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Development of an Off-Grid Photovoltaic (OGPV) System for Residential House Educational Kit

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Abstract: Nowadays, students are not interested in STEM because they feel it is too difficult for them to understand it. One of the science syllabuses for primary and secondary school is the solar PV system. The student will face a problem in understanding how the solar PV system produces electricity without a hardware model. Thus, with the help of this project, people especially students can understand the solar PV system well and in addition can attract the student's interest in STEM. This project aims to design and develop an educational kit of off-grid connected photovoltaic (OGPV) systems for residential houses. In this project, the total connected load, the maximum demand, and the maximum current for the residential house prototype model were determined before developing the complete educational kit model. Finally, the performance of the educational kit OGPV system for residential houses was evaluated. With the help of this project, the educator can easily deliver the content about the OGPV system effectively. This project also helps the students improve their understanding of this OGPV system.

Keywords: PV System, OGPV, Educational Kit

1. Introduction

Photovoltaic technology power generation has been widely implemented in recent years as one of the most promising energy-harvesting alternatives. The direct conversion of sunlight to electricity makes photovoltaic technology an increasingly attractive option for power generation. Photovoltaic technology used in energy conversion is one of the most prominent and appealing energy source generating methods, with proven reliability ranging from microwatt to megawatt. Due to their output's shown dependability, photovoltaic systems are used in many applications that call for low to high-voltage supplies [1].

The development of renewable energy sources is becoming increasingly important in today's world. As for the past recent years, energy has arisen as a worldwide problem. The demands of individuals and businesses are now met by 80% of conventional energy used and the demand is expected to grow by

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1.5% annually through 2030 [2]. The oil and gas resources are expected to run out one day, so renewable energy is one of the suitable energies to replace it. One of the renewable energies that can used is solar energy [2]. Off-grid photovoltaic (OGPV) systems are one of the most promising technologies in this field, as they can generate electricity in remote and rural locations, where access to the electric grid is limited or non-existent.

The development of a prototype OGPV system for a residential house educational kit would require a comprehensive understanding of the components and processes involved in the installation and operation of an off-grid system. This would include the selection of appropriate components such as solar PV modules, batteries, inverters, and charge controllers. In addition, a detailed design of the system, including the wiring and the control systems, would need to be developed. The efficient operation of the system would depend on the proper installation of the system components and careful consideration of the local environment.

The development of a prototype OGPV system for a residential house educational kit would be a challenging but rewarding project. It would provide an opportunity for students to gain experience with PV off-grid technology and to understand its potential as a viable energy source. Through this project, students would gain valuable knowledge and experience and would be better prepared to make informed decisions about the use of OGPV systems technology in their own homes.

2. Materials and Methods

2.1 Project methodology

This project was divided into several stages to make sure the project's flow was more organized and manageable to keep the project on track. Figure 1 shows the flowchart of the project. This flowchart helps to guide and complete the project smoothly. This project involves a literature review, designing, calculation, development, and evaluation process to complete the project.

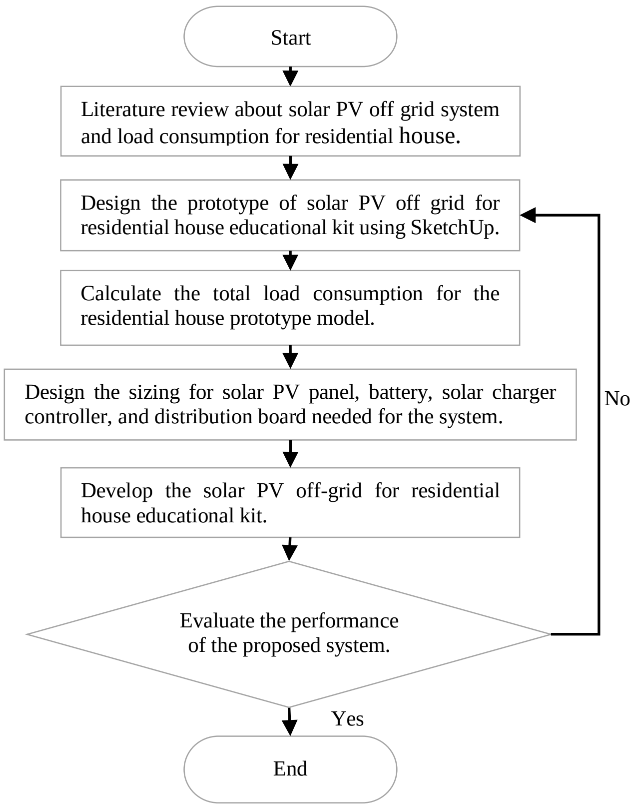

Figure 1: Flowchart of this study

The project started with a literature review about the OGPV system and the load consumption for the residential. The first step helps to study and analyze case studies as guidance for the project. The next step is to design the prototype of OGPV for a residential house educational kit using Sketch Up. It will briefly show how the design will be. After that, a calculation of the total load consumption for the residential house prototype model was performed to determine the value for all the components involved in this project. Lastly, the project will be developed, and the performance of the project will be evaluated.

