Analysis of instrumentation system for photovoltaic pyranometer used to measure solar irradiation level

Prisma Megantoro[1], Muhammad Akbar Syahbani[1], Sigit Dani Perkasa[1], Ahmad Rahmad Muzadi[1], Yusrizal Afif[1], Agus Mukhlisin[1], Pandi Vigneshwaran[2]
[1]Department of Electrical Engineering, Faculty of Advanced Technology and Multidiscipline, Universitas Airlangga, Surabaya, Indonesia
[2]Department of CSE, SRM Institute of Science and Technology, Tamil Nadu, India

Article Info

Article history:

Received Jul 10, 2022
Revised Aug 11, 2022
Accepted Aug 22, 2022

Keywords:

Photovoltaic system
Pyranometer
Renewable energy
Solar irradiance
Solar power

ABSTRACT

A pyranometer is a device used to measure the level of solar irradiation. This device has a sensor that measures the density of the electromagnetic flux of solar radiation on a flat plane. The electromagnetic flux density parameter is converted into an electrical parameter in watts per square meter. Pyranometers are used in weather station devices to analyze and predict weather conditions. Solar power generation systems are usually also installed with this device. It is intended to monitor solar irradiation's condition to examine the generating system's performance. This article discusses the photovoltaic-based pyranometer characterization method. The characterization method is carried out to determine the measurement parameters such as accuracy, precision, and hysteresis. Knowing these parameters will make it possible to see the performance of measuring solar irradiation levels by a measuring instrument for solar irradiation levels, like a pyranometer. The characterization method is to compare the measurement results with standard instruments. The solar irradiance level monitoring is also optimal, accurate, and precise with a reliable measurement method.

Corresponding Author:

Prisma Megantoro
Department of Electrical Engineering, Faculty of Advanced Technology and Multidiscipline
Universitas Airlangga
60115 Surabaya, Indonesia
Email: prisma.megantoro@ftmm.unair.ac.id

1. INTRODUCTION

In solar cell installations, solar irradiation is one of the essential things to predict photovoltaic energy output [1], [2]. Pyranometer works to measure light radiation on a plane surface [3]–[6]. Electromagnetic waves that penetrate the pyranometer will produce a flux whose magnitude depends on the wave's angle of incidence. Pyranometer is the most trusted scientific instrumentation tool in PV system monitoring [7]–[10].

The implementation of the pyranometer needs to be adjusted in advance to the type and characteristics of the geographical conditions of an area. The characteristics of the pyranometer include linearity, precision, accuracy, response time, and hysteresis [11]–[13]. It is important to characterize the pyranometer to find out how compatible it is with the location conditions that are the object of the monitoring system.

The error value of the irradiation measurement from the pyranometer can be known, one of which is the level of linearity. The graph reading between the irradiation value and the output value of PV will make a linear line. Based on this, the error value will be known based on the point farthest from the linear line (deviation value) [14]. Deviation from the irradiation reading is also caused by the hysterisis effect [14]–[18].

Several studies have been carried out in the characterization of pyranometers, especially for applications in solar generating systems. One of them is Nugraha *et al*. [19] who develop a pyranometer to measure diffusion radiation, global radiation, direct radiation, and radiation duration. Then Ali *et al*. [20] also develop a simple solar lux measurement using light dependent resistor (LDR). This research uses Arduino to process and display the measurement result. In the other hand, a research that develop mathematical model to predict the solar irradiation data is done by Meenal *et al*. [21]. The model can be used to reduce costly pyranometer usage.

In PV system monitoring, sensor response time is also crucial in predicting PV output. Although, every pyranometer device has its own characteristic and needs interface circuit. So, its electricity signal can be occured by the instrument or controller. The issue coming with type and specification of the interface circuit, like filter, operational amplifier or signal converter needed. Characteristics of the instrumentation system of pyranometer make the sensor can perform good measurement. Thus, analyzing the characteristics of the pyranometer makes it easier for observers to determine the error value in the measurement so that the measurement results are precise and accurate. Therefore, this research is conducted to analyze the different instrumentation systems for measuring irradiation levels using photovoltaic pyranometers.

2. METHOD

Research on the characterization of the pyranometer to measure the level of solar irradiation was carried out in several stages. These stages are shown in Figure 1. The first research stage is problem identification, where the problem in this study is an instrumentation system suitable for pyranometers. This instrumentation system is used so that the pyranometer output electrical signal can be measured and processed by the pyranometer. Such identification includes determining the appropriate sensor interface circuit. After that is a literature study to find out the research that discusses the pyranometer. This is to determine the novelty of this research.

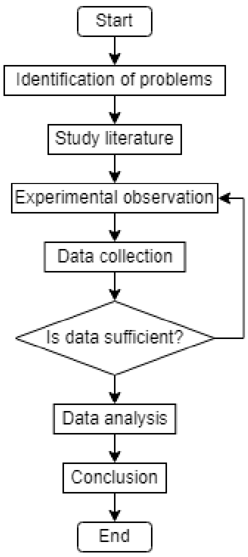


Figure 1. Research flow diagram

After that, the experimental observation stage was carried out, starting from the experimental set to the data collection method. The experimental set will be shown in the next subchapter. The method of data collection is to compare the sensor readings with a solar power meter (SPM), which is carried out by increasing and decreasing also is carried out 5 times. All data collected is then processed and analyzed in order to show the character values of the pyranometer sensor, such as; regression values, accuracy, precision, linearity error, and hysteresis error. In addition to being shown in the dataset, these parameters are also displayed in a graph. From the results of the analysis, conclusions will be obtained that show the character of the pyranometer sensor which has this type of photovoltaic.

