar Energy

Keywords

Rated Power, Solar Panel, Measurement, Sensors, Circuits, Voltage, Microcontroller

1. Introduction

Power generation from solar photovoltaic technology is estimated to have increased by a record of 156 TWh marking a 23% growth from 2019 and accounting for 3.1% of global electricity generation. It is the third largest renewable electricity technology behind hydropower and onshore wind after overtaking bioenergy in 2019 [1]. Globally, the solar resource is more widely accessible than other sources of energy and due to the continuous decline in the cost of production of solar panels, there is no doubt that it will grow to occupy a significant portion of the total global electrical energy production [2]. Manufacturers rate their photovoltaic panels based on the DC output power at an irradiance of 1000 W/m^2 (full sun) and a panel temperature of 25˚C in order to get you to buy their product. However, there is a scarcity of studies that attempted to measure the output power of a solar panel outside the laboratory. What prompted this research was the observation made while buying solar panels as we went with the labels on the panels which we found that most suppliers used to change in order to over rate panels.

This study focuses on developing a method to measure the rated peak power of a solar panel during procurement often done out of the laboratory. The method developed here is based on the logic of relative performance where it is considered that two solar panels of different power ratings maintain the same relative output power ratio when subjected to the same ambient conditions. For example, if under standard testing conditions (solar irradiance of 1000 W/m^2, temperature of 25˚C and 1.5 air mass density) two panels A and B deliver peak power values of 5 watts and 50 watts respectively, a relative ratio of 50/5 is obtained. It is therefore considered that panel B will always produce ten times more power than panel A provided they are both subjected to the same conditions whether standard or not.

2. Method and Requirements

There are basically two ways to measure any physical quantity namely; the direct and indirect methods of measurement. Given that the rated peak power of a solar panel is often measured under standard conditions (solar irradiance of 1000 W/m^2, ambient temperature of 25˚C, and an air mass coefficient of 1.5) in the laboratory [3] [4], the method adopted here is an indirect one given that the measurement is conducted under non-standard conditions and out of the laboratory. Contrary to the direct comparative method of measuring the potential difference of a battery with a potentiometer (using a reference cell with a fixed known voltage), this method is however considered indirect because it involves the use of a pilot photovoltaic cell with varying output power under varying environmental conditions under which the measurements are taken. This output power variation is considered to be the same as that of the solar panel under measurement. For example, considering that all other environmental variables remain fixed, if the solar irradiance drops from 1000 W/m^2 to 500 W/m^2, it is considered that the output power of both pilot cell and solar panel drop by 50% or the same proportion. The rated peak power of the solar panel is derived by expressing the measured output power of the solar panel to the output power of the pilot cell as a fraction and considered constant under any set of environmental conditions.

The pilot solar photovoltaic cell is used as a reference to which a tested solar panel is compared so as to obtain the rated peak power of the panel. The pilot cell is an integral part of the instrument and is calibrated in the laboratory in order to obtain its standard peak power rating. When taking measurements, it is attached to the side frame of the tested solar panel so that the two adopt the same angle of inclination to the sun or open sky. Both pilot cell and solar panel are independently driven at their respective peak power points on the current voltage (I-V) curves to obtain the peak power output for each. The fractional open circuit voltage method is used to determine the peak power point on the I-V curve [5] [6].

2.1. The Fractional Open Circuit Voltage Method of Tracking the Maximum Power Point

The main objective is to extract maximum power from the solar panel by operating it at the knee of the I-V curve as indicated in **Figure 1**.

The figure above depicts the behavior of a solar cell when subjected to operating under different sets of voltages with the corresponding output power curve in blue [7] [8]. The fractional open circuit voltage method of peak power point tracking exploits the near linear relationship between the maximum power point voltage (VMPP) and the open circuit voltage (VOC) of a solar panel under varying levels of irradiance and temperatures in order to estimate the VMPP by applying a factor k1 as in the following Equation (1);

$$\text{VMPP} \approx \text{k1VOC}. \tag{1}$$

where k1 is the constant of proportionality (reported to be between 0.71 and 0.78) [9].

