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Development of a MATLAB Application for Evaluating the Performance of Photovoltaic System

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Abstract: This research focuses on the development of a MATLAB application for evaluating the performance of a photovoltaic system by using a Graphical user Interface (GUI) platform. PV systems need to be evaluated because to performance of photovoltaic system output depends on Sunray which will eventually be affected in its performance evaluation because of the inconsistency of photovoltaic panel input values. Output power is dramatically reduced when photovoltaic (PV) modules are subjected to varying solar irradiation which certain areas are partially shaded. This research explained how the performance of a photovoltaic system may be examined using three distinct methods: acceptance ratio, energy performance index, and final system yield. Estimating the performance of a solar system using a computer approach, has been made. Acceptance Ratio, Energy Performance Index, measured Final System Yield, and predicted Final System Field were 0.134, 63.769%, 131.579 kWh kWp^{-1}, and 206.338 kWh kWp^{-1} respectively. While, the computational result was compared to the GUI application, it shows that differences of data are very small yet it makes the application function as expected Result shows performance of the photovoltaic system was worse than expected due to many aspects such as surrounding and system efficiency. GUI applications can be used and are eco-friendly without having users to go through complicated processes to install the application. Objectives that were introduced have been achieved throughout this research.

Keywords: Performance Of PV System, GUI Application, Acceptance Ratio, Energy Power Index, Final System Yield

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1. Introduction

Climate change is a pressing global issue caused by significant changes in meteorological parameters over time [1]. To address this problem, the use of renewable energy has become crucial. Renewable energy sources, such as solar energy, offer numerous benefits including reduced pollution, mitigation of global warming, and lower carbon emissions [2],[3]. Solar energy is particularly advantageous due to its abundant supply, eco-friendliness, cost-effectiveness, and noise-free nature [4]. Photovoltaic panels, composed of materials that can convert sunlight into electricity, play a vital role in harnessing solar energy. These panels have the potential to generate electricity by directly converting solar radiation into electrical energy through the absorption of photons and emission of electrons [5],[6]. To evaluate the performance of photovoltaic (PV) systems, this research aims to develop a user-friendly MATLAB application. Traditional methods, such as using Excel or Google Sheets, have limitations in terms of complex data visualization and analysis. The objectives of this research include determining PV system performance computationally, developing a MATLAB application for performance evaluation, and comparing the application's results with manual computations [7],[8]. The scope of the study focuses on designing the application in MATLAB and monitoring parameters such as PV output voltage, current, solar irradiance, panel temperature, output power, daily energy, and total energy.

2. Materials and Methods

The research methodology includes studying the research's machinery, tools, materials, procedures, and processes. This method may be used to evaluate the performance of solar systems using a MATLAB program. The objective is to develop an effective data-gathering strategy that reduces mistakes and produces reliable findings.

2.1 Method of collecting data for photovoltaic system

Organized data collecting is critical to ensuring a smooth research execution. Before collecting data, wipe the solar panel with a dust mop and note the weather conditions. Several equipment was used such as a Pyrometer and Solar Irradiance Meter for measuring data. For seven weeks, data was collected three times a day at specified times (9:00 a.m., 12:00 p.m., and 5:00 p.m.). The information gathered was saved online in a Google Spreadsheet. Data from January 2, 2023, at 12:00 p.m. is utilized specifically, to ensure high weather conditions and sun irradiation.

Table 1: Specific data on 2 January 2023

Date	2/1/2023
Time	1200
Weather	Sunny
Solar Irradiance (W/m2)	875.5
Temperature of PV Panel (°C)	42.8
PV Output Voltage (V)	41.3
PV Output Current (A)	0.9
PV Output Power (W)	37.17
PV Daily Energy (Wh)	400
PV Total Energy (kWh)	17.638

2.2 Computational method for evaluating performance of the photovoltaic system

The performance of a photovoltaic system may be assessed using three different computational methods: acceptance ratio, energy performance index, and final system yield. These approaches make use of obtained data to examine and analyse the system's efficiency and efficacy.