2.1. Photovoltaic pyranometer

Photovoltaic pyranometer has working concept like a photovoltaic cell. The active part of this device consists of a photovoltaic cell near the core of the circuit [22], [23]. The electrons that are carriers of electric charge are generated from photovoltaic cells exposed to solar radiation [24]–[26]. The practical solar radiation to do this ranges from 350 nm to 1150 nm.

This type of pyranometer is commonly used as a simulator for photovoltaic power generation systems. Then this device is used to calculate or predict the effectiveness of solar panels and system performance. This is because the spectrum of light that this type of pyranometer can be the same as the solar panels used in the system. In addition, it can also be used as a diagnostic point of performance or system failure.

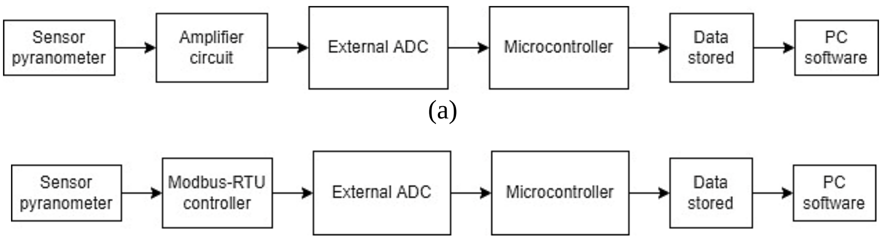
This study uses two receivepyranometer sensor devices of the same type. Pyranometer one has a variety SP-Lite 2 from Kipp and Zonen manufacturers. The device has a sensitivity of 10 V/W/m² with an irradiation level measurement range of up to 2000 W/m². In comparison, the second pyranometer is the SEM228 type from Sentec manufacture. There are two types of communication signal output from this pyranometer, namely those that use RS485 and those that use Modbus (4-20 mA). This pyranometer has a measurement range of up to 1500 W/m^2, which is narrower than the SP-Lite 2.

2.2. Measurement system

This study uses a microcontroller system to test the pyranometer device's measurement and characterisation. The microcontroller is used to acquire and process analog signal data from the sensor and the interface circuit. The measurement data is then recorded directly for simulation in the software. Figure 2 is a block diagram of the control system for testing two pyranometer sensors. Both control systems use an external analog to digital converter (ADC) 16-bit. Its goal is to increase the resolution so that the measurement will increase accuracy.

Figure 2(a) shows that the SP-Lite 2 pyranometer requires an amplifier circuit. This is because the output voltage of the sensor is UV scale. This pyranometer is an active sensor type, producing its output signal without power supply from other circuits. The AD620 amplifier circuit is used to amplify the voltage to an mV scale. This is done so that the sensor signal can be read by the ADC pin. The microcontroller board used is Arduino Uno, which has an ADC resolution of 10 bits. The data from the control system is then recorded and stored. Then the data set is processed and analyzed using software on a computer to determine the character of the sensor under study.

While Figure 2(b) shows a block diagram of the test control system for the Sentec SEM228 pyranometer. The output signal from this pyranometer is a Modbus signal of 4-20 mA, so it must be converted to an analog voltage of 0-5 V so that it can be read by the ADC pin of the microcontroller. After that, the data set is processed like the first pyranometer.



(b)

Figure 2. System control for measurement and characterization of pyranometers (a) system for Kipp and Zonen SP-Lite 2 and (b) system for Sentec SEM228

2.3. Data acquisition

The pyranometer measurement data acquisition process is carried out in the lab. This experiment uses artificial lighting from a 1000 W halogen lamp. The reason for using a halogen lamp is that it has light with a wavelength range that almost resembles direct sunlight from the sun. There is an ultraviolet glow from the light produced by a 1000 W halogen lamp.

Figure 3 shows an experimental set using a halogen lamp facing perpendicular to the pyranometer's lens. The distance between the halogen lamp and the pyranometer's lens was varied to obtain different irradiation level readings. The experiment was carried out alternately between pyranometer one and two, using a Lutron solar power meter (SPM) type SPM-1116SD. Both pyranometer experiments have variations in the value of the irradiation level from 0 to 1050 W/m². The range of variations of the experiment was carried out at 50 W/m² intervals.

