

Off-Grid Photovoltaic (OGPV) System Design for Residential House Using Glide Application

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Abstract: The challenge from NEM 3.0 after 10 years, the users are not allowed to receive electricity from the grid. The user will have to use the off-grid photovoltaic system known as SELCO because conventional sources of energy were decreased. The costing using conventional energy also was very expensive because extremely high global demand. As an initiative to reduce adverse effects on the environment and reduce costs, the consumer was encouraged to use solar energy and install solar PV. Therefore, the user needs to prepare the equipment which is several batteries, the cost, and the payback period after using the OGPV system or SELCO. This project focuses on the design of an off-grid photovoltaic system for residential houses using the Glide application. The aim is to provide information and requirements for installing OGPV systems or self-consumption (SELCO), considering the challenges presented by Malaysia's Net Energy Metering (NEM) Scheme and NEM 3.0. The project objectives include determining load requirements, designing system components (including solar PV, charger controller, inverter, and batteries), developing an automatic calculation system with the Glide application, and comparing the results with manual calculations. The research contributes to the advancement of renewable energy adoption and offers sustainable power solutions for residential buildings. The proposed system provides users with a user-friendly interface for obtaining necessary information and assisting in system design. In the research work, an automatic system was developed using the Glide application, allowing users to streamline the installation process for OGPV systems in residential houses. Then, the OGPV system design obtained through the Glide application was compared with the manual calculations to evaluate its effectiveness and efficiency. The knowledge gained from this project will contribute to future generations in the field of OGPV systems.

Keywords: NEM, SELCO, Solar PV, OGPV, Manual Calculation Method, Glide Application

1. Introduction

This project focuses more on an off-grid PV system because Malaysia has started introducing the Net Energy Metering (NEM) Scheme. NEM scheme stated that the energy produced from solar PV installation will be consumed first and any excess will be exported to TNB at prevailing displaced cost. Starting in Nov 2016, the government introduced NEM followed by NEM 2.0 (on 1st Jan 2019), and currently NEM 3.0 provide more opportunity for electricity consumers to install solar PV system the focus of their premises to save on electricity bill. Throughout this NEM 3.0, after 10 years the user that using the GCPV system in their residential house, the user needs to implement self-consumption (SELCO) which is OGPV [1]. The self-consumption known as SELCO applies when electricity is being generated for own usage residential house and any excess is not allowed to be exported to the grid. Therefore, the user of OGPV/SELCO needs an application that helps them to get some information and some requirements before installing solar PV. The solar power generated by the residential house will more effectively save energy and cost. Then, this project was created to provide information to users regarding OGPV/SELCO.

An OGPV is a photovoltaic system that is not connected to the utility grid [2]. Instead, the system is connected directly to the loads or a small distribution grid network. Then, DC power generated by photovoltaic modules is used to charge a battery bank via a charge controller. The DC power is later channeled to the inverter for conversion to AC power as required by AC loads. The function of a battery is a store electricity. The flow process of the OGPV system is shown in Figure 1 [3].

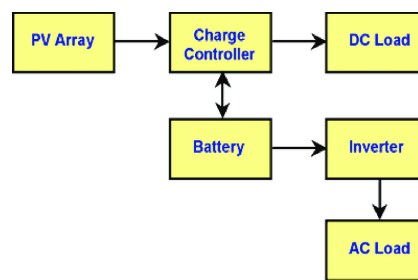


Figure 1: Flow Process of OGPV system

The scope of this project is to design the OGPV system for residential houses. A single-story house was chosen as a case study. Hence, this project is more focused on analyzing the design of the OGPV system in terms of the number of solar PV panels, type of solar charger controller, power rating of the inverter, the total battery in the OGPV system and payback period by using manual calculation and software which is the Glide application.

2. Materials and Methods

The project's methodology focuses on the development Off-Grid Photovoltaic (OGPV) system design for residential houses using mathematical calculation and glide application.

