A PROPOSITION OF A STANDALONE PHOTOVOLTAIC SYSTEM FOR EDUCATIONAL BUILDING IN MALAYSIA

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ABSTRACT
Since the ability of solar technology to electrify most building, they have been used widely in the power generation either in standalone or grid connected connection. Standalone or autonomous photovoltaic system is seen to have large benefits to the system owner including low maintenance, low upkeep cost, no waste or byproducts, and easy expansion by using multiple solar panels and batteries. Hence, this article presents a design phase and economic analysis of the Standalone Photovoltaic System (SAPVS) to electrify the educational building in Polytechnic Merlimau, Malacca. The design of the SAPVS started with the determination of SAPVS components before it proceeds to the design calculation. The results give the PV area, PV peak power, battery capacity, inverter and charge controller of 86.73m2, 10.4kWp, 62.37 kWh, 2 kW and 350 (A) respectively. Moreover, the financial life-cycle cost analysis was investigated. Finally, it is proved that an SAPVS is technically and economically viable and feasible to electrify an educational building in Malaysia.

Keywords: Standalone Photovoltaic, Battery, Technical, Life Cycle Cost, Feasibility.

1. INTRODUCTION

In most countries, global energy consumption is increasing and has given the challenges to the state holders. Primary energy which can be found in form of renewable or none-renewable source such as oil, gas, coal, wind, sun and uranium as their consumption rose by 2.3% in 2013, with an acceleration of 1.8% throughout 2012 in the world (Salvatore, 2013). Among all, fossil fuels are currently the world's main energy source. They will continue to generate 80% of the world's energy until 2030 as well as the growth in fossil fuel consumption leads to the elevation of CO2 emission and thus, global warming. Here, there are the global ecological concerns about the usage of fossil fuels have led to attempts to decrease the rate of fossil fuel consumption by developing renewable alternative energy sources using solar, wind, biomass and hydroelectric energy. Without any doubt, it is important to have more sustainable energy sources that are less dangerous to the environment while at the same time meet the rising demand for electricity. This need has pushed the concept of renewable and sustainable energy to the foremost of environmental sustainability debates. In objective to utilize the renewable source to meet the electricity demand, solar photovoltaic power has been found to be the best available alternative that can support this mission especially in large capability to generate electricity (Siddiqui & Said, 2015). Several benefits of solar photovoltaic technology including small scale of solar plant can take advantages of unused space of rooftops of existing building, the PV system are quiet and clean since they are not utilize any fuel other than sunshine (Ikkurti & Saha, 2015). Besides, solar energy is a locally available renewable resource, which means it does not need to be imported from other regions of the country or across the world. This will reduce the cost on the fuel and transportation which can also reduce our dependence on imported oil. Furthermore, a solar PV system can be constructed to any size based on energy requirements. The owner of a PV system can enlarge or move it if his or her energy needs change. For instance, homeowners can add modules every few years as their energy usage and financial resources grow. However, the most barriers to a more universal utilization of photovoltaic panel are the ability of the PV panel to generate the electricity from this is limited to day-time, it fluctuates over the year and relies on weather condition (Isa, Wei, & Yatim, 2015).

Buildings including commercial and residential type consume about 40% of world’s primary energy and they contribute to one-third of the greenhouse gas emission around the world (Agency, 2011). Thus, the improvement in electricity generation by a transformation of using the renewable energy sources in the building power generation would have a great impact in reducing the disadvantages of fossil fuel usage. In these regards, many attempts have been made to increase the implementation of photovoltaic panels to produce the electricity from a renewable energy source. Although the major dispute barrier to photovoltaic system is its high initial cost of installation, if the proper life cycle cost analysis is performed, it could be a beneficial and environment friendly solution to the system owner.