2.2 Components involved in OGPV design system

All the components used need to be considered carefully based on their characteristics that are suitable for the project. The components are solar PV module [3], inverter [4], battery [5], and solar charger controller [6].

Table 1: Components used for the project

Component	Type
Solar PV Module	Polycrystalline PV Module
Inverter	String Inverter
Battery	Lead Acid Battery
Solar Charger Controller	Pulse Width Modulation (PWM)

2.2.1 Function of the component in the system.

The function of solar PV modules is to convert sunlight directly into direct current (DC) electricity. While inverter is used to convert the direct current (DC) electricity generated from solar panels into alternating current (AC) electricity. Besides that, the battery used in this system is to store energy produced by the solar PV module. Lastly, a solar charger controller is used to regulate the voltage and current going from the solar panels to the battery so that the battery does not become overcharged.

2.3 Total load determination

The estimation of the load consumption for the OGPV system educational kit is required to produce the total power output of the system. The equation is as follows [7]:

$$T_{CL} = n \times p \quad \text{Eq.1}$$

$$M_{DL} = Demand\ factor \times T_{CL} \quad \text{Eq.2}$$

$$T_{MD} = M_{D1} + M_{D2} + M_{D3} + \cdots \quad \text{Eq.3}$$

$$N_{MD} = T_{MD} \times Coincidence\ factor \quad \text{Eq.4}$$

Where:

T_{CL} : $Total\ connected\ load$

n : $Quantity\ appliances$

p : $Power$

M_{DL} : $Maximum\ demand\ of\ each\ load$

T_{MD} : $Total\ maximum\ demand$

N_{MD} : $New\ maximum\ demand$

2.4 Determine the number of solar panels

The number of solar panels used is determined based on the total power consumption of the system divided by the power rating of the solar panel. The mathematical equation is as follows [8]:

$$N_{PV} = \frac{P_{Total}}{P_{PV_{Rate}}} \quad \text{Eq.5}$$

Where:

N_{PV} : $Number\ of\ Solar\ Panel$

P_{Total} : $Total\ of\ Power\ Consumption$

$P_{PV_{Rate}}$: $Power\ Rate\ of\ Solar\ Panel$

2.5 Determine solar charger controller rating

The solar charger controller can be rated by multiplying the number of solar panels with the short circuit current of the selected solar panels. Then, it will multiply with the safety factor considering loss which commonly used 1.3 to obtain the rated current for the solar charge controller. The mathematical equation is as follow [8]:

$$I_{CC} = (N_{PV} \times I_{SC} \times k_3) \quad \text{Eq.6}$$

Where:

I_{CC} : $Current\ rating\ for\ solar\ charge\ controller\ (A)$

I_{SC} : $Short\ circuit\ current\ of\ PV\ panel$

k_3 : $Safety\ factor\ considering\ loss$

2.6 Determine battery rating

To determine the battery rating of ampere-hour, the runtime of the system for a day will be determined to obtain the total power used per day. The total load is multiplied by the runtime of the system per day to obtain the watt-hour of the system per day. As the efficiency of the inverter is considered 85%, the watt-hour is multiplied by the obtained efficiency of the inverter to get the total watt-hour for a day. Since the power is equal to the current multiplied with voltage and then divided by watt-hour, the ampere-hour will be obtained to show how much ampere-hour is stored in a battery. The mathematical equation is as follow [18]:

$$Wh = P_{Total} \times RT_{hour} \quad \text{Eq.7}$$

$$Wh_{Total} = \frac{Wh}{\eta} \quad \text{Eq.8}$$

$$Ah = \frac{Wh}{V} \quad \text{Eq.9}$$

Where:

Wh : $Watt\text{-}hour$

P_{Total} : $Total\ load\ (W)$

RT_{hour} : $Run\ time\ of\ the\ system\ (hour)$

Wh_{Total} : $Total\ Watt\text{-}hour$

η : $Efficiency\ of\ the\ inverter\ is\ considered\ as$ 85%

V : $Voltage\ of\ the\ battery$

2.7 Determine power inverter rating

The total load should be less than 25% of the inverter rating. This is due to the losses and value of the load. To determine the value of total losses of the system, total load in value of Watt is multiplied by 25%. Hence, the total inverter rating can be obtained by summing up the total load with total losses of the system. The mathematical equation is as follows [8]:

$$P_{Loss} = P_{Total\_load} \times 25\% \quad \text{Eq.10}$$

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

Where:

P_{Loss} : $Total\ losses\ (W)$

P_{Total_load} : $Total\ load\ (W)$

$P_{inverter}$: $Total\ inverter\ rating\ (W)$

2.8 Components used for the project

All the components were determined by using the formula stated in 2.4 to 2.7. Table 2 shows the list of each component and the specifications used for the project.