2.1 OGPV Design Using Mathematical Calculation

Mathematical calculation is used to determine the value of the system configuration and rate of each component involved. The calculation for the crucial and main components will be elaborated.

2.1.1 Calculation on Maximum Demand

The number of electrical equipment for the house has been determined as load and the data have been analyzed. Load usage electrical is calculated by using a mathematical equation (Eq.1) [4]:

$$\text{New Maximum Demand (NM}_D\text{)} = T_{MD} \times \text{Coincidence Factor} \quad \text{Eq.1}$$

2.1.1 Daily Energy Consumption

The calculation of energy usage depends on the type of energy source and the amount of energy consumed. To calculate monthly energy usage to daily energy usage, the monthly energy usage must be divided by the number of days in the month. The mathematical equation (Eq.2) is as follows [5].

$$\text{Daily Energy Consumption (Wh)} = \frac{\text{Average Energy Consumption (kWh)}}{30} \times 1000 \quad \text{Eq.2}$$

2.1.2 The Number of Solar PV Panel

The number of solar PV panels is important to determine based on the total power consumption of the system divided by the power rating of the solar PV panel. The mathematical equation (Eq.3) is as follows [4]

$$N_{PV} = \frac{P_{Total}}{P_{PVRate}} \quad \text{Eq.3}$$

2.1.3 Solar Charger Controller Rating

Rating of the solar charger is by multiplying the number of solar PV panels with the short circuit current (I_{SC}) of the selected solar PV panels. To obtain the rating current for the solar charger controller, the answer will be multiplied by $k=1.3$ by using the mathematical equation (Eq.4) as follow [4] :

$$I_{CC} = N_{PV} \times I_{SC} \times k_3 \quad \text{Eq.4}$$

2.1.4 Battery Rating

The battery rating is necessary in order to decide the type and number of batteries that will be used in the system. The equation is defined as Eq.4 to Eq.7 [4].

$$Wh = P_{total} \times RT_{hour} \quad \text{Eq.5}$$

where Wh is the watt-hour value of the battery, P_{Total} is the total load while RT_{hour} is the run time of the system.

The total of watt-hour value:

$$Wh_{Total} = \frac{Wh}{\eta} \quad \text{Eq.6}$$

where Wh_{Total} is the total watt-hour of the battery, Wh is the watt-hour value of the battery and η is the efficiency of the inverter which is considered as 85%.

The rate of ampere-hour of battery:

$$Ah = \frac{Wh}{V} \quad \text{Eq.7}$$

where Ah is the value for ampere-hour of the battery, Wh is the load power of the system and V is the voltage value of the battery.

2.1.5 Number of Battery

The total number of batteries can be calculated dividing the system backup time needed per hour by the battery backup time needed per hour, the formula for the equation (Eq.8 to Eq.9) as below [4]:

$$P_{Battery} = V \times Ah \quad \text{Eq.8}$$

where Wh is the power rate of battery, V is the voltage value of battery and Ah is the rating of battery in ampere-hour.

The number of battery can defined:

$$N_{Battery} = \frac{t_{backup_{system}}}{t_{backup}} \quad \text{Eq.9}$$

where $N_{Battery}$ is the number of battery, $t_{backup_{system}}$ is the backup time required for the system and t_{backup} is the backup time of battery.

2.1.5 Power Inverter Rating

The inverter is functions to convert direct current (DC) output to alternating current (AC). The rate of the power inverter can be defined as Eq. 10 to Eq.11 [4].

$$P_{Loss} = P_{Total_load} + 25\% \quad \text{Eq.10}$$

where P_{Loss} is the total losses of the power, P_{Total_load} is the total power load and 25% is considered the total load should be less than 25% of the inverter rating.

Power inverter rating can be rated:

$$P_{inverter} = P_{Total_load} + P_{Loss} \quad \text{Eq.11}$$

2.1.6 Cost Analysis

As a user's budget is an important to calculate budget of the requirements of the PV system. The calculation can be calculated by using the equation (from Eq.12 until Eq.16) [6].

