

Development of a MATLAB GUI for Sizing and Techno-Economic Analysis of Grid-Connected Photovoltaic Systems at Taman Universiti, Parit Raja, Batu Pahat

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Abstract

This project presents the development and implementation of a MATLAB-based Graphical User Interface (GUI) tool to facilitate the sizing of grid-connected photovoltaic (GCPV) systems for single-story houses in Taman Universiti, Parit Raja. The GUI simplifies the potentially complex process of PV system sizing through the combination of energy, budget, architectural, and regulatory constraints into a single interactive tool. The GUI features 5 tabs that guide users through module selection, system design, and techno-economic analysis based on Net Energy Metering (NEM 3.0). The tool serves as a convenient solution for homeowners and non-technical people to maximise the GCPV investments. The REC Alpha Pure-R Series (430W) was the most suitable PV module for this location, considering factors such as cable efficiency, mismatch factor, degradation factor, average temperature factor, and peak sun hours. Similarly, the inverter selected for this system is the Huawei SUN2000-2KTL-M0 (3000W), as it matches the required inverter power of 2324.32W and provides a sufficient safety margin. The system is designed with 2 strings, each comprising 3 PV modules, connected to two separate maximum power point trackers (MPPTs), labelled as MPPT A and MPPT B.

1. Introduction

Renewable energy is the most economical green energy technology [1],[2]. Renewable energy comes from sources in nature that do not run out, like sunlight, wind, water and plants. The importance of renewable energy as an environmentally friendly and reliable technology has grown significantly as a substitute for fossil fuels, especially in response to the current energy shortage, global economic growth, and environmental pollution. Due to Malaysia's location near the equator gives it has abundant solar energy available year-round [3],[4]. Making it a suitable place for large-scale solar projects due to the country's average monthly solar radiation of 400 to 600 MJ/m². Several organizations, including the Malaysia Energy Centre, Tenaga Nasional Berhad (TNB), and the Sustainable Energy Development Authority Malaysia (SEDA), have supported the growth of solar energy. Hence, the installed solar energy capacity has increased from 205 MW in 2014 to 2165 MW in 2023[5]. This indicates that supportive government policies and actions in various sectors have significantly boosted the solar industry. Photovoltaic (PV) systems are a highly suitable renewable energy source. These systems capture solar energy and convert it into electricity using solar panels [6],[7]. PV systems work differently based on the weather. Photovoltaic systems produce the most electricity on sunny days, but the output drops on cloudy days. Then, the sizing of the Grid-Connected Photovoltaic (GCPV) systems is important because it determines the

amount of electricity that can be generated. This process can be complex, as it depends on various factors. Therefore, this project is significant as it simplifies the process. The sizing method of the GCPV system is based on the Sustainable Energy Development Authority (SEDA) [8], ensuring that the system sizing follows nationally recognized guidelines and standards.

A GCPV system is a solar power system that is directly connected to the public electricity grid. It uses solar panels, or PV modules, to convert sunlight into electricity. The PV modules generate electricity in the form of direct current (DC), and the electricity is sent to an inverter. The inverter plays the important role of transforming the DC electricity into alternating current (AC), which is the type of electricity that is used in homes and supplied by the utility grid. Once transformed, the electricity can either be used immediately to supply appliances in the building or fed into the electricity grid if there is surplus electricity. In Malaysia, through the Net Energy Metering (NEM) scheme, users can get credits or offset their electricity bills by sending surplus solar energy to the grid. GCPV systems are being widely applied in residential, commercial, and large-scale applications because of their efficiency, sustainability, and cost-effectiveness in the long run.

GCPV systems have become a common choice for renewable energy-based power generation, several challenges remain in design, installation, and operation [9]. System design must be emphasized to ensure the systems function effectively. Systems with inadequate designs may suffer from reduced performance, operational issues, or inefficiency, leading to higher costs and reduced economic viability [10]. Designing these GCPV systems is often referred to as system sizing. This involves selecting appropriate inverters and PV modules, configuring the PV array in series and parallel connections, estimating the system's output, and evaluating its economic performance [11], [12]. Despite the availability of various methods for system sizing, developing a fast and precise sizing approach remains challenging due to the wide range of PV module and inverter models on the market.

