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Design and Feasibility Study of a Standalone Photovoltaic System for Electrifying a Healthcare Centre in a Rural Area of Malaysia: A Case Study

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ABSTRACT

Malaysia is strategically located at the sunbelt viability, where it receives a large amount of sunshine every day. This makes the solar photovoltaic technology popularly utilized particularly in rural areas that are isolated from the main grid. These areas have the potential to use photovoltaic technology to meet load requirements. Compared to grid connected photovoltaic systems, standalone photovoltaic systems offer several benefits to system owners including low maintenance, low upkeep cost, no waste or by-products, and easy expansion through the use of multiple solar panels and batteries. This article presents a design phase of the Standalone Photovoltaic System (SAPVS) to electrify the healthcare centre in Kampung Tewowoh, Kluang, Johor. The design steps for SAPVS are discussed to obtain the required parameter for each component in the SAPVS. The results indicate that 16 panels, 1219.52Ah/day, 1437.5A and 350 (A) are needed for the PV panels, battery capacity, inverter, and charge controller, respectively. It is proven that SAPVs are technically viable and feasible for electrifying the healthcare centre in the specified area.

Keywords: Standalone photovoltaic system; healthcare centre; solar; technical design; solar panel

INTRODUCTION

Healthcare centres are important facilities especially in the rural area where it generally functions to provide an early detection of chronic disease thus will help to reduce the complications and perform the continuous healthcare monitoring. In this condition, the healthcare centre is needing the smart and efficient energy supply that would be able to cater their load. In rural areas where they have the problems to get the energy supply from the grid, the support from renewable energy such as solar and wind technology seems to be more effective and less costly as well as environment friendly. Access to reliable and uninterrupted electricity is essential for any healthcare facility to provide adequate medical services. However, many healthcare centres in remote and underdeveloped regions face challenges in obtaining a reliable and affordable source of electricity. The lack of access to reliable electricity can have severe consequences on the quality of healthcare services, patient care, and the overall health outcomes of the community.

LITERATURE REVIEW

Standalone photovoltaic (PV) systems offer an excellent solution to overcome the challenges of providing reliable electricity to healthcare centres in remote and underdeveloped regions. Stand Alone PV systems use solar panels to convert sunlight into electricity, which can be used to power medical equipment, lighting, and other essential electrical appliances. The design of a standalone

PV system is critical in ensuring the system's reliability, efficiency, and cost-effectiveness. A well-designed standalone PV system must meet the specific energy needs of the intended application, such as residential, commercial, or industrial use.

The design of a standalone PV system typically involves the following components, PV panel, battery, inverter, and charge controller as well as the AC and DC loads whereas its topology is presented in Figure 1. The design of a standalone PV system requires careful consideration of several factors, including the energy requirements of the intended application, the amount of sunlight available at the installation site, the climate, and environmental conditions. A well-designed standalone PV system can provide reliable and sustainable electricity for many years, contributing to economic development and social well-being in remote and underdeveloped regions.

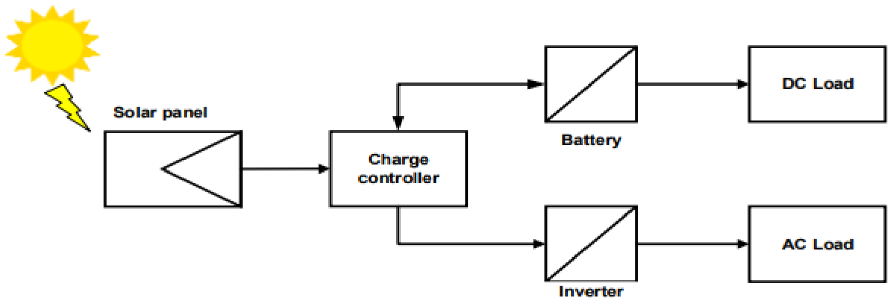

FIGURE 1. General block diagram of standalone photovoltaic system

Several works on standalone photovoltaic system (SAPVs) installation in rural areas have been done in various locations that can benefit the communities. As an example, a standalone photovoltaic system installed for a house in a rural area of Pakistan has been presented. The designed system consists of a 5.8kW PV with eight batteries of 12 V, 255 Ah, and a 1.4 kW inverter. The system analyses show that such system can support mainly lighting and appliances load in a rural house (Iqbal & Iqbal 2019)

Alwaeli & Mahdi (2017) discussed a work of standalone photovoltaic system implementation in a village in Sipitang, Sabah, Malaysia. The system consists of 4 parallel PV panels with 1-unit inverter, 1 charge controller and 2 batteries. The cost analysis for the developed system has an initial cost of 2,458 USD and a capital cost of 5,171.2 USD. Meanwhile Odeh & Ibrik (2022) discussed a standalone PV system that was installed in a remote village in Palestine where the SAPV size is 4.8kW to cater the village's load. Irwan et al., 2015 discussed SAPV systems that have been installed to support the 14 LED bulbs with rating power of 18W. They design and calculate the peak power of load is determined by 252W for the hour used and the average estimation of daily energy assumed to be 2.016kWh/day.