Around the world, many researches have been carried out to investigate the viability, feasibility, risk factors and financing indicators in the implementation of photovoltaic electrification systems. The famous research scope is to build the Standalone Photovoltaic System (SAPVS) integrating to the power system plant in the building that not only assist in electricity generation but also help in profits income to the building owner. Several works study on development of standalone PV system are including (Kamali, 2016), (Maheri, 2014), (Kamal & Hassan, 2016; Türkay & Telli, 2011), (Dash & Bajpai, 2015), (Sureshkumar, Manoharan, & Ramalakshmi, 2012) and (Ma, Yang, & Lu, 2014). The discussion in these cited papers are various including the sizing, economic operation of SAPVS and the reliability function of the developed system. However, this paper does not cover the fundamental methodology of the SAPVS design process. Except a few papers like (Hansen, Sorensen, Hansen, & Bindner, 2000), (Aziz, Djamal, & Kaci, 2015) and (Hasan, Islam, Hossain, Sarjana, & Hasan, 2016) which discuss the fundamental design method of SAPV system. However, their discussion only covers the technical part of design and not cover the economic benefits in their study. Therefore, this presented article focus on the development of SAPVS for the educational building in Polytechnic Merlimau, Malacca as well as the SAPVS design with storage system to cater the buildings demand under the climate condition of Peninsular Malaysia. In addition, the life cycle cost analysis also explained in detail to evaluate the effectiveness of the developed SAPVS.

2. STANDALONE PHOTOVOLTAIC SYSTEM DESCRIPTION

The general configuration of SAPV System shown in Figure 1 is considered in this study. The system basically consists of solar panels, inverter, batteries and load. The function of the PV array is to convert the sunlight directly into DC electrical power. Battery is an important component in all of standalone PV which it will be used to store the excess electricity produced by the PV system. The stored electricity or energy can be used for night time or during the emergency cases. Charge controller is used to regulate and controls the output from the solar array to prevent the batteries from being over charged or over discharged. The function of charge controller is being done by dissipating the excess power into the load resistance as this is the optional for the system owner to put the SAPVS in safety precautions. An inverter is used to convert the 12V, 24V or 48 Volts direct current (DC) power from the solar array and batteries into an alternating current (AC) electricity and power of either 120 VAC or 240 VAC for use in the home to power AC mains appliances such as TV's, washing machines, freezers, etc. The wiring configuration is also the important component needed in the APVs as to ensure the electricity connection can be delivered successfully. In this regard, the cables need to be correctly rated for the voltage and power requirements.

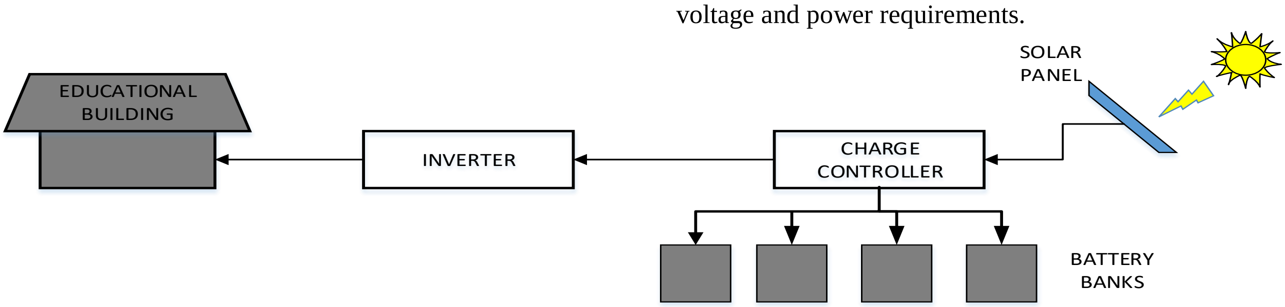

Fig. 1. Standalone Photovoltaic System (SAPVS) components

2.1 SAPVS Design Criteria

The electricity produced by PV array is related to the light intensity falling on the PV array, ambient temperature, cell temperature, load status and the technical characteristics of PV module used. In order to design a SAPVS for the considered educational building, the size of the PV array and the battery bank capacity have to be determined. The design of PV array used can be calculated using the equation (1):

$$A_{PV} = \frac{E_L}{G_{in} \times \eta_{PV} \times TCF \times \eta_{OUT}} \qquad (1)$$

where A_{PV} is an area of PV installation, E_L is an electricity load, G_{in} solar radiation per day on PV panels, TCF is the temperature correction factor, η_{PV} is PV efficiency and η_{OUT} is equivalence of battery efficiency and inverter efficiency which give $\eta_{Bat} \times \eta_{INV}$. The storage capacity of a battery will represent the size of the battery, which can be calculated using equation (2):

$$B_s = \frac{N_C \times E_L}{DOD \times \eta_{OUT}} \qquad (2)$$

where B_S is a battery size, N_C is a number of an autonomous days as well as DOD is a maximum permissible depth of discharge of the battery. In order to calculate for the required number of PV modules, the projection of available solar radiation to the irradiance output of the selected PV module can be done. Thus, the total output power from the PV panel is calculated using equation (3):