Under any set of environmental conditions, the peak power is derived by measuring the open circuit voltage VOC then using Equation (1), the peak power current (*IMPP*) flowing when the panel is operated at the peak power voltage

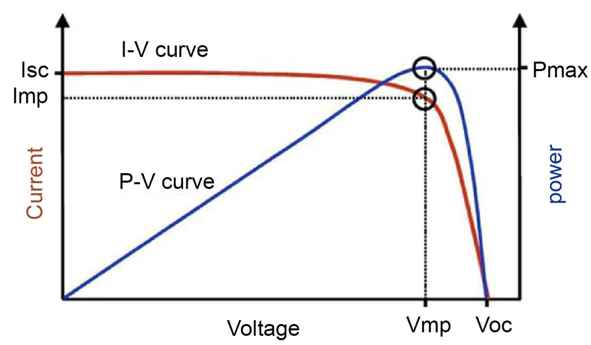


Figure 1. Characteristic I-V curve of a solar panel.

VMPP is measured. The peak power is therefore the resulting product of the peak power voltage (VMPP) and the peak power current (IMPP). During the measurement of the standard peak power of a solar panel under any set of environmental conditions, its peak output power is simultaneously obtained alongside that of the pilot cell by using the fractional open circuit voltage as described above. The ratio of the panel's peak output power to that of the pilot cell is computed and further multiplied by the rated peak power output of the pilot cell as obtained in the laboratory during its calibration. The resulting value expressed in Equation (2), is the rated peak power of the solar panel tested.

$$\text{SRP} = \frac{\text{SPPP}}{\text{PCPP}}(\text{PCRP}) \tag{2}$$

where: SRP = solar panel rated power,

SPPP = solar panel peak power,

PCPP = pilot cell peak power,

PCRP = pilot cell rated power.

2.2. Requirements

The electronic load (**Figure 2**): The electronic load is a test instrument designed to sink current and absorb power out of a power source, they can be set to a desired resistance value and are used since simple resistors keep changing when they sink power and heat up [10]. Internally, they are made up of a combination of semiconductor elements and they are generally used to test and characterize power supplies such as batteries, solar panels and power converters. Electronic loads are designed so that they can draw a constant current or maintain a constant voltage for a set period [11]. This is realized via the use of a MOSFET driven by and OPAMP with a set reference to the positive input of the OPAMP used to limit the current or voltage required to pass through the load [12]. Two electronic loads are required to drive the solar panel and pilot cell at the intended points on the I-V curves. They are built using the LM317 operational amplifiers, power resistors, and are both driven by the microcontroller.

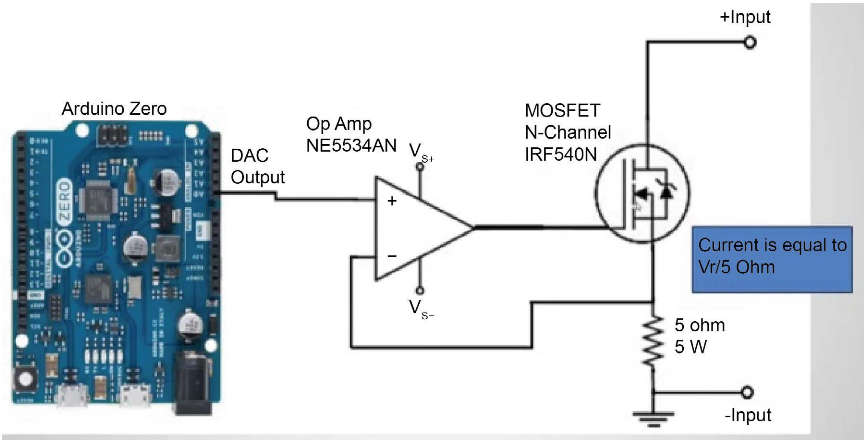


Figure 2. An electronic load driven by a microcontroller.