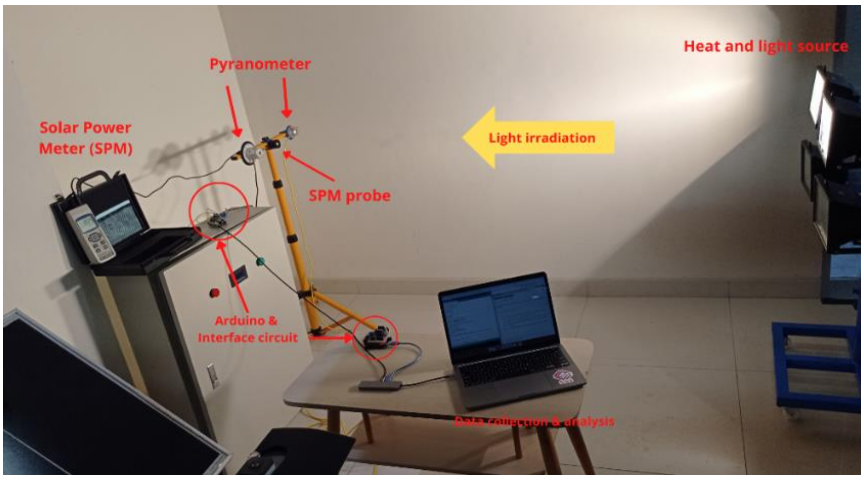


Figure 3. Experiment set for data collection

The data acquired from the two pyranometers are the interface circuit's output voltage (amplifier/Modbus controller) and the ADC value displayed on the Arduino serial monitor. Then the data set is compared with the irradiation value of the SPM. After that, the regression formula is obtained.

2.4. Characterization

The sensor characterization process in this study is needed to determine the character and performance of the pyranometer. The pyranometer is used to measure the solar irradiation parameters. Where the measurement results are used to analyze the potential of solar energy, it is also used to determine the performance of solar power generation systems.

The characteristics of the pyranometer sensor analyzed in this study are; accuracy, precision, linearity, and hysteresis. The first analysis is the accuracy of each sensor. Accuracy shows the performance of a measuring instrument. Accuracy determines how precise a measuring instrument is in giving a particular value [27]. This analysis was done by comparing the sensor's output value with the standardised measuring instrument's output value. The comparison is conducted by (1).

$$Error = \left|\frac{Standart\ value - test\ value}{Standart\ value}\right| \quad (1)$$

The second analysis is the precision of each sensor. The accuracy shows the performance of a measuring instrument gives a constant scale value many times. This can be calculated from the standard deviation obtained, which can be calculated by (2).

$$\sigma x = \frac{\sqrt{\sum_{i=1}^{n}(x_i - x)}}{(n-1)} \quad (2)$$

Then linearity is the relationship between input and output parameters that can be represented as a straight line in a graphic [28]. Linearity is closely related to proportionality of input and output. On the other hand, the hysteresis is the parameter that determines the sensor's response. Test conducted with varying the input parameter into increasing and decreasing points. The increasing points and decreasing points will show the different graphs. That graph will obtain the highest difference point called the hysteresis point. This point shows the actual response of the sensor if it is given an increase or decrease in input or if it has any precision loss. This characterization process is also vital to determining the regression equation.

3. RESULTS AND DISCUSSION

Compared to previous researchs, this article presents a characterization method and shows the results on solar irradiation measurements using a pyranometer. This is coupled with the use of a photovoltaic type pyranometer which has the principle of converting solar irradiation into electrical signals. It also provides a suitable interface circuit for this type of pyranometer. This is so that electrical signals can be processed digitally by microprocessor or microcontroller-based devices.

3.1. Regression formula

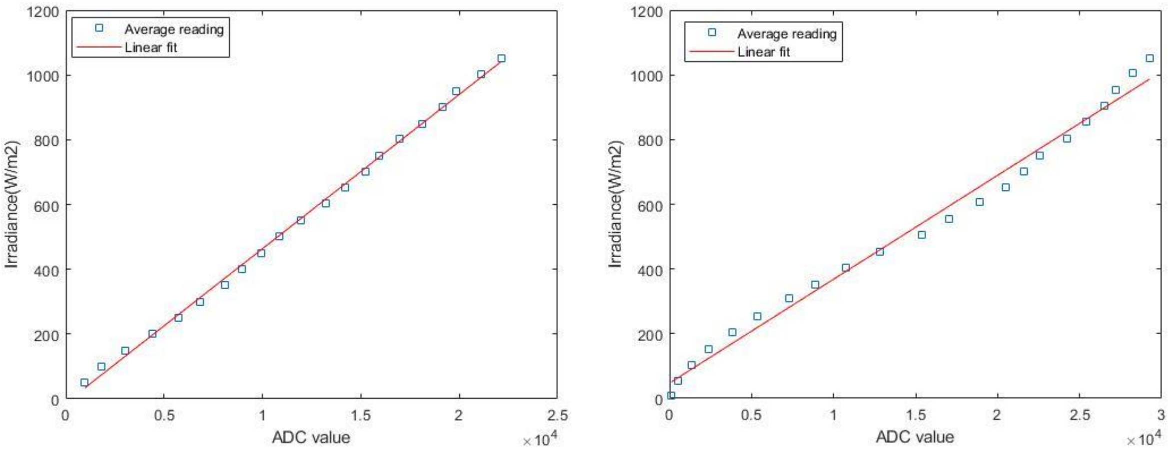
Figure 4 shows the comparison of ADC reading in instrumentation system for SP-Lite 3 and SEM228. Figure 4(a) shows the AD620 instrumentation amplifier was set for the first pyranometer experiment with a gain of 1168%. With the output voltage range of the pyranometer of 0–3.2 mV, the resulting AD620 output voltage of 0–3674 mV. The output voltage of the amplifier without light intensity is 324 mV. The irradiation intensity of 1051 50 W/m² produces an input voltage of 3.2 mV, which is very small. With this output voltage range, the maximum ADC value that can be read is 30215, which can't be more than that. The experiment was carried out 20 times with variations in the sun intensity increasing at intervals of 50 W/m². From the investigation for pyranometer one, we get (3) regression:

$$Irr_1 = 0.0476 \ x \ ADC_1 - 12.4486 \quad (3)$$

Figure 4(b) shows the experimental pyranometer two uses a Modbus controller to convert a 4-20 mA current signal into an analog voltage. The output voltage range of this Modbus controller is 0-3.5 V. With this voltage range, the Arduino ADC pin can read the pyranometer output. From the experiment for pyranometer two, we get (4) regressions:

$$Irr_2 = 0.0321 \ x \ ADC_2 + 47.39 \quad (4)$$

The regression formula generated by the above process is used to convert the ADC value into the irradiation level value in units of W/m². That way, the accuracy and precision parameters can be known.



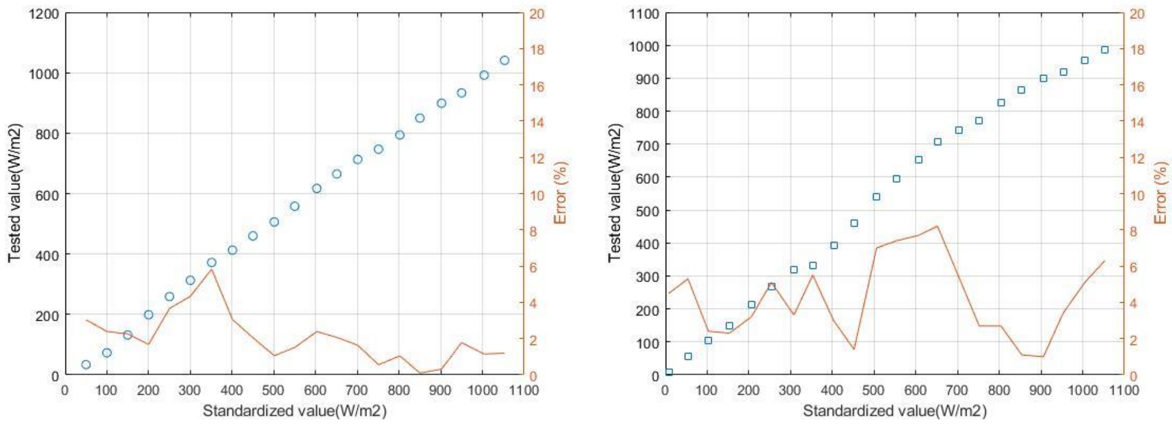
(a) (b)

Figure 4. ADC reading value vs level irradiation (a) Kipp and Zonen SP-Lite 3 and (b) Sentec SEM228

3.2. Accuracy and precision analysis

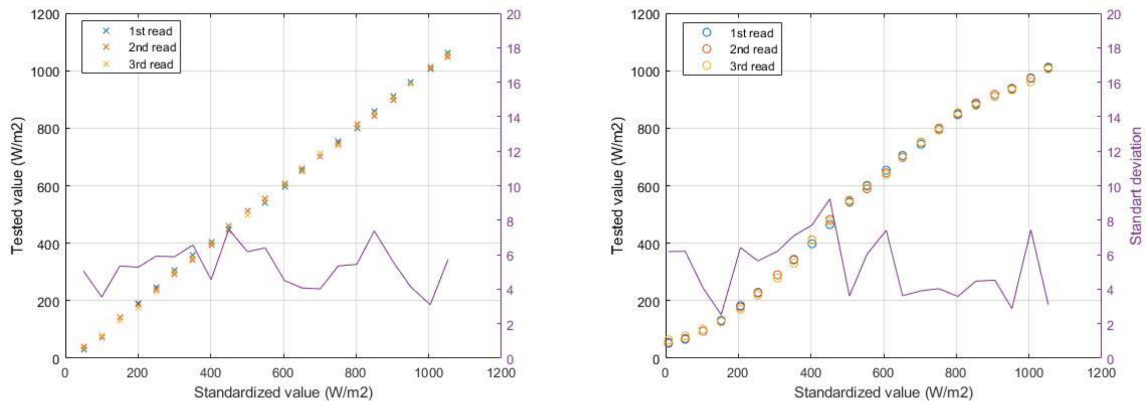
This test was carried out in the range of solar irradiation levels from 9.1–1052 W/m² with an average change interval of 49.66 W/m². Tests to analyze accuracy and precision were carried out four times. The experiment process uses the same standard measuring instrument, the same lighting source, the same experimental operator, and the same measuring operator. Figure 5 shows an analytical graph of the accuracy of the two pyranometers tested. Figure 5(a) indicates that the SP-Lite 3 type pyranometer has reasonably good accuracy with an average error value of 2.05 W/m². Therefore, the Kipp and Zonen pyranometer has minimum accuracy of 94.17%. While Figure 5(b) shows that the SEM228 type pyranometer has good accuracy with an average error value of 4.27 W/m². The Sentec pyranometer has minimum accuracy of 91.76%.