2.2.1 Acceptance ratio

The acceptance ratio is a statistic used in photovoltaic (PV) systems to evaluate system performance by comparing actual energy production to predicted energy output [9]. The formula used as in Eq.1, Eq.2 and Eq.3 help to assess the efficacy of the system with respect to its anticipated or expected performance [10]. Solar irradiation, temperature, system setup, and other relevant characteristics are commonly used to predict projected energy output.

$$AR = \frac{P_{out\ measured}}{P_{out\ expected}} \quad Eq.1$$

$$P_{out\ expected} = P_{A\ stc} \times \frac{G_i}{G_{stc}} \times f_{mm} \times f_{temp} \times f_{clean} \times f_{degrad} \times f_{unshade} \times \eta_{cable} \times \eta_{inv} \quad Eq.2$$

$$f_{temp} = 1 + \left[\left(\frac{\gamma_{Pmax}}{100}\right) \times (T_{mod} - T_{STC})\right] \quad Eq.3$$

Where,

$P_{out\ expected}$	expected AC power generation (Wh)
$P_{A\ stc}$	peak power of PV array at STC (W)
G_i	solar irradiance received on poa (Wm^{-2})
G_{stc}	solar irradiance at STC, 1,000 Wm^{-2}
f_{mm}	power de-rate factor due to mismatch(decimal)
f_{temp}	temperature de-rating factor during measurement (decimal)
f_{clean}	power de-rate factor due to dirt (decimal)
f_{degrad}	power degradation factor due to LID and aging (decimal)
$f_{unshade}$	unshaded factor (decimal)
η_{cable}	efficiency of the cable (decimal)
η_{inv}	maximum efficiency of the inverter (decimal)
γ_{Pmax}	temperature coefficient for peak power (%°C^{-1}) or (K^{-1})
T_{mod}	module temperature (°C)
T_{STC}	cell temperature at STC, 25°C

When the inverter is in power clipping mode, the maximum alternating current power output is restricted to the maximum alternating current power rating. As a result, the acceptance ratio (AR) might decrease.

2.2.2 Energy Performance Index (EPI)

In terms of PV system performance, the Energy Performance Index (EPI) is a metric employed to assess and measure the overall efficiency of a photovoltaic system. It serves as an indicator of how efficiently the system converts solar energy into usable electrical energy [11]. The AC output energy is the amount of AC energy generated by the GCPV system in a particular period which can be calculated using Eq. 4 [12].

$$E_{out\ expected} = P_{A\ stc} \times PSH_i \times f_{mm} \times f_{temp\ ave} \times f_{clean} \times f_{degrad} \times f_{unshade} \times \eta_{cable} \times \eta_{inv} \quad Eq.4$$

Solar irradiation formula expressed in Eq. 5 which for the PV modules can be determined by using

$$H_i = \sum_k G_{i,k} \times \tau_k \quad Eq.4$$

Thus, peak sun hour can be calculated as shown in Eq.5, Eq. 6 and Eq.7

$$PSH_i = \frac{H_i}{G_{stc}} \quad Eq.5$$

$$f_{temp\ ave} = 1 + \left[\left(\frac{\gamma_{Pmax}}{100}\right) \times \left(T_{mod,avg} - T_{STC}\right)\right] \quad Eq.6$$

$$T_{mod,avg} = \frac{\Sigma_k G_{i,k} \times T_{mod,avg}}{\Sigma_k G_{i,k}} \quad Eq.7$$