$$P_{PV} = A_{PV} \times I_P \times \eta_{PV} \qquad (3)$$

where P_{PV} is a peak PV power, A_{PV} is an area of PV installation (m^2) and I_P is a peak solar irradiance (W/m^2). Other component in APVs is an inverter and charge controller. The main task of charge controller in a standalone photovoltaic system is to keep the batteries at highest possible state of charge while protecting them from over-discharge by the loads and overcharge by the photovoltaic array. Reference (Wu, Xiao, Wu, Zhang, & Wang, 2011) present the fast charging method that is applied to micro grid photovoltaic system to eradicate battery over/undercharge because of solar radiation changes. Therefore, the design of charge controller is important to ensure the charge controller should avert overcharge of batteries in spite of the seasonal changes in the load demand, system sizing and solar irradiation. Moreover, it should also be capable to handle short circuit current of the PV array. In other hand, the inverter that function to convert the DC voltage to AC voltage must also be able to handle the maximum power of electric loads therefore it should be selected around 20% higher than the total power of the required loads.

2.2 Economical Cost Analysis

The economic cost analysis is an important procedure to evaluate the returns of the developed SAPVS. One of the tools in economic analysis is using Life Cycle Cost (LCC) whereby the life cycle cost of a photovoltaic system is made up of the initial capital investment (C_{cap}), the present value of battery replacement cost (Cb_{rep}) and the present value of operation and maintenance cost (C_{OM}). Life cycle cost formulation is written in equation (4) (Sureshkumar et al., 2012), (Nikhil & Subhakar, 2013), (Jamil, Kirmani, & Rizwan, 2012), (Ismail, Moghavvemi, & Mahlia, 2014) and (Razak, Sopian, Nopiah, Zaharim, & Ali, 2007):

$$LCC = C_{cap} + Cb_{rep} + C_{OM} \tag{4}$$

In this regard, the initial capital investment (C_{cap}) is the sum of the investments of each part of the PV system such as PV array (C_{cap_pv}), batteries (C_{cap_Batt}), inverter (C_{cap_inv}), charge controller (C_{cap_cc}), and installation (C_{cap_ins}). This kind of investments is dependent on the peak power rating of the PV module. The initial capital cost can be written as in equation (5) as well as each of the cost of PV array and batteries can be calculated using equation (6) and (7), respectively.

$$C_{cap} = C_{cap\_PV} + C_{cap\_bat} + C_{cap\_inv} + C_{cap\_cc} + C_{cap\_ins} \tag{5}$$

$$C_{cap\_PV} = UC_{PV} \times N_{PV} \times P_{PV} \tag{6}$$

$$C_{cap\_Batt} = UC_{Batt} \times B_s \tag{7}$$

where UC_{PV}, N_{PV}, UC_{Batt} and B_S is a unit cost of PV, number of PV panel, unit cost of battery and battery size, respectively.

The operation and maintenance cost include the taxes, insurance, maintenance, recurring costs in which they are widely specified as a percentage (%) of the initial capital cost. All operating costs are increased at a rate of *i* and discounted at rate of *d*. Hence, the present value of operation and maintenance costs for a SAPVS lifetime of *N* years can be calculated using equation (8):

$$C_{OM} = C_{cap}(\%) * \left(\frac{1+i}{d-i}\right) * \left[1 - \left(\frac{1+i}{1+d}\right)^N\right] \tag{8}$$

Furthermore, the present value of battery replacement cost (Cb_{rep}) is mainly a function of the number of battery replacements (r) over the system lifetime (N), without taking the salvage value of replaced batteries. It is defined as in equation (9):

$$Cb_{rep} = C_{batt} * \sum_{j=1}^{r} \left(\frac{1+i}{1+d}\right)^{Nj/(1+r)} \tag{9}$$

In addition, the annual life cycle cost of SAPVS and the unit electricity cost can be calculated using equation (10) and (11), respectively.