Therefore, the SP-Lite 3 has a higher accuracy rate than SEM228. This can be caused by the op-amp AD630 interface circuit, which can convert electrical signals with high linearity. Figure 6 shows the graph of the precision analysis of the two pyranometers tested three times. Figure 6(a) indicates that the SP-Lite 3 type pyranometer has a fairly good precision with a maximum value of 7.47. Therefore, this pyranometer has a precision of 92.53%. While Figure 6(b) shows that the SEM228 type pyranometer has good accuracy with a deviation value of 9.23. This second pyranometer has a precision of 90.77%. Therefore, the second pyranometer has a higher level of precision than the first pyranometer.



(a) (b)

Figure 5. Accuracy test results (a) Kipp and Zonen SP-Lite 3 and (b) Sentec SEM228



(a) (b)

Figure 6. Precision test results (a) Kipp and Zonen SP-Lite 3 and (b) Sentec SEM228

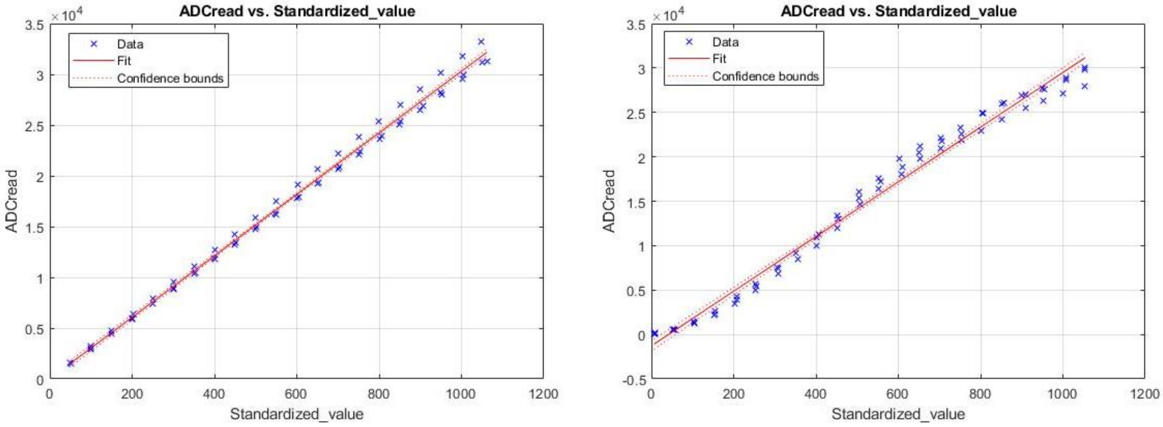
3.3. Linearity of the pyranometers

Linearity testing aims to determine whether two variables have a linear relationship or not significantly. This test examines how much influence variable x as input has on variable y as output. This happens both the influence is directly proportional or inversely. The more linear the relationship between the two variables, the higher the correlation. This test is used as a prerequisite in correlation analysis or linear regression. This test was conducted by comparing the system control output variable to standardized measurement instrument reading.

Figure 7 shows that the SEM228 pyranometer device has better linearity than the SP-Lite 2 device. The linearity test was done with 95% confidence bounds. pValue of the Standardized_value variable on both tests is very small; each is 1.3977e-72 and 2.1197e-60. Therefore, means that the variables are statistically significant in the model. The result in Figure 7(a) shows that the SP-Lite 3 pyranometer has an R-squared 0.995 with an average linearity error of 1.59%. According to Figure 7(b), a test on SEM228 found that R-squared 0.985 with average linearity error, of 1.53%. Therefore, the SEM228 pyranometer will be more accurate and precise if the Arduino program on the pyranometer uses the conversion (4) obtained from the regression process.

3.4. Sensor's hysteresis

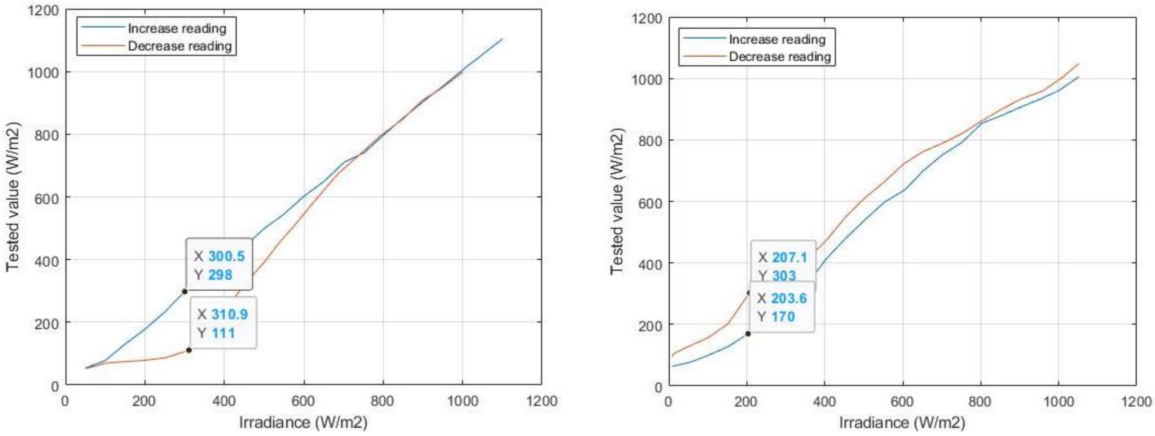
Hysteresis is an error that forms a graph of the difference between increasing and decreasing measurements. The test is done by changing the input variable with an increase of 8–1053 W/m². Then continued with a decrease from 1053–9 W/m². The input variable is the level of light irradiation. Figure 8 shows the difference in response between the SP-Lite 2 and SEM228 pyranometers when an increase and decrease test was applied. The decreasing test is done by changing the input irradiance 11 times with an average interval of 49.66 W/m². While the conversion was also carried out 11 times with an average interval of 52.56 W/m².