Energy performance index (EPI) can be defined as

$$EPI = \frac{E_{out\ measured}}{E_{out\ expected}} \times 100\% \quad Eq.8$$

Where,

$E_{out\ predicted}$	predicted AC energy generation (kWh)
$E_{out\ expected}$	expected AC energy generation (kWh)
$E_{out\ measured}$	measured AC energy generation (kWh)
PSH_i	peak sun hour received in-plane of array (h)
$f_{temp\ ave}$	temperature de-rating factor (decimal)
H_i	solar irradiation received on poa ($kWhm^{-2}$)
EPI	energy performance index
T_k	recording interval (h)
$G_{i,k}$	in-plane solar irradiance (Wm^{-2})
$T_{mod,k}$	effective module temperature (°C)
$T_{mod,avg}$	average irradiance-weighted cell temperature from one year of weather data using the project weather file (°C)

2.2.3 Final system yield

The quantity of energy generated by the PV system per unit of PV capacity is represented by the final system yield, often known as annual final system yield or simply system yield [13]. Depending on the circumstances, it might be given as an annual value or as monthly or daily values. The final system yield includes anticipated, expected, and measured numbers as shown in Eq. 9, Eq. 10 and eq. 11 will help assessing and comparing the PV system's performance.

$$\gamma_{f\ predicted} = \frac{E_{out\ predicted}}{P_{A\ stc}} \quad Eq.9$$

$$\gamma_{f\ expected} = \frac{E_{out\ expected}}{P_{A\ stc}} \quad Eq.10$$

$$\gamma_{f\ measured} = \frac{E_{out\ measured}}{P_{A\ stc}} \quad Eq.11$$

Where,

$\gamma_{f\ predicted}$	predicted final system yield ($kWh\ kWp^{-1}$)
$\gamma_{f\ expected}$	expected final system yield ($kWh\ kWp^{-1}$)
$\gamma_{f\ measured}$	measured final system yield ($kWh\ kWp^{-1}$)

2.3 GUI application development

The Specification and Parameter Tab allows users to input parameters and PV system specifications [14]. The GUI Application computes the performance of the photovoltaic system, including Acceptance Ratio, Energy Performance Index, and Final System Yield. The Formulas Tab provides the formulas used, and the Result Tab displays the expected values for PV system performance [15]. Additionally, the application includes a Guidelines Tab to assist users in utilizing the application effectively.

2.3.1 Guidelines tab

Guidelines Tab is a centralized spot where users may find crucial information and tools to help them better understand and utilize the GUI application. The illustration provides as shown in Figure 1 will help users to have better understanding on the operation of PV system. Reference also has been provided to the users in order to make sure the system is working either good or bad according to the result achieved.

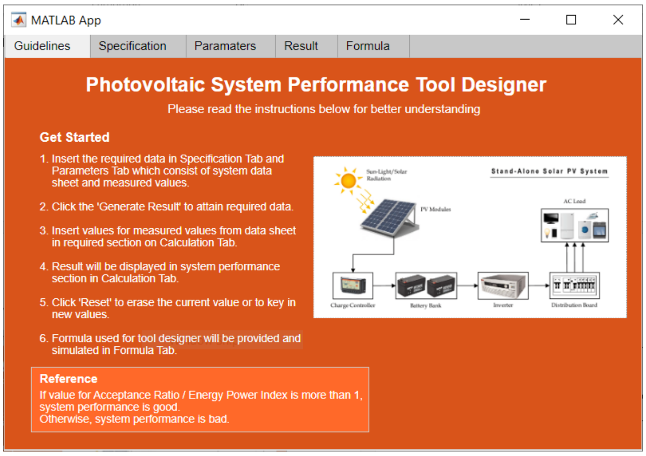

Figure 1: Guidelines tab window of GUI application on MATLAB

2.3.2 Specification tab

The specification tab serves different types of specification where information component can be found in its data sheet that were publish by component's brand or manufactures as shown in Figure 2. Users can key in detailed information about their PV system specification regardless any product types and brands. It enables users to make educated decisions, understand the capabilities and limits, and use the item or feature successfully based on their unique needs or preferences.