- PV Panel price can be calculated:

$$Total\ PV\ Panel\ Price\ (RM) = Cost\ Per\ Panel(RM) \times Total\ Needed\ Panel \quad \text{Eq.12}$$

where *Total PV Panel Price (RM)* is the *Cost Per Panel in RM* multiply with *Total Needed Panel*

- Inverter price can be calculated:

$$Total\ Inverter\ Price\ (RM) = Inverter\ P_{OUTDC} \quad \text{Eq.13}$$

Where *Total Inverter Price (RM)* equal to inverter maximum DC Power

- Battery Price can be calculated:

$$Total\ Battery\ Price(RM) = Cost\ Per\ Battery(RM) \times Total\ Needed\ Battery \quad \text{Eq. 14}$$

Where *Total Battery Price(RM)* is the *Cost Per Battery(RM)* multiply with *Total Needed Battery*

- Installation Price

$$Total\ Labour\ Price = Labour\ Rate \quad \text{Eq. 15}$$

Wiring price can be calculated:

$$Total\ Wiring\ Price = \frac{\%}{100} \times \sum(PV\ panel + inverter + labour)price \quad \text{Eq.16}$$

Where, the percentage is set by 30% from the total price of solar PV panel, inverter and labour in this project.

- Maintenance Price

$$Total\ Maintenance\ Price = Annual\ Cleaning + Annual\ Inspection \quad \text{Eq.17}$$

- Total Overall Costing

$$Total = \sum(PV \text{ panel} + Inverter + Battery + Labour + Installation + Maintenance)price \quad Eq.18$$

where total overall costing is sum price of PV panel, inverter, battery, labour, Installation and maintenance.

2.1.7 Determine Total Payback Period

The payback period calculates after determine the cost of maintenance that user liable to pay before installed the solar module. The equation that used to calculate payback period have as follows (Eq.19) [34]:

$$Payback \text{ Period per year} = \left(\frac{Total \text{ Cost Analysis Price (RM)}}{Total \text{ Monthly Saving (RM)}} \right) \div 12 \text{ Month} \quad Eq.19$$

Where Payback Period per year is the *Total Cost Analysis Price (RM)* divided by *Total Monthly Saving (RM)* and divided by 12 month per year

2.1.8 Location of Observation

This project is focusing on a single-storey house at Jalan Seri Tanjung, Taman Seri Tanjung, Tanjung Kling, 76400, Melaka in Figure 2. It can maximise the use of solar energy using sunlight that provided 12 hours a day. The average of Sun Peak Hour (PSH) in Malaysia is 4 to 4.5kWh/m² per day in relation 1kW/m² [6].

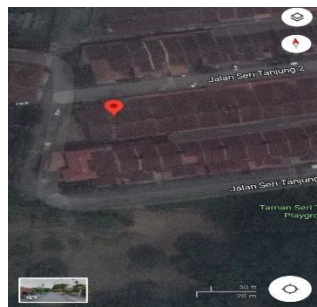


Figure 2 : Location of single storey house

2.1.9 Development of glide application

A glide application is a software designed for mobile phones and websites that can assist in creating user interfaces and improving team efficiency. It supports various functions related to the OGPV system, such as calculating monthly energy consumption, determining the number of PV panels, estimating OGPV system capacity, evaluating power losses, calculating battery capacity and inverter rating, estimating installation costs, and determining the total payback period.

The interface of Glide application was shown in Figure 3 using mobile phone and Figure 4 using website. The website link for this application can refer through this link <https://ogpv-system-for-resi-geh4.glide.page>.