$$A_{LCC} = LCC * \left(\frac{1 - \left(\frac{1+i}{1+d}\right)}{1 - \left(\frac{1+i}{1+d}\right)^N} \right) \tag{10}$$

$$ECU = \frac{A_{LCC}}{365 * E_L} \tag{11}$$

3. RESULT ANALYSIS AND DISCUSSION OF SAPVS

The proposition of SAPVS for an educational building is located in Polytechnic Merlimau, Melaka (PMM) with the longitude and latitude coordinate for the location are 2.168 and 102.4275, respectively. The solar radiation for this location are illustrated in Figure 2, where the data were taken from the PVGIS web sources. According to the radiation pattern, it shows that the PMM location has the potential to implement the SAPVS. However, the correct and proper design of SAPVS installation is highly importance as to obtain the maximum benefits from the solar energy generation. Moreover, the placement of solar panel in a proper tilt angle will contribute to the best output of power generation. Tilt angle is defined as the angle of inclination of a module measured from the horizontal. Since the considered site is located at 2.168 ˚ North latitude and 102.4275˚ east longitude, the optimal angle for solar panels is adjusted to be at 15˚ degree facing south. This tilt angle was chosen for optimal year around performance of the PV system because of the PV panels were fixed and not rotational.

The load consumption pattern in the educational block in PMM is assumed to be simple and not requiring the large quantities of electrical energy. The electrical loads in the educational block are included the lighting, projector and the lab equipment which has not operate in 24 hours. This loads consumption is assumed to be constant around the year. The corresponding load profile for the educational block in PMM is illustrated in Figure 3.

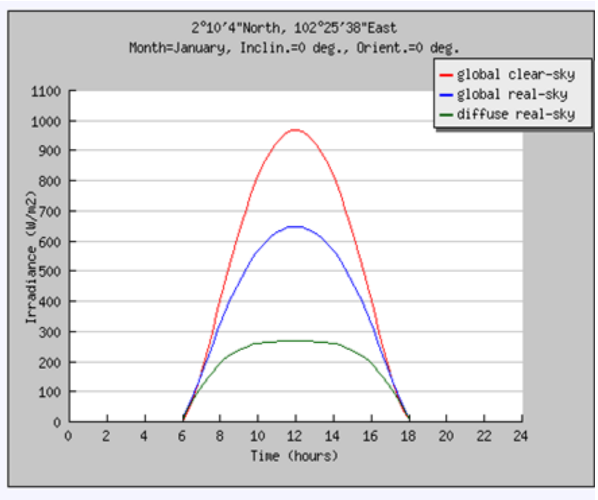

Fig. 2. Solar radiation for PMM location

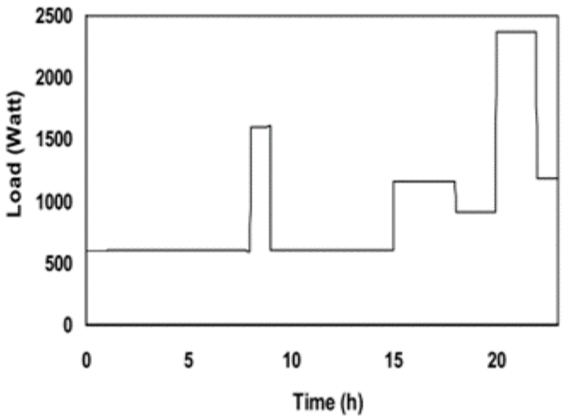

Fig. 3. The load profile of educational block in PMM

3.1 Sizing of SAPVS

In calculation of proper sizing for the SAPVS, the TCF is assumed to be 80% due to 15 – 20 % loss in efficiency and as the result of increasing cell temperature to around 60°. The photovoltaic panel, battery and inverter efficiency is assumed to be equal to 16%, 90% and 95% respectively. In addition, the highest electricity demand of 24kW and lowest solar irradiation of 3.37 kWm^{-2} day^{-2} is used in the equation (1) would make the total area needed to support the electricity demand is calculated to be 86.76 m^2. Furthermore, the peak PV power is then calculated using equation (2). It is assumed that the peak solar irradiance is 1000 (Wm^2) generated within the area, thus make the P_{PV} is equal to 10.4kW$_p$. This study use the SolTech 1STH-350-WH (350W) solar panel which the technical characteristic for this PV is provided by the manufacturer (SolTech) and it is tabulated in Table 1. A total number of 30 modules are required to cover the calculated peak PV power.