(a) (b)

Figure 7. Linearity test results (a) Kipp and Zonen SP-Lite 3 and (b) Sentec SEM228

The graph is shown by Figure 8(a) test results and SPL-Lite 3 reduction. Where in the graph there is a significant path difference at irradiance below 800 W/m². The difference in values that causes the peak hysteresis occurs at the radiation point of around 300–310 W/m². This can be caused by the character of the sensor that makes the response to a decrease in the input irradiance deviate from the increase in the input irradiance. Figure 8(b) shows that there is no significant difference between an increase and a decrease. Therefore, the hysteresis effect on the SEM228 pyranometer can be neglected.



(a) (b)

Figure 8. Hysteresis test results (a) Kipp and Zonen SP-Lite 3 and (b) Sentec SEM228

3.5. Overall system characteristics

After analyzing the characteristics of the instrumentation system on the 2 pyranometers being tested. Then the conclusion of the test results is presented in the Table 1. Table 1 shows good results of the SP-Lite 3 pyranometer with an interface circuit using the AD620 op-amp module. The AD620 module is set to increase the passive voltage from the pyranometer to 0–3.58 V. With this voltage range, it can be read and processed on the Arduino program. Not quite there, the instrumentation system is also added with an external ADC module to increase the voltage reading resolution to 16-bit. While the results of the characterization of the SEM228 pyranometer also show good results, it's just that the accuracy and precision are still below SP-Lite

3. The SEM228 pyranometer is equipped with a Modbus controller interface circuit. This modbus converts a 4-20 mA current signal into a 0–5 V voltage signal. With gain and zero point settings, the instrumentation system for this SEM228 can output a voltage of 0.02–3.67 V.

Table 1. The instrumentation system's characteristic for pyranometer SP-Lite 3 and SEM228

No.	Parameter	SP-Lite 3	SEM228
1	Maximum error	5.83%	8.24%
2	Accuracy	94.17%	91.76%
3	Standard deviation	7.47	9.23
4	Precision	92.53%	90.77%
5	Non-linearity error	1.59%	1.53%
6	Maximum hysteresis error	187 W/m²	133 W/m²

4. CONCLUSION

Photovoltaic pyranometer has the same way of working as photovoltaic cell. This type of sensor device can convert solar irradiation energy into electrical energy. This pyranometer works by capturing sunlight at an angle perpendicular to the probe. The Kipp and Zonen SP-Lite 2 pyranometer has a spectral range of 400–1100 nm with an irradiation measurement range of up to 2000 W/m². While the Sentec SEM228 pyranometer has a spectral range of 0.3–3 μm with a measurement range of up to 1800 W/m². The test results of several characteristic parameters of the instrumentation system on the two pyranometers show that the SP-Lite 3 instrumentation system has a higher level of accuracy and precision than the SEM228 instrumentation system. This is because the SP-Lite 3 instrumentation system has better linearity. On the other hand, the SP-Lite 3 instrumentation system lacks a more pronounced hysteresis effect than the SEM228. This can be caused because the SP-Lite 3 has a fast response time, which is less than 500 ns. The use of an interface circuit between the pyranometer and the microcontroller is very useful for processing or converting electrical signals so that they can be processed by a microcontroller board, such as an Arduino. In addition, the use of an external ADC is also useful for increasing the measurement resolution so that a higher level of accuracy and precision of the instrumentation system is obtained.

ACKNOWLEDGEMENTS

The authors would like to thank LPPM Universitas Airlangga for providing this research grant programme. We also thank all colleagues and students of Electrical Engineering from the Faculty of Advanced Technology and Multidiscipline, Airlangga University for their support of this research.

REFERENCES

[1] P. Megantoro, P. Anugrah, Y. Afif, L. J. Awalin, and P. Vigneshwaran, "A practical method to design the solar photovoltaic system applied on residential building in Indonesia," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 23, no. 3, pp. 1736–1747, 2021, doi: 10.11591/ijeecs.v23.i3.pp1736-1747.

[2] P. Megantoro, H. F. A. Kusuma, S. A. Reina, A. Abror, L. J. Awalin, and Y. Afif, "Reliability and performance analysis of a mini solar home system installed in Indonesian household," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 1, pp. 20–28, 2022, doi: 10.11591/eei.v11i1.3335.

[3] A. Azouzoute, A. A. Merrouni, E. G. Bennouna, and A. Gennioui, "Accuracy measurement of pyranometer vs reference cell for PV resource assessment," *Energy Procedia*, vol. 157, no. 2018, pp. 1202–1209, 2019, doi: 10.1016/j.egypro.2018.11.286.