2. Methods

The research methodology shown in Figure 1 focuses on the flow process of the project. This method is used to determine the sizing and Techno-economic analysis of Grid-Connected Photovoltaic systems using MATLAB GUI at single-story house in Taman Universiti, Parit Raja. The GUI assists the users in choosing the appropriate PV module, determining the number of modules needed and designing the overall system. Other than that, GUI offers Techno-Economic analysis including total cost, energy saving and payback period. Therefore, this approach provides a user-friendly system for planning a GCPV system for residential.

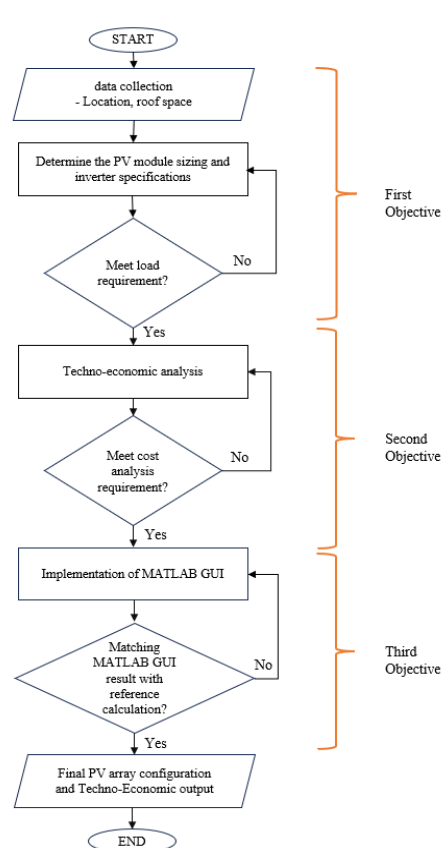


Fig. 1 Flowchart

2.1 GUI application development

2.1.1 TAB 1: Determine the PV module

Figure 2 illustrates the tab 1 for PV module determination. This tab allows the user to determine the recommended PV module according to technical and environmental specifications. The user input is the value of cable efficiency, inverter efficiency and peak sun hours (PSHi) values. This method calculates four preselected PV modules considering temperature coefficient, degradation rate, and the size of the PV system. This tab calculates the energy output per unit area. Then, the table is generated to display the result of energy output per area of the modules, and the most performing module is automatically used for application in the next steps. Users can proceed to the next tab of the system design by clicking “Proceed to array sizing”.

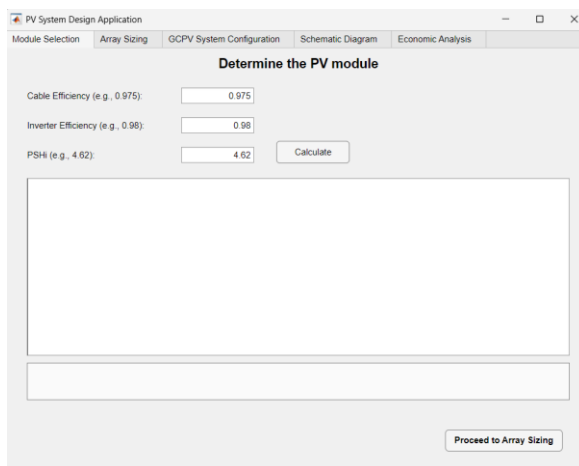


Fig. 2 Tab 1 Determine the PV module

2.1.2 TAB 2: Dimensioning of PV array

Figure 3 estimates the required number of PV modules based on the roof size, budget, and household energy consumption. The user needs to key in all the input required to finalize the appropriate number of PV modules that can be fitted on the roof. The lowest number of PV modules among the constraints will be chosen as the Final number of PV modules. Users can proceed to the next tab of the system design by clicking “Proceed to GCPV system configuration”.