Figure 3: Interface of Glide application using mobile phone

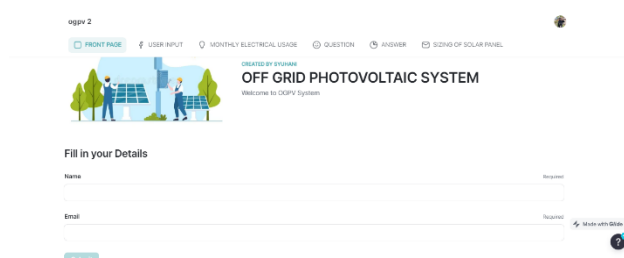


Figure 4: Interface of Glide application using website

(i) Calculation for Energy Consumption Tab

The monthly electrical usage tab comes next after user click Go button on the previous tab. The user must enter 3 months of energy consumption by refer TNB Bill in Figure 5.

Total Energy Consumption (kWh)	Daily Energy (Wh/Day)
1	

First Month (kWh)	<input type="text"/>
Second Month (kWh)	<input type="text"/>
Third Month (kWh)	<input type="text"/>

Figure 5: Interface for user input data for calculation energy consumption

(ii) Load Analysis 1 Tab

User needed to enter the quantity of load and it will continue to the next tab which is Load Analysis Tab 2 as shown in Figure 6.

FRONT PAGE	MONTHLY ELECTRICAL USAGE	Load Analysis 1	Load Analysis 2	Result Load Analysis	SOLAR PANEL	BAT
CFL CEILING MOUNTED LIGHT	<input type="text"/>					
AIR-CONDITIONER	<input type="text"/>					
CEILING FAN	<input type="text"/>					
SOCKET OUTLET (13A)	<input type="text"/>					

Figure 6 : Interface of load analysis 1 tab

(iii) Load Analysis 2 Tab

Figure 7 was displayed the power (W) and demand factor of each load that user used. This tab is important to generate the result of total maximum demand and New Maximum Demand (W) in next tab.

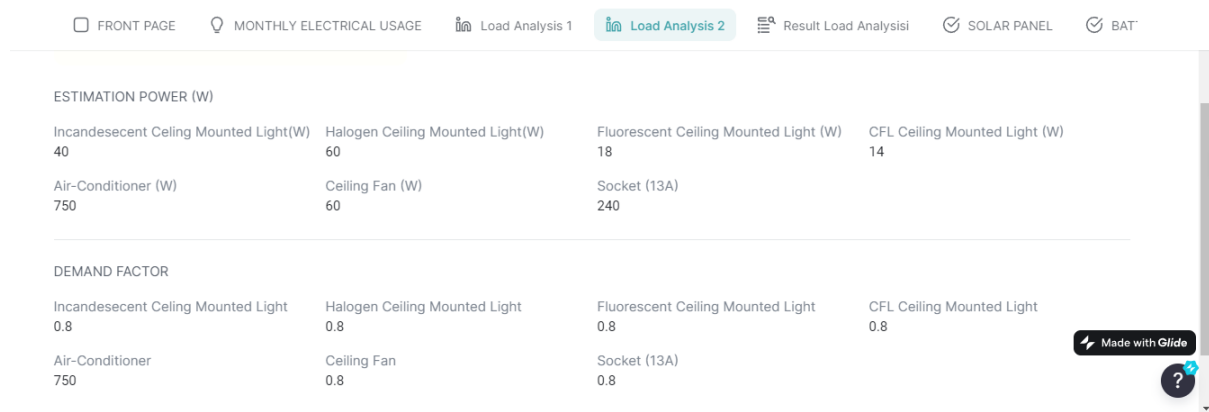


Figure 7 : Interface of load analysis 2 tab

(iv) Result load analysis tab

Figure 8 shows the result of load analysis tab is automatically generated after submit on previous page. This tab was displaying the total of connected load of each load that user enter before. In the above of this tab, it shown the total maximum demand and New Maximum Demand (W). It have been used to calculate battery sizing at the battery sizing tab.