Table 2: Components of the project

Components	Detail
DC MCB	6A, 12V
AC MCB	6A, 240V/415V
Solar PV Panel	30W, 12V/18V, Polycrystalline
Battery	7Ah, 12V, Lead Acid Battery
Solar Charger Controller	10A, 12V/24V, PWM
Inverter	20W, DC 12V to AC 220V

3. Results and Discussion

3.1 Single line diagram

A single-line diagram is a simplified representation of an electrical system. It shows the circuit flow in the project. This project, is divided into two parts which are outside the house and inside the house. Outside the house, it consists of a solar PV panel, solar charger controller, battery, inverter, distribution board, and switch. Inside the house, it consists of an AC lamp, a DC lamp, and DC fan. The current flow starts from the solar PV panel to the solar charger controller to regulate. After that, it will go through the battery and to the DC load. Then the current will flow through the inverter to convert direct current to alternating current. After that, it will go through the AC load.

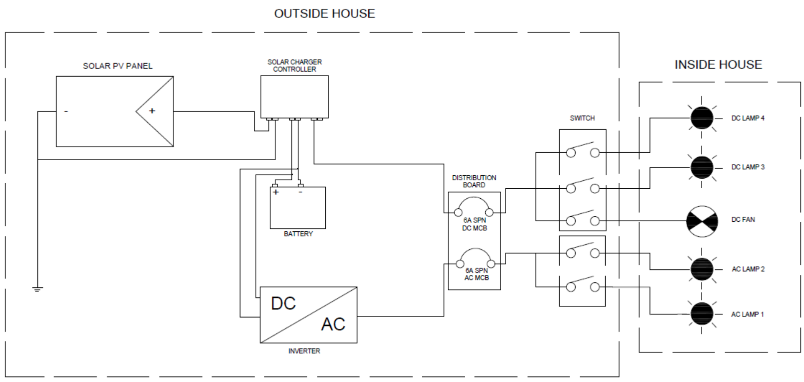

Figure 2: Single line diagram

3.2 Total load determination

Total load determination is one of the important information needed to design a suitable solar OGPV system for the project. Total load determination has been calculated in Table 3:

Table 3: Total load determination

No.	Description	Quantity	Load power (W)	Total Connected Load (W)	Demand Factor	Maximum Demand (W)
1	LED Lamp	4	5	20	0.8	16
2	Fan	1	5	5	0.8	4
				Total Maximum Demand		20 W
				Coincidence Factor		0.9
				New Maximum Demand		18 W

3.3 Hardware prototype

The prototype of the system has been done successfully and it also functioning well. Figure 3 and Figure 4 show the prototype view from the front and the top.

Figure 3: Front view of the prototype

Figure 4: Top view of the prototype

3.4 Evaluation of the prototype performance from solar to battery

Table 4 shows the results of voltage, current, and power flow from solar to battery from 7.00 a.m. until 6.00 p.m. It shows that the highest voltage flow is 13.0V from 11.00 a.m. until 3.00 p.m. While the highest current flow from solar to battery is at noon. Usually, during that time, the irradiance of the sun is higher than the other time. The power, is got from the multiplication of voltage flow and current flow.

Table 2: Voltage, current, and power flow from solar to battery

Time	Voltage (V)	Current (A)	Power (W)
7.00 am	12.5	0.174	2.175
8.00 am	12.6	0.195	2.457
9.00 am	12.8	0.224	2.867
10.00 am	12.9	0.398	5.134
11.00 am	13.0	0.442	5.746
12.00 pm	13.0	0.445	5.785
1.00 pm	13.0	0.443	5.759
2.00 pm	13.0	0.442	5.746
3.00 pm	13.0	0.442	5.746
4.00 pm	12.9	0.395	5.096
5.00 pm	12.9	0.395	5.096
6.00 pm	12.8	0.225	2.880

4. Conclusion

In conclusion, the total connected load, the maximum demand, and the maximum current for the residential house prototype model have been determined in this project by calculating using mathematical equations. To determine the rating of MCB, the total connected load, the maximum demand, and the maximum current need to be determined first to get the suitable sizing MCB for the system. Besides that, the educational kit of the OGPV system for residential houses has been developed. The prototype consists of a solar PV panel, lead-acid battery, inverter, solar charger controller, AC and DC MCB, switch, AC and DC lamps, and DC fan. This. In addition, the performance of the educational kit OGPV system for residential houses has been evaluated. This project can help the educator deliver the content about the OGPV system more effectively and easily. This project also helps the students improve their understanding of this OGPV system.

In future research, it is recommended to use more durable and long-lasting material with water-resisting ability to preserve its longevity. Other than that, adding the LCD screen to monitor the voltage, current flow, and power consumption in the system would also help to monitor the performance of the prototype. Lastly, use the bigger power of the solar PV panel so the system can last longer.

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