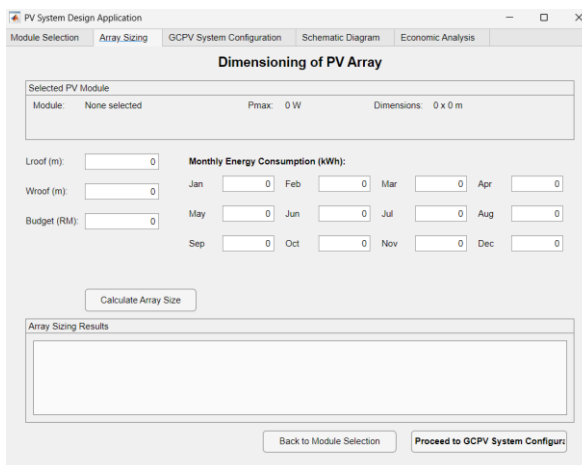


Fig. 3 Tab 2 Dimensioning of PV array

2.1.3 TAB 3: GCPV System Sizing

Figure 4 outlines the configuration of GCPV system. The system automatically used the selected module and number of PV modules from the previous tab. This tab calculates the string configuration, maximum and minimum modules in series. Provided with two MPPT inputs. Finally, determine the final PV array configuration. Users can proceed to the next tab of the system design by clicking “View schematic diagram”.

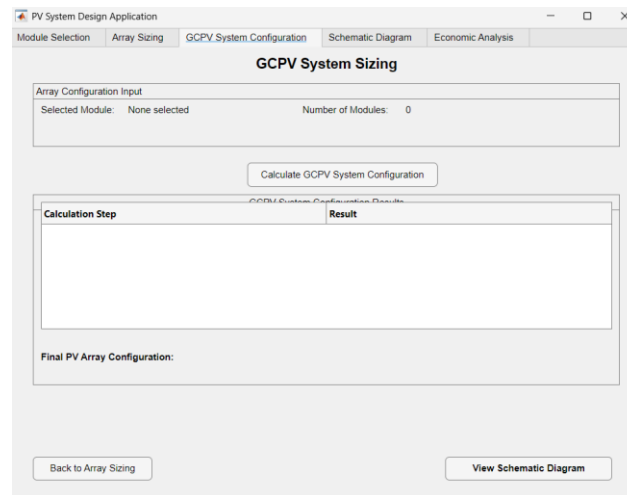


Fig. 4 Tab 3 GCPV System Sizing

2.1.4 TAB 4: PV system Schematic Diagram

Figure 5 provides a graphical representation of the intended PV system design. Summarizes the most critical configuration such as selected PV modules, number of PV modules, Inverter and Final PV array configuration. The diagram enables users to visualize how the system components are wired. The tab will update automatically based on the result in the previous tabs. Users can proceed to the next tab of the system design by clicking "Proceed to Economic analysis".

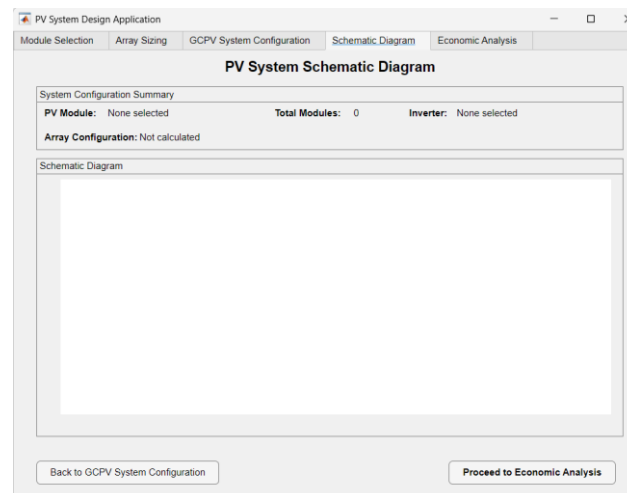


Fig. 5 Tab 4 PV system schematic diagram

2.1.5 TAB 5: Techno-Economic Analysis (NEM 3.0)

The final tab determines the financial feasibility of the GCPV system using Malaysia's Net Energy Metering (NEM) 3.0 policy is shown in Figure 6. This tab calculates the grid usage, solar export, self-consumption, and subsequently calculates bills before and after NEM 3.0 using Malaysian tariff prices. Then the financial aspects, which are monthly savings, payback period, and levelized cost of energy, are also computed. The results are presented in tabular form, and users are also able to generate a comprehensive PDF report.