Moreover, Kamali (2016) studied the design of a standalone photovoltaic system to electrify a house in the rural fringe of Famagusta, Cyprus. In their work, the designed system has the capability to cover residents' electricity demand (17.23 (kW h/day)) during the winter (with the lowest solar irradiation). Utilizing a mathematical model, the PV panels area, PV peak power, the battery capacity, inverter, and charge controller sizes were determined to be 46.73 (m2), 7.5 (kW), 44.78 (kW h), 2 (kW) and 350 (A) respectively.

Normazlina et al. (2018) discussed a design phase of the SAPVs to electrify the educational building in Politeknik Merlimau Melaka. In their work, the design started with the determination of SAP components before it proceeded to the design calculation. Hassan et al., (2016) has considered the direct current (DC) appliances and alternative current (AC) appliances to design their SAPVs system whereas the average daily load requirement is 31.5 kWh/day. Thus, they prefer to use the SAPV with the support of a battery as an energy storage. Although the SAPV is considered as a simple power generation that is able to feed the load demand, it still needs to be designed appropriately to generate enough power throughout the year and have enough battery capacity to meet the requirements. Hence, this article is intended to draw up the step-by-step design process for a SAPV to full-fill the requirement of a healthcare centre in Kampung Tewowoh, Kluang, Johor.

METHODOLOGY

The proposed standalone photovoltaic system to power up the healthcare centre in Kampung Tewowoh is consist of the electrical loads, PV panels, batteries, inverters, and balance of system components. A step to design the SAPV system is illustrated in Figure 2 while the elaboration of each step is explained in further sections.

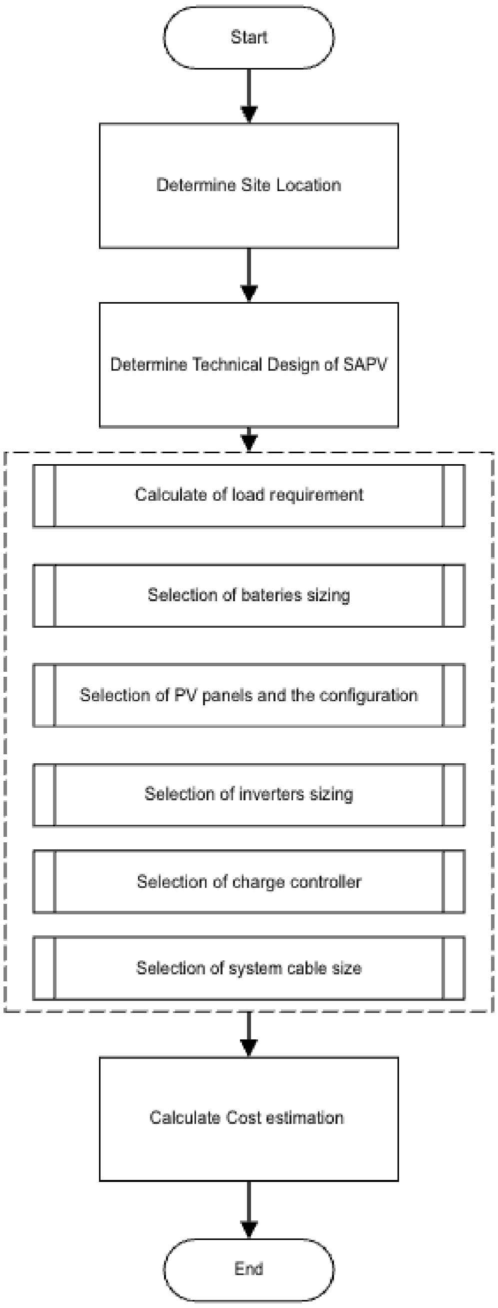

FIGURE 2. Overview of methodology

DETERMINE SITE LOCATION

Kampung Tewowoh is located at the 2.03o N latitude and 103.3168o E longitude which shown in Figure 3, is recognized location to has the potential ambient temperature as well as the wind resources which also contributed to the generating reliable PV power.