[4] N. B. Blum *et al.*, "Measurement of diffuse and plane of array irradiance by a combination of a pyranometer and an all-sky imager," *Solar Energy*, vol. 232, no. January, pp. 232–247, 2022, doi: 10.1016/j.solener.2021.11.064.

[5] F. Vignola *et al.*, "Effects of changing spectral radiation distribution on the performance of photodiode pyranometers," *Solar Energy*, vol. 129, pp. 224–235, 2016, doi: 10.1016/j.solener.2016.01.047.

[6] M. Boyd, "Methodology and calculator for high precision regression fits of pyranometer angular responsivities and the associated uncertainties," *Solar Energy*, vol. 119, pp. 233–242, 2015, doi: 10.1016/j.solener.2015.06.048.

[7] R. Levinson, M. Egolf, S. Chen, and P. Berdahl, "Experimental comparison of pyranometer, reflectometer, and spectrophotometer methods for the measurement of roofing product albedo," *Solar Energy*, vol. 206, no. June, pp. 826–847, 2020, doi: 10.1016/j.solener.2019.11.103.

[8] D. S. Lee and J. H. Jo, "Application of simple sky and building models for the evaluation of solar irradiance distribution at indoor locations in buildings," *Building and Environment*, vol. 197, no. January, p. 107840, 2021, doi: 10.1016/j.buildenv.2021.107840.

[9] J. Möllenkamp, T. Beikircher, and A. Häberle, "Recalibration of SPN1 pyranometers against pyrheliometer and its relevance for the evaluation of concentrating solar process heat plants," *Solar Energy*, vol. 197, no. December 2019, pp. 344–358, 2020, doi: 10.1016/j.solener.2019.12.055.

[10] A. Razagui, K. Abdeladim, K. Bouchouicha, N. Bachari, S. Semaoui, and A. Hadj Arab, "A new approach to forecast solar irradiances using WRF and libRadtran models, validated with MERRA-2 reanalysis data and pyranometer measures," *Solar Energy*, vol. 221, no. April, pp. 148–161, 2021, doi: 10.1016/j.solener.2021.04.024.

[11] X. Liu and Y. Wu, "Experimental characterisation of a smart glazing with tuneable transparency, light scattering ability and

electricity generation function," *Applied Energy*, vol. 303, no. July, p. 117521, 2021, doi: 10.1016/j.apenergy.2021.117521.
[12] G. C. Wang, B. Urquhart, and J. Kleissl, "Cloud base height estimates from sky imagery and a network of pyranometers," *Solar Energy*, vol. 184, no. November 2018, pp. 594–609, 2019, doi: 10.1016/j.solener.2019.03.101.
[13] J. C. Baltazar, Y. Sun, and J. Haberl, "Improved methodology to evaluate clear-sky direct normal irradiance with a multi-pyranometer array," *Solar Energy*, vol. 121, pp. 123–130, 2015, doi: 10.1016/j.solener.2015.07.015.
[14] N. Srećković, N. Lukač, B. Žalik, and G. Štumberger, "Determining roof surfaces suitable for the installation of PV (photovoltaic) systems, based on LiDAR (Light Detection And Ranging) data, pyranometer measurements, and distribution network configuration," *Energy*, vol. 96, pp. 404–414, 2016, doi: 10.1016/j.energy.2015.12.078.
[15] J. M. Perrin, G. Thuillier, M. Fehrenbach, and F. Huppert, "A comparison between radiative transfer calculation and pyranometer data gathered at Observatoire de Haute Provence," *Journal of Atmospheric and Solar-Terrestrial Physics*, vol. 67, no. 5, pp. 449–463, 2005, doi: 10.1016/j.jastp.2004.11.010.
[16] G. P. Mantas and A. S. Rapti, "Investigation of the aging rate of a star-type pyranometer due to the discoloration of the receiver," *Solar Energy*, vol. 50, no. 1, pp. 1–7, 1993, doi: 10.1016/0038-092X(93)90002-6.
[17] V. Srikrishnan, G. S. Young, L. T. Witmer, and J. R. S. Brownson, "Using multi-pyranometer arrays and neural networks to estimate direct normal irradiance," *Solar Energy*, vol. 119, pp. 531–542, 2015, doi: 10.1016/j.solener.2015.06.004.
[18] F. R. Riedijk and J. H. Huijsing, "A smart balanced thermal pyranometer using a sigma-delta A-to-D converter for direct communication with microcontrollers," *Sensors and Actuators A: Physical*, vol. 37–38, no. C, pp. 16–25, 1993, doi: 10.1016/0924-4247(93)80006-3.
[19] M. R. Nugraha and A. Adriansyah, "Development of a solar radiation sensor system with pyranometer," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 2, pp. 1385–1391, 2022, doi: 10.11591/ijece.v12i2.pp1385-1391.
[20] A. H. Ali, A. S. Nada, and A. S. Shalaby, "Economical and efficient technique for a static localized maximum sun lux determination," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 2, pp. 777–784, 2019, doi: 10.11591/ijpeds.v10.i2.pp777-784.
[21] R. Meenal, A. Immanuel Selvakumar, and E. Rajasekaran, "Review on mathematical models for the prediction of solar radiation," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 15, no. 1, pp. 56–61, 2019, doi: 10.11591/ijeecs.v15.i1.pp56-61.
[22] K. Adye, N. Pearre, and L. Swan, "Contrasting distributed and centralized photovoltaic system performance using regionally distributed pyranometers," *Solar Energy*, vol. 160, no. July 2017, pp. 1–9, 2018, doi: 10.1016/j.solener.2017.11.042.
[23] B. Y. Kim *et al.*, "Calibration of the Pyranometer Sensitivity Using the Integrating Sphere," *Asia-Pacific Journal of Atmospheric Sciences*, vol. 54, no. 4, pp. 639–648, 2018, doi: 10.1007/s13143-018-0085-0.
[24] C. Hernández-Jacobo, R. Rentería-Ramirez, D. Escobedo-Márquez, C. Álvarez-Macias, R. Loera-Palomo and B. Reyes-Durán, "Analysis And Modeling Of The Impact Of Albedo On The Electrical Properties Of Photovoltaic Modules," *2021 IEEE 48th Photovoltaic Specialists Conference (PVSC)*, 2021, pp. 1270-1273, doi: 10.1109/PVSC43889.2021.9518545.
[25] S. Roy, S. Chandra Panja, and S. Narayan Patra, "An embedded system to measure ground-based solar irradiance signal," *Measurement*, vol. 173, no. October 2020, p. 108598, 2021, doi: 10.1016/j.measurement.2020.108598.
[26] E. Z. Ahmad, K. Sopian, A. Ibrahim, C. K. Gan, and M. S. A. Razak, "Experimental investigation of passively cooled photovoltaic modules on the power output performance," *International Journal of Power Electronics and Drive Systems*, vol. 13, no. 1, pp. 520–527, 2022, doi: 10.11591/ijpeds.v13.i1.pp520-527.
[27] P. Megantoro, A. Latif, B. A. Pramudita, and P. Vigneshwaran, "Automatic limit switch calibrator for control valve at steam turbine of a geothermal power plant," *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 3, pp. 1245–1251, 2021, doi: 10.11591/eei.v10i3.3031.
[28] K. V. Santhosh and B. K. Roy, "An adaptive calibration circuit for RTD using optimized ANN," *2013 7th International Conference on Intelligent Systems and Control (ISCO)*, 2013, pp. 49-54, doi: 10.1109/ISCO.2013.6481121.