The battery size that required to support the storage function is calculated using equation. The required capacity of battery storage is calculated to be 62.37 (kW h), assuming the number of continuous cloudy day (N_c) as 2 days and maximum permissible depth of battery discharge (Dod) as 90%. The battery's voltage and capacity are 12 (V) and 200 (Ah), and a total number of 25 batteries are needed in this study. As it was mentioned before, the inverter capacity should be at least 20% higher than the total power of the loads thus an inverter with 2000 (W) capacity is selected which is widely available in the market.

Table 1. Specification of SolTech 1STH-350-WH (350W)

Electrical characteristics	Value	Unit
Maximum power rating (P_{max})	350	W
Number of cells	60	Pcs
Maximum power voltage (V_{mp})	42.98	V
Maximum power current (I_{mp})	8.13	A
Module efficiency	16.22	%
Short circuit current (Ruz, Garrido, Vázquez, & Morilla)	8.93	A
Open circuit voltage (V_{OC})	51.47	V
NOCT	50	^{O}C

3.2 Life Cycle Cost Calculation of SAPVS

Another aspect considered in the development of SAPVS for the educational building in PMM is an economic benefit which represented by the life cycle cost analysis. In this regard, the feasibility study is performed by calculating the cost of initial investment, battery replacement, and operation & maintenance of the system throughout its life cycle using current market prices. The cost parameters used in this study consider Malaysia price as they are given in Table 2.The calculation of the capital cost of PV array (C_{cap_PV}) and battery (C_{cap_Batt}) using equation (6) and (7) give the amount of MYR520000/kWh and MYR7796/kWh, respectively. Furthermore, the total capital cost of the system are MYR 581,146/kWh , the replacement cost of battery , $C_{b_{rep}}$ is calculated to be 1100 MYR/Pcs and operation and maintenance cost C_{OM} is MYR 1000. Overall, the life cycle cost for the developed SAPVS is MYR 6046018.4. This cost is seen profitable for the 25 years lifetime of SAPVS since the electricity generated can cover the electricity cost purchased from the main utility company, Tenaga National Berhad (TNB).

Table 2. Cost parameters for the components in SAPVS

Component cost	Price in MYR
PV panel unit cost, UC_{PV}	500
Battery unit cost, UC_{Batt}	1250
Inverter, C_{cap_inv}	800
Charge controller, C_{cap_cc}	250
Inflation rate, *i*	8%
Discount rate, *d*	10%
Installation cost, C_{cap_ins}	10% from the PV cost

4. CONCLUSION

Since the increasing in prices and emission level caused by nonrenewable energy resources, peoples now are moving forward to utilize renewable energy resources to generate their electricity. Currently, the generation of electricity using solar technology is gaining popularity around the world due to its advantages including quiet, clean to environment and zero fuel cost. Therefore, an evaluation to determine the appropriate viable design and feasibility analysis as well as the financing indicators and risk factors must involve in the photovoltaic system design. This is because the high initial cost was the most limiting factor in the widespread use of the system. However, this problem of photovoltaic system initial costs has proven that it can be more competitive in comparison with conventional energy resources. This study is emphasized on the design phases and economic analysis of the SAPVS development for the educational building in PMM. In the design, the lowest rate of solar radiation (3.37 kWm2/day) is considered to avoid any failure in electric generation. Besides, the estimated electricity demand of the building (24kW) is assumed to be constant throughout the year for a simplicity. Using the mathematical equation, the size of the components in SAPVS have been calculated. As a result, the PV panels area, PV peak power, the battery capacity, inverter and charge controller sizes were found to be 86.73m^2, 10.4kW$_p$, 62.37 kWh, 2 kW and 350 (A) respectively in order to fulfill the estimated electricity demand. The needed number of PV panels and battery are 30 modules of 350W and 25 unit of batteries, respectively. The analysis of lifecycle cost give the unit cost of generated electricity was calculated to be MYR 6046018.4 which is look more profitable for the 25 years lifetime of SAPVS. This cost is quite high but the returns from the electricity generated from the SAPVS is believed can cater the energy cost purchased from the TNB. In the future research work, the analysis on return of investment (ROI) and payback period (PP) of the SAPVS can be calculated to observe the profit duration gained by the system owner. As a conclusion, it is proved that SAPVS is technically and economically viable and feasible to electrify an educational building in Malaysia. In addition, the mathematical model used in this study can be considered to design and evaluate the feasibility of standalone photovoltaic electrification system in any geographical location.

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