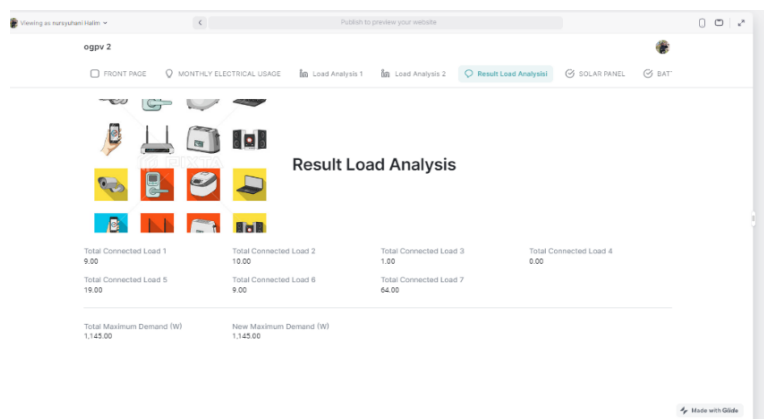


Figure 8 : Interface of result load analysis tab

(v) Sizing of OGPV System Tab

This tab is generated automatically and the user is not required to enter data in this tab. This tab is had relation with the monthly electrical usage tabs.

(vi) Solar PV Panel Tab

The solar PV panel tab in Figure 9 used to determine two types battery and cost for each solar panel.

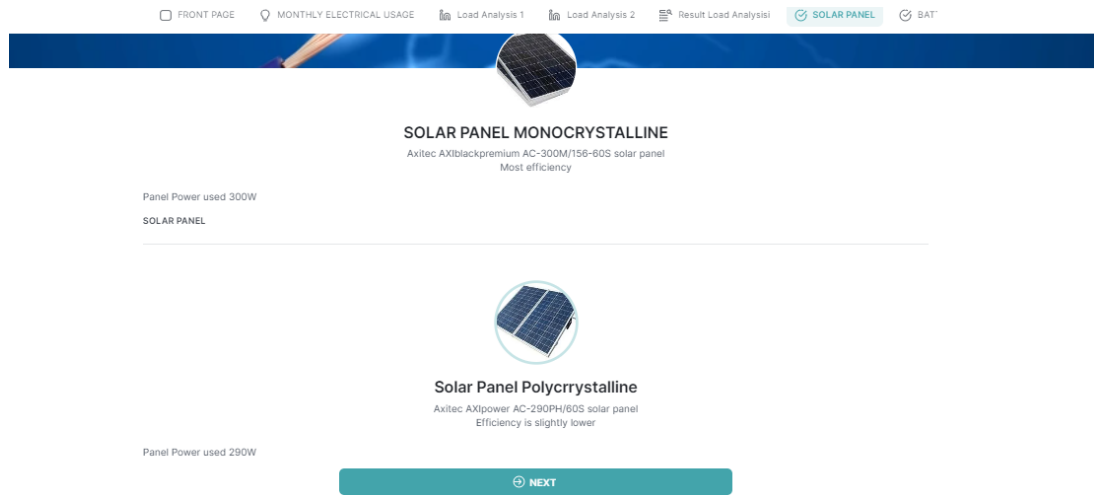


Figure 9 : Interface of solar PV panel tab

(vii) Battery Sizing Tab

The battery sizing tab in Figure 10 used two types of model battery that suggested to single storey house and cost for each battery.

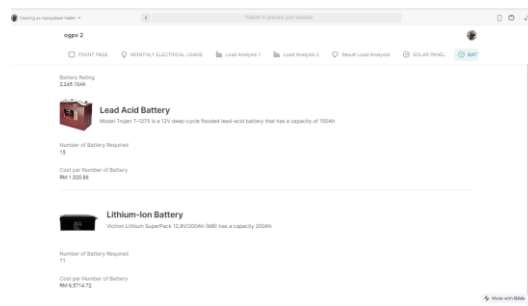


Figure 10: Interface of battery sizing tab

Figure 11 shows an interface of inverter sizing tab has included rating power inverter (kW) and costing for two types of inverters.