The Arduino UNO microcontroller (Figure 3): The main component that runs the control unit is the Arduino UNO board embedded with the ATmega328 microcontroller used to handle the controls and logic. This microcontroller is chosen based on its availability, the USB interface which allows for programming via the USB port and its compatibility with the LM370 operational amplifier, the IRF540n MOSFET, current and voltage sensors. It has 14 digital pins with 6 pins capable of pulse width modulation outputs, a 16MHz clock, a USB connector, a 9V power jack and a reset button. It is an open-source microcontroller board developed by Arduino.cc and it is coupled with a push button to enable the user to interact with the device.

The functions attributed to the microcontroller are; to obtain both open circuit voltages and compute the respective peak power voltages then tune the gates of the MOSFETS in both electronic loads in order to achieve the required voltage drop across the drain of both loads. It also receives and interprets readings from the current and voltage sensors as well as displays results on the screen.

The pilot cell (Figure 4): is a small solar cell used as a reference during the measurement since its rated peak power (*CRPP*) predetermined in the laboratory is already known. It is a detachable part of the SOPAROMETER and is meant to be attached to the side frame of the tested solar panel during the measurement.

Three sets of measurements are made when characterizing the pilot cell namely; random measurements in the house, standard measurements in the laboratory and measurements taken under frozen conditions. A 100W incandescent lamp was used with a dimmer as the source of light for the pilot cell. The calibration circuit is illustrated in Figure 5.

Figure 3. The arduino Microcontroller.

Figure 4. Pilot cell under frozen conditions.

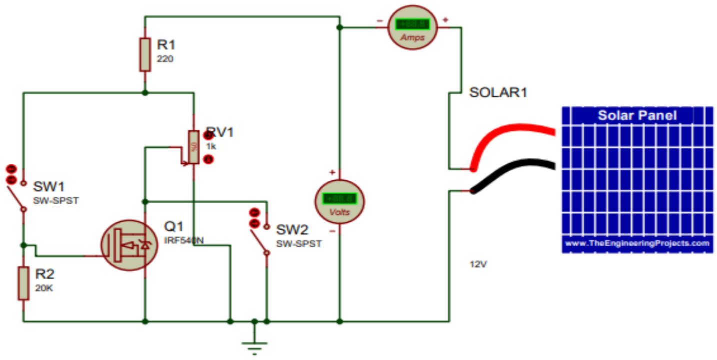


Figure 5. Calibration circuit used for the pilot cell.

3. Design of the Soparometer

The instrument is designed following the architecture depicted in Figure 6 below:

The components that make up the Soparometer are two current sensors, two voltage sensors, two IRF540n MOSFETs, an LM370 operational amplifier, a 16 × 2 LCD, the pilot cell and 2 MC4 connectors. The Soparometer design considered that: the device measures the open circuit voltages and currents of both pilot cell and solar panel at the same instant. Consequently, the current and voltage sensors are connected to analog inputs of the Arduino UNO microcontroller while the LM30 OPAMP meant to drive the MOSFET is hooked up to the ARDUINO output terminals with pulse width modulation (PWM) capability.

The measurement is coordinated by the programmed Arduino UNO microcontroller interconnected with other components as depicted in Figure 7 by using an algorithm designed to operate as shown in the following flow chart.

Once the pilot cell is attached to the frame of the solar panel and both are placed under plane unobstructed lighting, the measurement is triggered by the start button. The open circuit voltages of the pilot cell and solar panel are read simultaneously. Then the microcontroller calculates the maximum power point voltages of both and drives the electronic loads to run at these voltages. The current measurements are then obtained from the current sensors and the respective output powers are obtained. The rated peak power of the solar panel can be obtained as depicted in equation (2) and displayed on the 16 × 2 LCD.

4. Results and Discussions

The electronic circuit outline highlighted in Figure 8, is made using proteus software which is then subsequently used to generate the blueprint for the printed circuit board. The following sections contain photos of the printed circuit board, its blueprint and the instrument.

Electronic components were soldered onto the PCB, followed by further tests to ensure functionality as shown in Figure 9.

MC4 connectors are soldered to the solar panel input of the instrument so as to easily interface with existing solar panels in the market.