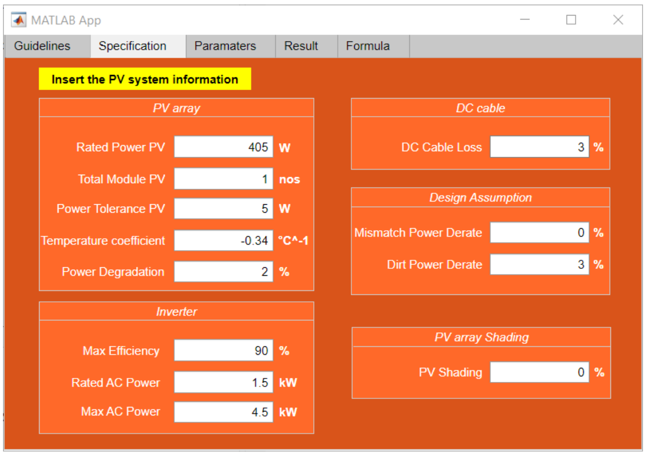

Figure 2: Specification tab window of GUI application on MATLAB

2.3.3 Parameters tab

The Parameters Tab as shown in Figure 3 focuses on the output of a PV system using real-time data. It allows users to access and adjust a variety of settings that affect the program's or system's behaviour and functionality. These options are organized in a tabular design, making it easy for users to navigate through different sections or categories of options.

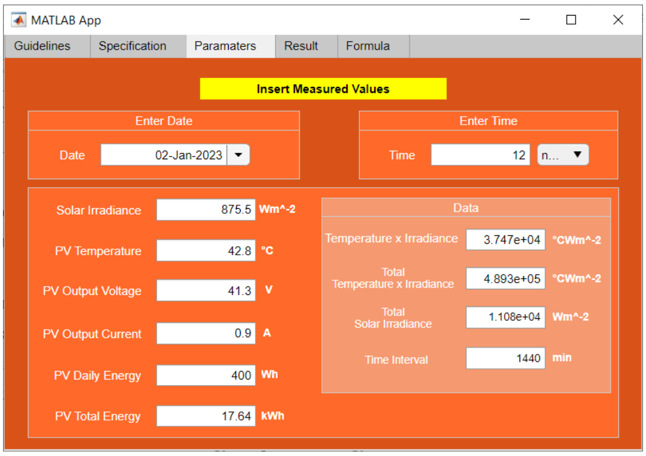

Figure 3: Parameters tab window of GUI application on MATLAB

2.3.4 Result tab

Users may obtain a variety of outcomes under result tab, such as power output, energy output, acceptance ratio, energy performance index, and system yield field as depicted in Figure 4. Users may make educated judgements, draw conclusions, and take relevant measures for their research endeavours by analysing these outcomes.

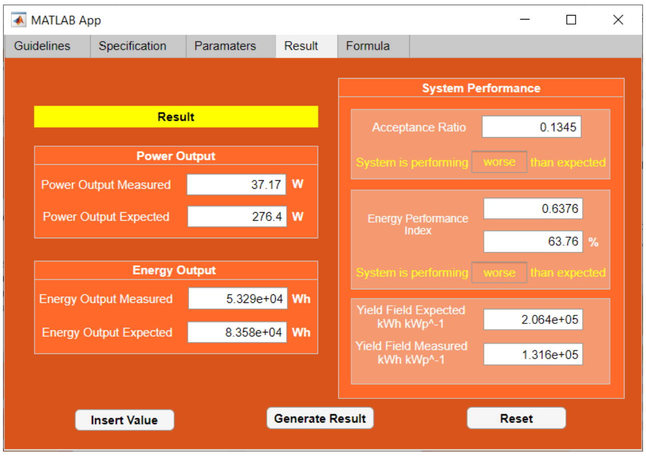

Figure 4: Result tab window of GUI application on MATLAB

2.3.5 Formula tab

Users may obtain a variety of outcomes under this tab, such as power output, energy output, acceptance ratio, energy performance index, and system yield field. Users may make educated judgements, draw conclusions, and take relevant measures for their research endeavours by analysing these outcomes. Figure 4 shows the formula tab window of GUI application on MATLAB.