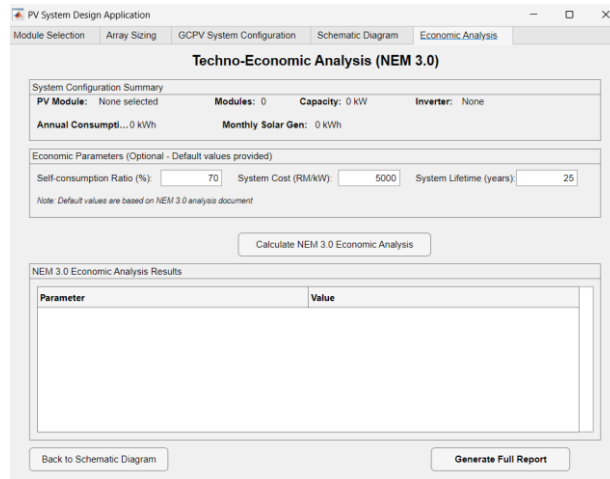


Fig. 6 Techno-Economic Analysis (NEM 3.0)

3. Results and Discussion

3.1 Results of MATLAB GUI

3.1.1 Tab 1: The recommended PV module

Figure 7 compares four photovoltaic (PV) modules based on power output and efficiency per unit surface area. The REC Alpha Pure-R module is 430 W of peak power but has the highest per square meter energy yield of approximately 851.38 W/m². This module thus maximises the available area among all the PV modules. On the other hand, the First Solar Series 6+, Sunrise Aquaman 72MHLPro, and LONGi LR5-72HBD possess greater maximum power ratings of 480 W, 545 W and 540 W, respectively. The power output per square meter of the modules is comparatively lower, around 700 to 740 W/m². This means a larger physical area must be used to produce the same amount of energy. Although temperature coefficients and degradation rates differ based on various modules, the most significant consideration in figuring out the most suitable module is the energy produced as compared to the space covered. Therefore, the REC Alpha Pure-R is advisable since it can produce the most energy per unit of space.

	Module	Pmax (W)	Coef (°C)	Degradation	f_temp_ave	Area (m ²)	Eout/Area
1	REC Alpha Pure-R	430.0000	-0.2400	0.9300	0.9328	1.9341	851.3825
2	First Solar Series 6+	480.0000	-0.3200	0.9200	0.9104	2.5199	704.2942
3	Sunrise Aquaman 72MHLPro	545.0000	-0.3480	0.8750	0.9026	2.5810	736.1557
4	LONGi LR5-72HBD	540.0000	-0.3400	0.8630	0.9048	2.5833	720.5482

Recommended PV Module: REC Alpha Pure-R with 851.38 W/m²

Fig. 7 Tab1 The recommended PV module

3.1.2 Tab 2: Dimensioning of PV array

Figure 8 shows the array sizing results provide a comprehensive summary of the allowable limit of photovoltaic (PV) modules under various design constraints. The highest limit is 60 modules for the architectural constraint, which is the maximum PV modules that can fit in the space available. Nonetheless, budgetary constraints set a budget limitation that restricts the system to a maximum of 13 modules, thereby making the project affordable. Secondly, the AC power limitation restricts the system to 12 modules to avoid overloading the inverter or other equipment on the AC side, thereby maintaining the electrical integrity of the system. However, the energy constraint imposes a minimum of 6 modules to be able to produce electricity that satisfies the estimated load or consumption requirement. Considering all these aspects, the number of photovoltaic modules ultimately selected is 6, following the minimum number imposed by the constraints. Choosing the smallest limiting factor guarantees that the system effectively addresses the energy needs within the constraints of available land, budget, or electrical availability. This method optimizes all the required factors, leading to an accurate and workable design of the photovoltaic system.