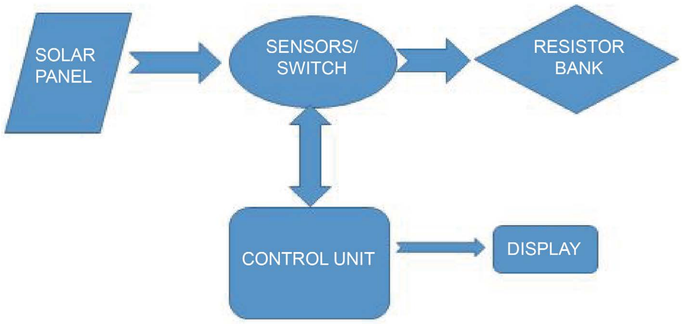


Figure 6. Design architecture of soparometer.

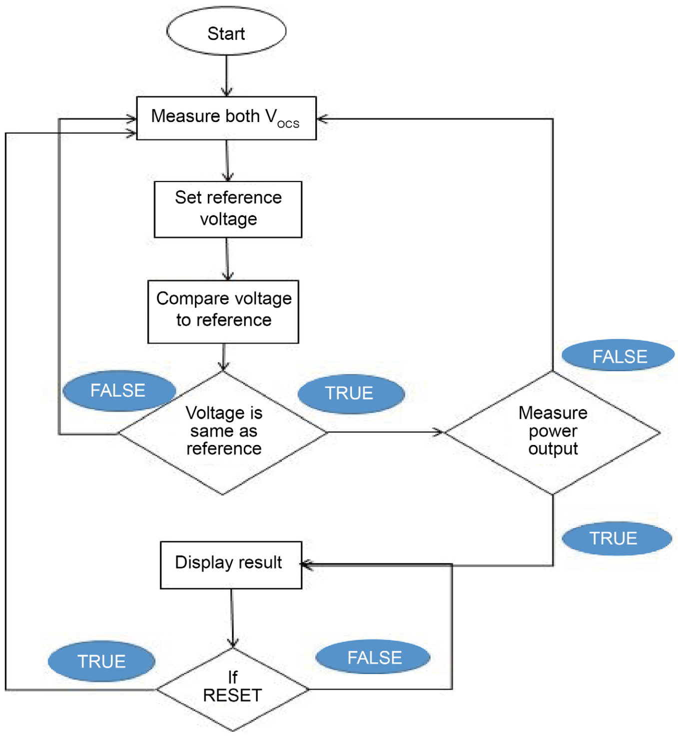


Figure 7. Flow chart of algorithm to measure the rated peak power of a solar panel.

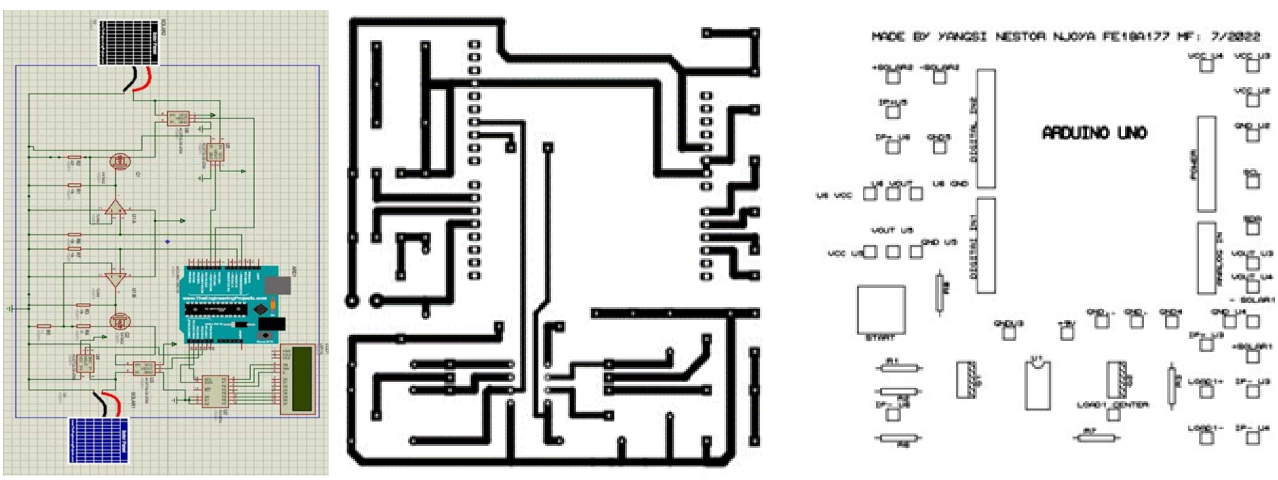


Figure 8. Circuit design and outline.