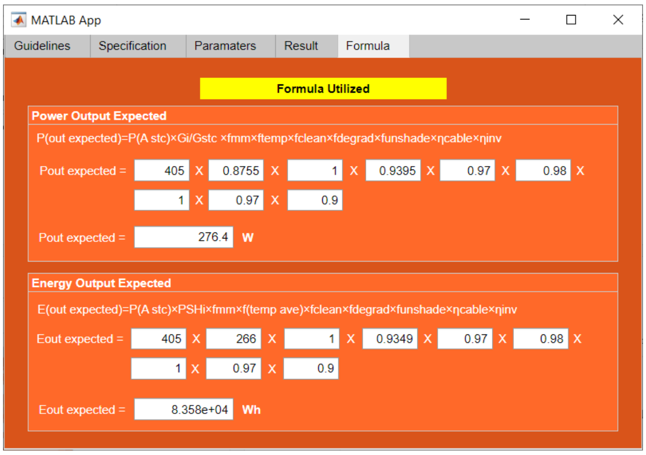

Figure 4: Formula tab window of GUI application on MATLAB

3. Results and Discussion

3.1 Finding on performance of photovoltaic system

This section contains the data gathering findings as well as an overview of the performance of the photovoltaic system. It contains critical computations including the acceptance ratio, energy power index, and final system yield. Some parameter values, such as de-rate factor owing to mismatch and dirt, unshaded factor, and cable efficiency, were referred to and assumed. Table 2 summarises the information gathered in order to anticipate the performance of a solar system.

Table 2: PV system specification

Specification	Description
Rated Power PV	405 W
Total number PV modules	1 module
Power Tolerance of PV module	0~5 W
Temperature coefficient	-0.34 %$°C^{-1}$
Power degradation 0-1 year	2%
Shading	No shading
Inverter maximum efficiency	90%
Rated AC power	1.5 kW
Maximum AC power	4.5 kW
DC cable loss	3 %
Dirt derate power	3 %

The performance of the photovoltaic system is being assessed using computational methods that incorporate system specs with real-time data gathered over a 7-week period. The computational method required to use three different method which are acceptance ratio, energy performance index and final system yield. Comparison of the values acquired from each computational approach to the findings received via the GUI application can be seen as in Table 3, Table 4, and Table 5.

Table 3: Values of AC power and acceptance ratio

System Performance	Manual Result	GUI Result
AC power output measured (W)	37.17	37.17
AC power output expected (W)	276.4463	276.4
Acceptance Ratio	0.134	0.1345

The acceptance ratio of 0.134 suggests that the system performed worse than predicted. This is due to the observed AC power output of 37.13W, which is less than the inverter's maximum AC power rating (4.5 kW) without power clipping. The most likely energy production estimate takes into account factors such as installed capacity, solar resource availability, and losses due to shade, dirt, or system inefficiencies. These variables can have an impact on the system's ability to convert sunlight into useful electrical energy.

Table 4: Values of energy output and Energy Power Index (EPI)

System Performance	Manual Result	GUI Result
Energy Output Measured (kW)	53.2896	53.2896
Energy Output Expected (kW)	83.567	83.58
Energy Power Index (%)	63.769	63.76

The PV system's Energy Power Index (EPI) is 69%, suggesting that it is operating below expectations. For best performance, a value of 1 or greater is preferred. According to the data sheet, the lower EPI value can be attributable to the inverter's maximum efficiency of 90%. Despite this, there is no AC power clipping since the DC/AC ratio is 0.27, which is less than the normal power clipping value of 1.11.