FIGURE 3. Location of Kampung Tewowoh, Kluang, Johor

At this location, the solar radiation pattern is estimated to be as shown in Figure 4, where it can reach up to 4212 wh/m2/

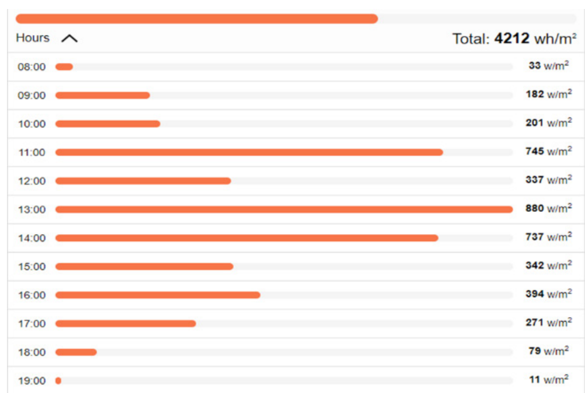

FIGURE 4. Solar radiation pattern at the location site

CALCULATION OF LOAD REQUIREMENT

The process started with the determination of the loads. In this study, only the electrical loads are considered. There are two types of load considered, DC load and AC load shown in Table 1.

TABLE 1. Electrical loads for healthcare

No	Load	Qty	Voltage, VL(V)	Current IL(A)
1	Lighting (4ft)	2	12Vdc	480mA
2	Lighting (2ft)	2	12Vdc	240mA
3	Sterilization machine	1	230	7.5
4	Oxygen Tank (nebulizer)	1	230	7.5
5	Air conditioner (1 HP)	1	12	8.61
6	Laptop charger	1	230	7.5
7	USB Phone Charger	3	5	0.5

Furthermore, the equations in (1) and (2) are used to obtain the load's characteristics.

$$Pac = Qty \times VL \times IL \quad (1)$$

$$Eac\ Wh\ per\ day = Pac \times hr/day \times day/\ 7\ \text{day} \quad (2)$$

As the results, the value of Pac and Eac were tabulated in Table 2. The value Eac is calculated for 8 hours in 5 days per week due to assumption that the mobile clinic is operating in those days to full fill the community health requirement.

TABLE 2. Electrical loads characteristics

No	Load	Qty	AC load power, Pac (W)	AC load, Eac (Wh)
1	Lighting (4ft)	2	20	114.3
2	Lighting (2ft)	2	10	57.1
3	Sterilization machine	1	6	34.3
4	Oxygen Tank (nebulizer)	1	138	788.3
5	Air conditioner (1 HP)	1	824	4708.6
6	Laptop charger	1	150	857.1
7	USB Phone Charger	3	7.5	42.8

SELECTION SIZING OF BATTERIES

In a standalone photovoltaic system, the battery's sizing is important as to compensate for the daily variations and fluctuations in solar radiation. Irwan et al., (2015) have listed several criteria of battery to be considered in selecting and designing the batteries capacity for the standalone photovoltaic system. The criteria are including normal voltage, self-discharge, coulombic efficiency, battery capacity and day of autonomy. In this project, the calculation is focused on the day of autonomy for a battery. Days of autonomy means the period that the system is not dependant on energy generated by a PV module due to no sunshine in a day. Regarding this, the design should consider the sun peak hours of the site location. A peak sun hour is defined as one hour in which the intensity of solar irradiance (sunlight)n reaches an average of 1,000 watts of energy per square meter. In this case, the peak hours of sun per day for the given location of Kampung Tewowoh, Kluang, Johor is assumed to be 4.53 kWh/m2/day.

Equation (3) and (4) is used to calculate the battery capacity and total capacity of the battery, respectively. The number of batteries needed for parallel wiring is calculated using Equation (5) as well as the series wiring is calculated using Equation (6). The total number of batteries needed in this project is calculated using Equation (7).

$$C_{ave}\ \frac{Ah}{day} = \left(\frac{E_{ac}}{\eta_{dc}} + E_{dc}\right) \div V_{dc} \tag{3}$$

$$C_{bat_{tot}} = \frac{C_{ave}\frac{Ah}{day} \times F_a}{B_{DOD}} \tag{4}$$

$$N_{bat\_p} = \frac{C_{bat_{tot}}}{C_{ave}} \tag{5}$$

$$N_{bat\_s} = \frac{V_{DC}}{V_{bat}} \tag{6}$$

$$AN_{bat\_tot} = N_{bat\_p} \times N_{bat\_s} \tag{7}$$

From the calculation, the result has been tabulated in Table 3.