Array Sizing Results	
Architecture Constraint:	60 modules
Energy Constraint:	8 modules
Budget Constraint:	13 modules
AC Power Constraint:	12 modules
Final Number of Modules:	6

Fig. 8 Tab 2 Final number of PV modules

3.1.3 Tab 3: GCPV System sizing

Figure 9 explains the design of the PV array configuration, provides a detailed explanation of the arrangement relative to the chosen inverter, the SUN2000-2KTL-L1 with a 3000 W output rating. The specifications of the inverter establish important electrical limits, such as the maximum voltage, current, and power that can be input, which have a direct influence on the number of modules that can be arranged in series. The result indicates that the highest possible number of modules for series connection is nine, according to the limiting electrical specification. Conversely, the lowest number of series modules is three. The ideal number of modules connected in series has been discovered to be six, which strikes a balance that maintains voltage and current at safe and efficient levels. The inverter is equipped with two Maximum Power Point Trackers (MPPTs), which can monitor a single string of modules connected in series. In order to enhance energy harvesting and efficiency of the inverter operation, the six photovoltaic (PV) modules are split evenly between the two MPPTs. Hence, MPPT A controls one string consisting of three modules, and MPPT B regulates another string consisting of an additional three modules. This even distribution allows for effective energy harvesting, averts mismatch losses, and guarantees that the inverter operates within the provided electrical parameters.

Calculation Step	Result
Step 1(b): Selected Inverter	SUN2000-2KTL-L1 (3000 W)
Step 2: Max Modules in Series (min of N1, N2, N3)	9
Step 3: Min Modules in Series (max of N1, N2)	3
Step 4: Optimum Modules in Series	6
Step 5: Max Strings per MPPT	1
Step 6: Number of PV modules per MPPT	3

Final PV Array Configuration: MPPT A: 1 x 3 modules | MPPT B: 1 x 3 modules

Fig. 9 Tab 3 GCPV System sizing results

3.1.4 Tab 4: PV system Schematic Diagram

Figure 10 shows the configuration and schematic diagram of the GCPV system that was obtained from the previous tab. The system uses REC Alpha Pure-R photovoltaic (PV) modules with 6 modules installed. These modules are connected to two Maximum Power Point Tracking (MPPT) inputs of the inverter, which are MPPT A and MPPT B, each with 1 string of 3 modules. The inverter utilised in the system is a SUN2000-2KTL-L1, a common model in residential PV applications. The schematic diagram provides the graphical representation of the PV system layout, divided into DC and AC sides.