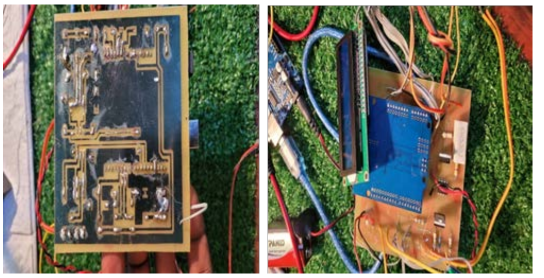
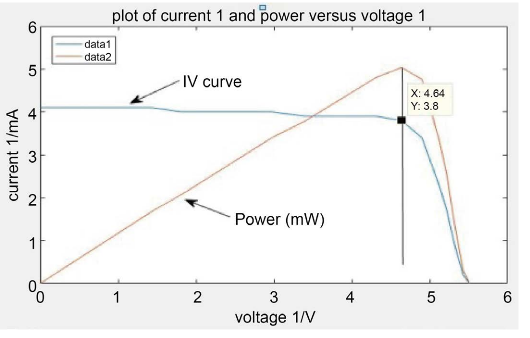
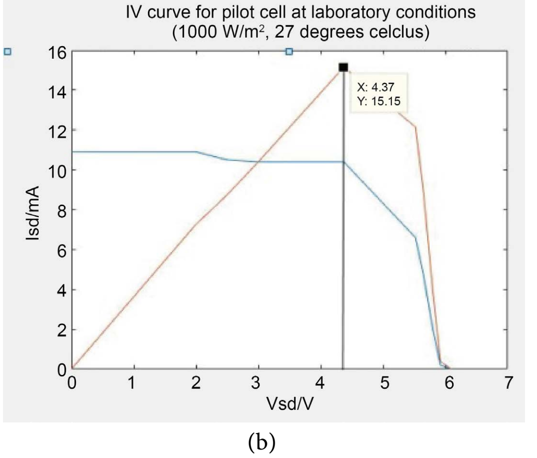


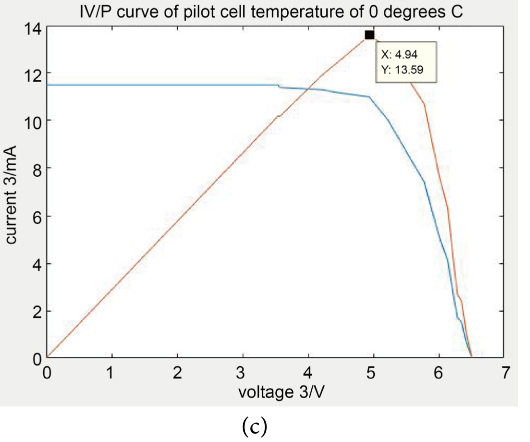
Figure 9. The printed circuit board and mounted components.



(a)



(b)



(c)

Figure 10. (a) Pilot cell I-V curve under random room conditions; (b) Pilot cell plot under standard laboratory conditions; (c) Plot of pilot cell I-V curve under frozen conditions.

Figure 10 depicts a plot of the measurements under various conditions using MATLAB software.

Repeated measurements were done on the circuit design implemented and two solar panels of rated peak power values 100 W and 50 W were tested. The results obtained were 85.73 W rated peak power and 43.26 W rated peak power for both solar panels respectively. Given that the ACS712(20A) current sensors were used during the measurement, they appeared insensitive to the small currents from the pilot cell thereby generating an infinite (or error) result each time the solar panel output power would divide that of the cell. The results obtained were obtained by manually using an ammeter connected in series with the pilot cell and solar panel. It might take extensive testing and experimentation in an advanced laboratory before a definitive and unambiguous conclusion can be obtained on the performance of the designed system. However, the method remains a promising one given that the results obtained from repeated measurements are concise.