Figure 11: Interface of inverter sizing

(viii) Cost Analysis Tab

Several details costing that suitable for user used in OGPV system has been displayed in the Figure 12 and Figure 13 which are types of solar PV panel, battery, inverter and completely with the cost. This tab also has been provided the total costing OGPV system which are included components in OGPV system price (PV solar panel, battery and inverter), maintenance price, total overall costing and total payback period.

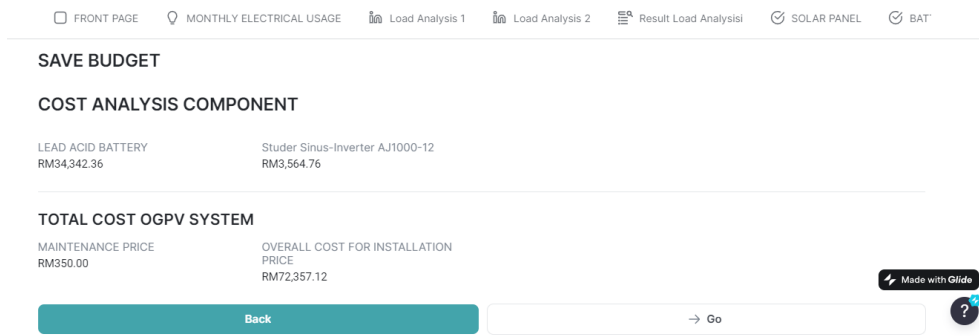


Figure 12: Interface of cost save budget analysis tab

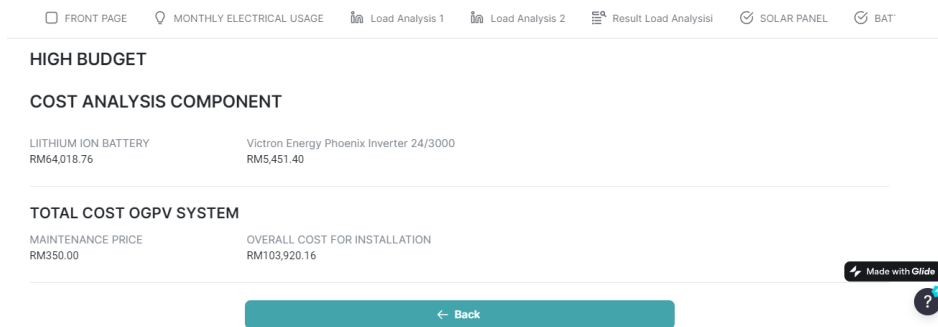


Figure 13: Interface of cost high budget tab

3. Results and Discussion

The section is presented into two subtopics which are the results obtained from the mathematical calculation and Glide application. The floor plan and the total load determination was determine using single storey house in Jalan Seri Tanjung, Taman Seri Tanjung, Tanjong Kling, Melaka. Furthermore, the comparison results of total energy consumption for monthly and daily using manual calculation method and glide application.

3.1 Floor Plan using AutoCad software

Figure 14 shows the floor plan for single storey house, there are a living room, three bedrooms, two bathrooms, one utility room, a kitchen area, a laundry room, a dining area, a working space and one circulation area.

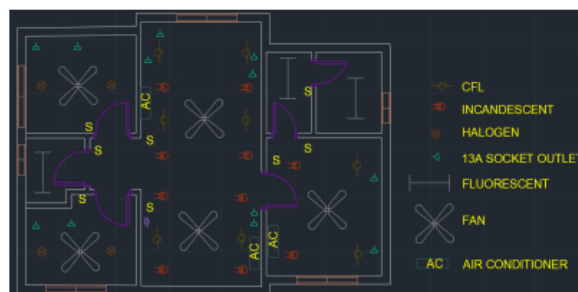


Figure 14: Floor plan for single storey house

3.2 Total Load Determination

Table 1 shows that total load determination is required to determine battery and inverter sizing.