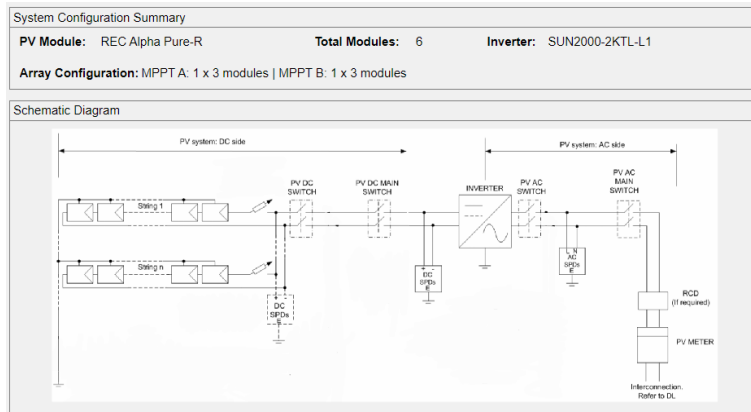


Fig. 10 Tab 4 GCPV System configuration summary

3.1.5 Tab 5: Techno-Economic results (NEM 3.0)

Figure 11 shows that the techno-economic outcomes of the GCPV system under the NEM 3.0 scheme are found to be efficient in both energy generation and cost saving. The system offers a monthly average output of 350.4 kWh, which is sufficient to fulfil a significant portion of the user's monthly average consumption of 383.6 kWh. Approximately 70% of the energy generated from the sun is directly utilized by the user, whereas 30% is fed back to the grid. When the energy exports are considered, grid net consumption becomes much lower at only 33.1 kWh, which effectively removes the dependency on external power sources. Economically, the system is able to attain substantial savings, decreasing the cost of monthly electricity from RM 112.46 to as low as RM 6.56, which is a monthly saving of RM 105.89 or around RM 1,270.73 annually. The upfront cost of the solar energy system is RM 12,900, and based on the current savings rate, the payback period would be approximately 10.2 years. Additionally, the system's levelized cost of energy (LCOE) is approximated to be RM 0.1227 per kilowatt-hour, which is a competitive tariff structure in relation to traditional electricity tariffs. Overall, this solar PV system is a cost-effective, eco-friendly solution that saves a significant amount of money on energy expenses and grid reliance, making it an asset in the long run.

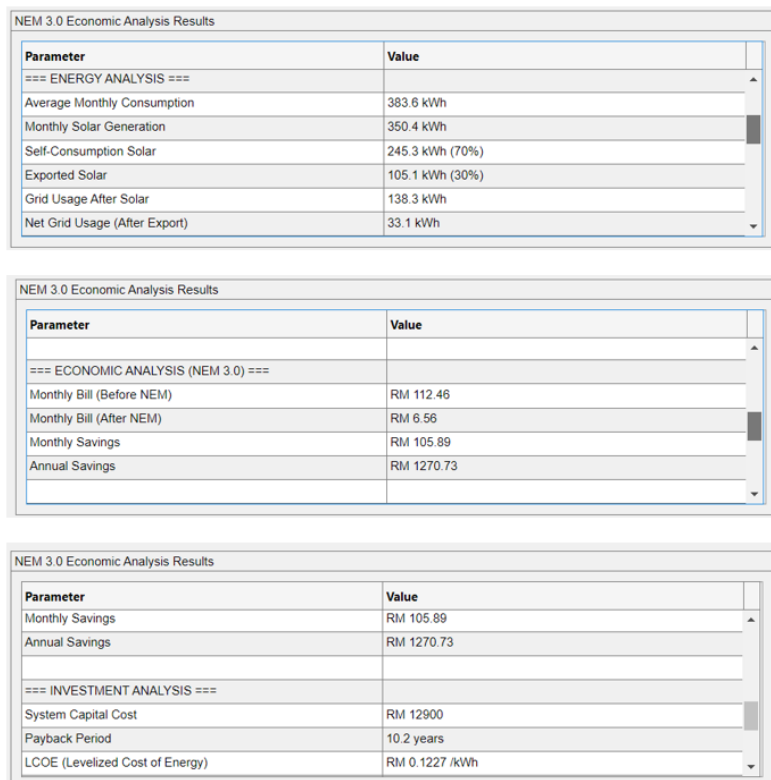


Fig. 11 Tab 5 Techno-Economic result (NEM 3.0)

4. Conclusion

In this project, a Graphical User Interface (GUI) for the sizing and techno-economic analysis of grid-connected photovoltaic (GCPV) systems was successfully created using MATLAB, exclusively for domestic applications. A number of constraints, such as available roof area, energy requirement, and budget limitations, are incorporated in a user-friendly interface consisting of five interactive tabs. The GUI navigates the users from the selection of PV modules to system design and financial analysis under Malaysia's NEM 3.0 policy. The output at the end provides comprehensive data on energy yield, system configuration, and economic parameters such as monthly savings, payback period, and levelized cost of energy (LCOE). The results show that the GUI provides an efficient and easy-to-use tool for homeowners to analyse and invest in solar energy systems despite the lack of technical expertise. The tool thus has high potential in helping the Malaysian renewable energy goal by enabling greater adoption of solar PV systems at the household level.

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Conflicts of Interest

The author declares no conflict of interest.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Nur Shafiqah binti Rusli and Ahmad Fateh bin Mohamad Nor; **data collection:** Nur Shafiqah binti Rusli; **analysis and interpretation of results:** Nur Shafiqah binti Rusli; **draft manuscript preparation:** Nur Shafiqah binti Rusli. All authors reviewed the results and approved the final version of the manuscript.

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