Table 5: Values of final system yield

System Performance	Manual Result	GUI Result
Measured Final System Yield ($kWh\ kWp^{-1}$)	131.579	131.6
Expected Final System Yield ($kWh\ kWp^{-1}$)	206.338	206.4

The Measured Final System Yield falls short of the Expected Final System Yield. This can be ascribed to PV system performance degradation, in which efficiency and output steadily decline over time. PV panel degeneration, material deterioration, and environmental exposure all contribute to this reduction. Predicting the ultimate system yield frequently relies on modelling, simulation, or manufacturer specifications, which may not be completely accurate under real-world situations. As a result, the projected and actual ultimate system yields may differ.

The GUI programme was used to illustrate its operation using various user-supplied data values. The PV system requirements remained constant, whereas the recorded data parameters changed for various dates such as January 31, 2022, January 4, 2023, and January 13, 2023. These dates were chosen to correspond with real-time data. With constant time and weather circumstances, manual computations were done utilising these revised data. Both the computational technique and the GUI computation were changed as needed, and the results for each modification were documented in Table 4.5.

3.2 Comparison of variation PV system parameters

The GUI programme was used to illustrate its operation using various user-supplied data values. The PV system requirements remained constant, whereas the recorded data parameters changed for various dates such as January 31, 2022, January 4, 2023, and January 13, 2023. These dates were chosen to correspond with real-time data. With constant time and weather circumstances, manual computations were done utilising these revised data. Both the computational technique and the GUI computation were changed as needed, and the results for each modification were documented in Table 6.

Table 6: Result comparison for computational method with GUI application

	Manual Result			GUI Result		
Date	31/12	4/1	13/1	31/12	4/1	13/1
AC power output expected (W)	283.82	239.418	293.295	283.8	239.4	293.3
Acceptance Ratio	0.117	0.155	1.143	0.131	0.1553	1.14
Energy Output Expected (kW)	83.567	83.567	83.567	83.58	83.58	83.58
Energy Power Index (%)	63.769	63.769	63.769	63.76	63.76	63.76
Measured Final System Yield ($kWh\ kWp^{-1}$)	131.579	131.579	131.579	131.6	131.6	131.6
Expected Final System Yield ($kWh\ kWp^{-1}$)	206.338	206.338	206.338	206.4	206.4	206.4

The change in decimal place had an indirect influence on acceptance ratio numbers, with the GUI application being more accurate than the computational technique. This occurred because the value for the computational approach was reduced to two decimal places, whilst the GUI application computed the result using the whole numbers.

4. Conclusion

This research comprehensively presents the detailed findings of employing computational methods to assess photovoltaic system performance, underpinned by a thorough analysis of diverse research articles. The primary objective of quantifying photovoltaic system performance computationally has been achieved, involving the utilization of various parameters such as Acceptance Ratio, Energy Performance Index, measured Final System Yield, and expected Final System Field with corresponding values of 0.134, 63.76%, 131 $kWh\ kWp^{-1}$, and 206.4 $kWh\ kWp^{-1}$. The second goal, creating a user-friendly graphical user interface (GUI) for performance evaluation using MATLAB, has been successfully realized where the GUI's design prioritized user intuitiveness and interaction ease, consistently generating results aligned with the data collection method's accuracy, as demonstrated in this research. Lastly, the study effectively met its final objective, comparing the GUI's performance assessment with manual design, revealing minimal deviation which affirming the GUI's precision in evaluating photovoltaic system performance and validating its suitability for real-world applications.

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References

[1] A. Mohanty, "Impacts of climate change on human health and agriculture in recent years," 2021 IEEE Region 10 Symposium (TENSYMP), pp. 1-4, 2021, doi: 10.1109/TENSYMP52854.2021.9550876.

[2] F. E. Tahiri, K. Chikh, M. Khafallah, A. Saad and D. Breuil, "Modeling and performance analysis of a solar PV power system under irradiation and load variations," 2017 14th International Multi-Conference on Systems, Signals & Devices (SSD), pp. 234-238, 2017, doi: 10.1109/SSD.2017.8166952.