Table 1: Load calculation for single storey house

Type of load	Qty	Watt (W)	Total Connected Load (W)	Demand factor	Maximum Demand (W)
Incandescent Ceiling Mounted Light (450 lumen)	10	40	400	0.8	320
Halogen Ceiling Mounted Light (800 lumen)	4	60	240	0.8	192
Fluorescent Ceiling Mounted Light (450 lumen)	3	18	54	0.8	43.2
CFL Ceiling Mounted Light (800 lumen)	8	14	112	0.8	89.6
Unit Air- Conditioner	3	750	2250	0.5	1125
Ceiling Fan	5	60	300	0.8	240
Socket Outlet (13A)	12	240	2880	0.8	1152
Total Maximum Demand (W)					4318.8
Coincidence Factor					0.9
New Maximum Demand (W)					3882.42

3.3 Comparison the monthly and daily total energy using manual calculation method and Glide application

The data of the system is obtained by using manual calculation and Glide application. The data is compared to obtain the difference value so that it is relevant to be implemented to the OGPV system shown in Table 2. The comparison calculation from manual method and glide application has obtained similar results. It is because each method was used the data directly from user.

Table 2: Table of comparison between manual calculation and Glide application

Manual Calculation Method	Comparison Subject	Glide Application
1969kWh	Month (kWh)	1969kWh
21877.78 Wh/day	Daily (Wh)	21877.78Wh/Day
4,318.8	Total Maximum Demand(W)	4,318.8
3,882.42	New Maximum Demand (W)	3,882.42

3.4 Comparison cost of component

The comparison of each component used in this system is shown in Table 3. The cost of each component is chosen based on the research and comparison done from previous studies. The comparison shows the difference type, model, the rating and difference cost using manual calculation

and glide application for each component. The calculation from glide application used for estimation and cause the costing have slightly differences from manual calculation.

Table 3: Differences cost using manual calculation and Glide application

Component	Type	Model	Rating	Differences cost using manual calculation and Glide application (RM)
Solar PV Panel	Polycrystalline	Axitec AXIpower AC-290PH/60S solar PV panel	290W	RM 196.88
	Monocrystalline	Axitec AXIblackpremium AC-300M/156-60S solar PV panel	300W	RM 185.80
Battery	Lead-Acid Battery	Trojan T-1275	12V, 150Ah	RM 618.69
	Lithium-Ion Battery	12V 150Ah Lithium ion Lifepo4 Rechargeable Battery	12V, 120Ah	RM 1153.82
Inverter	-	Studer Sinus-Inverter AJ1000-12	2.182kW	-
		Victron Energy Phoenix Inverter 24/3000	2.182kW	-

3.5 Comparison the error percentage (%)

The comparison of error percentage (%) the total overall costing for save and high budget was determined different values of both manual calculation and Glide application as shown in Table 4. The result of error percentage affected the decimal point of total cost number solar PV panel battery and total cost of batteries. An error percentage (%) from high budget was higher than save budget because the calculation of high budget more different values.

Table 4: Comparison of error percentage (%)

Save Budget	Total Overall Costing	High Budget	Total Overall Costing
Manual Calculation	RM 52,967.48	Manual Calculation	RM 82,395.16
Glide Application	RM 40,395.52	Glide Application	RM 54,990.18
Error Percentage (%)	23.74%	Error Percentage (%)	33.27%

3. Conclusion

In conclusion, this paper has been provided the effectiveness of the automatic calculation system, comparison and analysis were conducted between the OGPV system designs generated by the Glide application and the manual calculations. Moreover, the development of the automatic calculation systems using the Glide application offers a convenient and time-saving alternative for designing OGPV systems, potentially benefiting both homeowners and solar energy professionals.

Even though this project was a success, a few changes of suggestion could be made for the future. The following are suggestions for future work that can be improved:

- i. Use more monthly TNB Bill for calculate energy consumption.
- ii. Specification on types each of load that needs to be inserted by user in the Glide application.
- iii. Adding more types of models for solar PV panel, battery and inverter.

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