BIOGRAPHIES OF AUTHORS

Prisma Megantoro has been a lecturer in Electrical Engineering, Faculty of Advanced Technology and Multidiscipline, Universitas Airlangga since 2020. He received a bachelor's degree and master's degree from Universitas Gadjah Mada, Yogyakarta, Indonesia in 2014 and 2018. His current research is focused on solar photovoltaic technology, embedded system, and the internet of things. He can be contacted at email: prisma.megantoro@ftmm.unair.ac.id.

Muhammad Akbar Syahbani was born in Nusa Tenggara Barat, Indonesia in 2001, after graduating from high school, he continued his studies in electrical engineering at the Universitas Airlangga in 2020. Now he is actively researching renewable energy at Universitas Airlangga Research Community. He can be contacted at email: muhammad.akbar.syahbani-2020@ftmm.unair.ac.id.

Sigit Dani Perkasa is a fifth-semester undergraduate student majoring in electrical engineering at Universitas Airlangga. He is active in the research of renewable energy, instrumentation, and microcontroller system as a part of Universitas Airlangga's Research Centre for New and Renewable Energy Engineering (RCNREE). He can be contacted at email: sigit.dani.perkasa-2020@ftmm.unair.ac.id.

Ahmad Rahmad Muzadi was born in Jombang, East Java, Indonesia in 2000. After graduating from high school, he continued his studies in electrical engineering at the Universitas Airlangga in 2020. He is interested in renewable energy and wants to develop it further. Now he is actively researching renewable energy at Research Community of Airlangga University. He can be contacted at email: ahmad.rahmad.muzadi-2020@ftmm.unair.ac.id.

Yusrizal Afif has been a lecturer in Electrical Engineering undergraduate program in Faculty of Advanced Technology and Multidiscipline at Universitas Airlangga. Received his bachelor's and master's degree in Engineering at Sepuluh Nopember Institute of Technology, Surabaya, Indonesia. He is actively doing research in high voltage technology, renewable energy and electrical installation. He can be contacted at email: yusrizal@ftmm.unair.ac.id.

Agus Mukhlisin was born in Nganjuk, on August 08, 1990. He received a bachelor's degree and master's degree from Institute Technology of Sepuluh November, Surabaya, Indonesia in 2015 and 2017. His current research is focused on system and control of electric vehicle, battery management system, charging station, dynamic system simulation. He can be contacted at email: agus.mukhlisin@ftmm.unair.ac.id.

Pandi Vigneshwaran has completed Ph.D. in Anna University, Chennai, Tamil Nadu, India. He completed his M.E. in Computer Science and Engineering and B.E. in Computer Science Engineering from Anna University Chennai and Madurai Kamraj University respectively. He is having 18 years of teaching experience and worked at various levels and got good exposure in academics as well as administration. He can be contacted at email: vigenesp@srmist.edu.in.