[3] K. P. Satsangi, G. S. Sailesh Babu, D. B. Das and A. K. Saxena, "Performance Evaluation of Grid Interactive Photovoltaic System," 2018 International Conference on Computing, Power

and Communication Technologies (GUCON), pp. 691-695, 2018, doi: 10.1109/GUCON.2018.8674959.

[4] M. H. Radhi, E. J. Mahdi and A. K. Mftwol, "Design and Performance Analysis of Solar PV System Size 2.56 kWp," 2019 4th Scientific International Conference Najaf (SICN), pp. 70-73, 2019, doi: 10.1109/SICN47020.2019.9019373.

[5] N. Bhoopal, P. Sumanjali, D. G. Kumar, A. Ganesh, S. Saravanan and M. Prameela, "Performance Evaluation of Optimal MPPT for PV System Considering Partial Shading Conditions," 2021 International Conference on Computing, Communication and Green Engineering (CCGE), pp. 1-4, 2021, doi: 10.1109/CCGE50943.2021.9776353.

[6] P. V. Rosu, A. -T. Plesca, G. Gabor and G. Chiriac, "Optimizing the Operation of Photovoltaic Panel Systems," 2020 International Conference and Exposition on Electrical And Power Engineering (EPE), pp. 318-321, 2020, doi: 10.1109/EPE50722.2020.9305534.

[7] L. Yu, "Matlab Programming Environment Based on Web," 2018 IEEE 4th Information Technology and Mechatronics Engineering Conference (ITOEC), pp. 509-512, 2018, doi: 10.1109/ITOEC.2018.8740716.

[8] L. T. Hong, J. Ahmed, H. Nabipour-Afrouzi and S. Kashem, "Designing a PSCAD based PV simulator for partial shading to validate future PV application planning," 2018 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), pp. 526-531, 2018, doi: 10.1109/APPEEC.2018.8566639.

[9] A. Mohd., H. Zainuddin, N. Muhammad, and F. Liyana, “Acceptance Ratio Analysis: An Early Fault Indicator for Grid-Connected Photovoltaic System,” International Journal on Advanced Science, Engineering and Information Technology, vol. 11, no. 3, pp. 1214–1223, 2021

[10] SEDA, "Design and Sizing of grid-Connected Photovoltaic Power System,” Sustainable Energy Development Authority (SEDA) Malaysia, pp. 100-107. 2022

[11] N. M. Kumar et al., “Operational performance of on-grid solar photovoltaic system integrated into pre-fabricated portable cabin buildings in warm and temperate climates,” Energy for Sustainable Development, vol. 57, pp. 109–118, Aug. 2020, doi: 10.1016/j.esd.2020.05.008.

[12] Bhogula Navothna, & Sandhya Thotakura, “ Analysis on Large-Scale Solar PV Plant Energy Performance–Loss–Degradation in Coastal Climates of India:, 10. 2022, https://doi.org/10.3389/fenrg.2022.857948

[13] M. Hosenuzzaman, N. A. Rahim, J. Selvaraj, and M. Hasanuzzaman, “Factors affecting the pv based power generation,” Theiet.org, pp. 20 (6 .)-20 (6 .), 2014, Accessed: Jan. 30, 2023. [Online]. Available: https://digitallibrary.theiet.org/content/conferences/10.1049/cp.2014.1467

[14] A. Almaktoof, N. Shebani, and A. Elfallah, “GUI-PV Application Tool for Teaching Performance of PV System using MATLAB-Graphical User Interface Environment,” 2021 IEEE 1st International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering MI-STA, May 2021, doi: 10.1109/mi-sta52233.2021.9464367.

[15] Pa. Valar, “A graphical user interface (GUI) based method for designing a mini hydro-power,” Uthm.edu.my, 2022, doi: http://hdl.handle.net/123456789/6966.