TABLE 3. Battery sizing characteristics

C_{ave}	C_{battot}	Number of Battery (Unit)		
		N_{bat_p}	N_{bat_s}	AN_{bat_tot}
152.44 Ah/day	1219.52 Ah	4	4	16

A battery with 305Ah has been selected where the battery model selected for this project is lead acid battery type brand Rolls Battery with model number 6FS305-HC. Moreover, the specifications of the battery designed for this project is tabulated in Table 4 and the configuration of the needed batteries is illustrated in Figure 5.

TABLE 4. Batteries specifications

Item	Values
Average AC daily load, E_{ac}	6431.1 Wh
DC loads. E_{dc}	171.4 Wh
DC system voltage, V_{dc}	48V
Days of autonomy, F_a	4 days
Battery discharge limit, BDOD	50%
Temperature for battery storage	25OC
Battery voltage, V_{bat}	12V

Based on Table 4, the batteries configuration has been designed which is 4 units of batteries in series wiring and 4 units of batteries in parallel wiring. So, the total number of batteries needed is 16 unit of batteries.

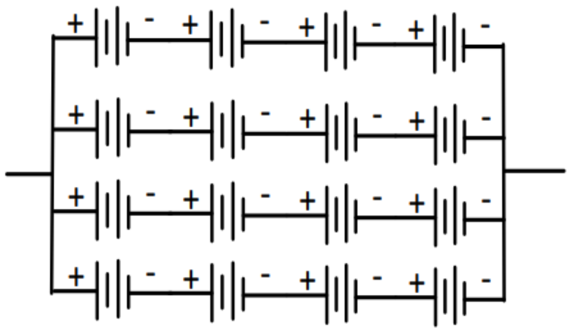

FIGURE 5. Batteries configuration

SELECTION OF PV PANELS SIZE AND THE CONFIGURATIONS

The PV panels are constructed from the number of cells and turn up to the modules. Cells of the PV are made from the semiconductor material which converts the energy of photons that received from sunlight into a direct current (DC) electricity. There are various types of PV cells which depend on the material and intended applications. Normally, crystalline and amorphous silicon materials are widely used in PV technology (Alwaeli & Mahdi, 2017). The calculation of array sizing considers the current of the PV array where the Equation (8) to (10) is used to calculate the PV array size, number of panels in parallel and number of panels in series, respectively. Finally, the total required panels needed is $Npvp \times Npvs = 4 \times 4 = 16$ panels.

$$I_{PV\_tot} = \frac{C_{ave} Ah/day}{\eta_{bat} \times t_{sun} {}^{h}/_{day}} \quad (8)$$

$$\text{No. of panels in parallel, } N_{pv-p} = \frac{I_{PV\_tot}}{I_{PV}} \quad (9)$$

$$\text{No. of panels in series, } N_{pv\_s} = \frac{V_{oc}}{V_{PV}} \quad (10)$$

From the calculation, the result has been tabulated in Table 5.

TABLE 5. PV panels size and the configurations

$I_{PV\_}tot$	I_{PV}	$Npv\text{–}p$	Npv_s
152.44 Ah/ day	1219.52 Ah	**4 unit** of batteries	**4** unit of batteries

The specification of the PV panel is listed in Table 6.

TABLE 6. PV panels specification

	Parameter	Value
1	Maximum Power, P_{max}	240W
2	Maximum power point voltage, V_{mp}	$18.24V_{DC}$
3	Maximum power point current, Imp	13.16A
4	Open short voltage, V_{oc}	21.8V
5	Short circuit current, I_{SC}	13.95A
6	Nominal voltage, V_{PV}	12V
7	Dimensions	1530 x 760 x35 mm

SELECTION OF THE CHARGE CONTROLLER

Charge controller in the SAPV is the device that function to limit the rate at which the electric current is added to or drawn from electric batteries to protect against the electrical overload, overcharging and overvoltage. This will prevent conditions that reduce battery performance and lifespan as to ensure the safety risk. In a simple charge controller design, it will stop charging the battery when they exceed a set high voltage level and reenable charging process when the battery voltage drops back below that level. There are two types of technology used in charge controller namely Pulse Width Modulation (PWM) charge controller and Maximum power Point Tracker (MPPT) where both types able to adjusting the charging rates depending on the battery's level to allow charging closer to its maximum capacity. In this project, the charge controller type of MPPT has been selected where the detail in the Table 7.