5. Conclusion

From the characterization of the pilot cell to the implementation of the main circuit design, the method used has relied entirely on the fractional open circuit voltage method of determining the maximum power point voltage. It is a method that has yielded quite interesting results and has also been adopted in big arrays to track and exploit the peak power from solar panels. Future innovations that will render expensive tracking methods cheap can be investigated for it is the major missing link that is left to make this method accurate and affordable to all. Given that the major motivation behind this project is the correlation between the surface area of a solar panel and its rated peak power, it will be an alternative solution and an interesting domain for software engineers to develop software capable of deducing the parameters of a solar panel via photo recognition and by sizing solar panels according to their grade and technology used.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Onah, C.O., Kpochi, P.K. and Goodman, A.O. (2020) Design and Implementation of an Automatic Changeover Switch with Generator Trip-Off Mechanism. *International Journal of Engineering Science Invention* (*IJESI*), **9**, 41-48.

[2] Sojoudi, M., Madatov, R. and Sojoudi, T. (2011) Optimization of Efficiency of Solar Cells by Accelerated Electron Ray to Have an Optimal and Constant Energy. *International Journal on Technical and Physical Problems of Engineering* (*IJTPE*), **3**, 68-71.

[3] Dieudonne, K., Kodji, D. and Bachirou, B. (2004) Status of Renewable Energy in Cameroon. *Renewable Energy and Environmental Sustainability*, **6**, Article No. 2. https://doi.org/10.1051/rees/2021001

[4] Wohlgemuth, J. and Kurtz, S. (2014) Photovoltaic Module Qualification Plus Testing. 2014 *IEEE* 40*th Photovoltaic Specialist Conference* (*PVSC*), Denver, 8-13 June 2014, 3589-3594. https://doi.org/10.1109/PVSC.2014.6924883

[5] Asbeck, F. (2019) Solar 101 Energy for You & Me. Sol World. 2019. https://www.academia.edu/41574682/SOLAR_101_ENERGY_FOR_YOU_and_ME

[6] Jose, A., Campayo, J.J., Ekaitz, Z., Oscar, B., Pablo, E. and Zamora, I. (2013) Obtaining the Characteristics Curves of a Photocell by Different Methods. *International Conference on Renewable Energies and Power Quality* (*ICREPQ*'13), Bilbao, 20-22 March 2013, 814-819. https://doi.org/10.24084/repqj11.455

[7] Ali, M., Shayan, E. and Javad, O. (2020) Maximum Power Point Tracking Methods Used in Photovoltaic Systems. *Signal Processing and Renewable Energy*, **4**, 19-39.

[8] Bendib, B., Belmili, H. and Krim, F. (2015) A Survey of the Most Used MPPT Methods: Conventional and Advanced Algorithms Applied for Photovoltaic Systems. *Renewable and Sustainable Energy Reviews*, **45**, 637-648. https://doi.org/10.1016/j.rser.2015.02.009

[9] Ross, R.G. (2013) FSA Engineering & Reliability Development Methods—Can They Be Applied Today? *InterSolar* 2012, San Francisco, CA. https://www2.jpl.nasa.gov/adv_tech/photovol/ppr_86-90/Ross%20SEMI-VG_07-08-12.pdf

[10] Jordan, D.C. and Kurtz, S.R. (2013) Photovoltaic Degradation Rates—An Analytical Review. *Progress in Photovoltaics*: *Research and Applications*, **23**, 12-29. https://doi.org/10.1002/pip.1182

[11] Hacke, P., *et al.* (2014) Application of the Terrestrial Photovoltaic Module Accelerated Test-to-Failure Protocol. 2014 *IEEE* 40*th Photovoltaic Specialist Conference* (*PVSC*), Denver, 8-13 June 2014, 930-936. https://doi.org/10.1109/PVSC.2014.6925066

[12] TamizhMani, G. and Sharma, S. (2008) Hot Spot Evaluation of Photovoltaic Modules. *Reliability of Photovoltaic Cells*, *Modules*, *Components*, *and Systems*. https://doi.org/10.1117/12.794237