TABLE 7. Specification of charge controller type of MPPT

Item	Values
Array short circuit current, $I_{SCarray}$	69.75 V
Array open circuit voltage, $V_{OCarray}$	$\mathbf{87.2V}$
type of charge controller selected is Tracer 8415AN (50A-1WA) series with **Irated**	80A

SIZING OF INVERTERS

Inverter is a power electronic device that functions to convert the DC to AC currents that will be used in AC load or supply back to the grid. The sizing of the inverter, in a first place, needs to consider the actual power used by the appliances that will run at the same time during the generation process. The design of the inverter must contemplate the following characteristics:

1. AC load power is a total AC load to be applied.
2. AC projected surge power
3. AC output voltage which allows to choose and provide $120V_{AC}$, $208V_{AC}$ or $240V_{AC}$
4. Frequency should match 60/60 Hz

Table 6 shows the total power of the appliances for this project.

TABLE 8. Inverter specifications

Item	Values
Peak AC Daily load, Pac	1437.5 Watt
AC Projected surge power (3 units)	4312.5 Watt
Inverter efficiency	99%
DC input voltage	$48\ V_{DC}$
AC input voltage	$4230\ V_{AC}$
Frequency	50Hz

SELECTION OF SYSTEM CABLE SIZE

Correct cable size and cable type will contribute to the enhancement of performance and reliability of the photovoltaic system. This is due to the dc-wires between the photovoltaic modules and batteries through the voltage regulator that must withstand the maximum current that is produced by the PV modules. The equations to calculate the cable size for the PV modules through the battery's voltage regulators is shown in the following (11) (Ishaq et al., 2019):

$$\textit{The cross sectional area of the cable}, A = \frac{\rho l I}{Vd} \times 2 \tag{11}$$

where the $\rho = resistivity\ of\ the\ copper\ wire$ which equals to 1.724 x 10-8Ωm(AWG). In this project, the cable size for PV modules through the batteries voltage regulators is selected to be 1.22mm2, cable size between battery bank and inverter is 32mm2 and the cable size between the inverter and the load is 3mm2.

DISCUSSION

A technical design of SAPV system for the healthcare centre located in Kampung Tewowoh, Kluang, Johor is based on the load consumption. The utilization of the renewable energy that is strongly available in this location site is believed to give more benefits to these village communities. The technical design presented in this article must be precisely as to ensure that the power generated can support the healthcare centre. The overall topology of this proposed SAPV system for the healthcare centre is shown in Figure 6.

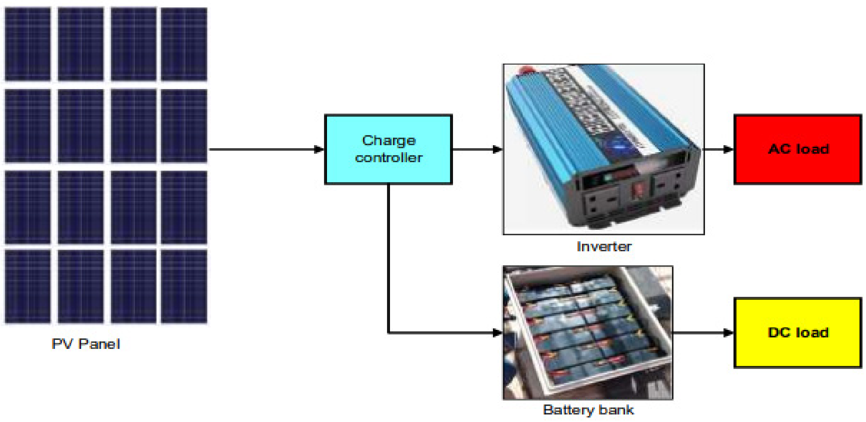

FIGURE 6. Topology of standalone photovoltaic system for the healthcare centre

In the other hand, the cost estimation for this project is tabulated in Table 9.

TABLE 9. Cost estimation for the standalone photovoltaic system of healthcare system in Kampung Tewowoh

No	Component	Qty	Price (RM)	Total (RM)
1	Pv panel	16	1,296	20,736
2	Solar charge controller	1	2,145	2,145
3	Battery	16	4,314	69,024
4	Inverter	1	4,100	4,100
5	Balance of system (bos)	1	3,000	3,000
	Total			99,005

CONCLUSION

As a conclusion, this project is proposed to grab the advantage of solar radiation in rural locations which is believed to provide the least cost energy to the communities. In addition, the mathematical design which contains several basic equations used in this technical design step can be considered to develop and evaluate the compatibility of standalone photovoltaic electrification in any geographical location. Meanwhile, it is believed that this simple design process can contribute to significant understanding for those beginner researchers in solar engineering.

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