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PV SYSTEM FOR PHOTOBIOREACTOR SIZING AND EVALUATION USING TRNSYS SIMULATION

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ABSTRACT

This paper presents sizing and performance evaluation of a standalone photovoltaic system to supply power of small scale photo-bioreactor system. PSH method is used to determine PV panel and battery capacity, then the sizing results is tested and evaluated using TRNSYS model. The results shows for small scale photobioreactor daily electricity load of 1440 Wh, the PV system requirement is consist of 500 Wp PV panel and 500 Ah battery capacity for 12V system.

Keywords : PV Sizing, PSH, , Photobioreactor, TRNSYS.

1. Introduction

Photovoltaic (PV) systems, either on-grid and standalone system have been widely used for various type of applications around the world. In a standalone PV system, sufficient solar panels and battery capacity is required to ensure reliability of the system (Pascual, 2007). PV systems sizing can be carried out using deterministic and stochastic methods (Markvart and Castener 2003). Both methods have advantages and disadvantages. Deterministic method is chosen in this paper due to its simplicity and quick calculation. A deterministic method refers to the assumption that the load profiles and energy resources are constant, neglecting the statistical phenomenon of each component of the system. Although this method will be less accurate than the statistical approach, it can be used to provide initial size design of PV panel and storage systems (Al Riza, 2011a).

A simple deterministic method using the Peak Sun Hour (PSH) concept can be used to obtain a quick sizing estimate of the PV system. This method is suitable for the locations where daily solar radiation data is not available, so the PSH value from Global Solar Map can be used. PSH is defined as the equivalent number of hours per day when solar irradiance averages 1,000 W/m^2 as described in Fig. 1 (Sen, 2008).

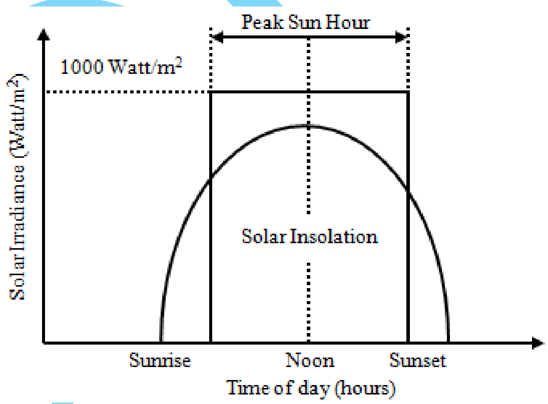

Figure 1: PSH (Peak Sun Hour) (Sen, 2008)

System size is calculated based on the energy balance concept by means energy produced by PV system and stored in the battery can fully supply the load energy demand (Al Riza, 2011a). Average PSH value on the earth can be observed from Global Solar Power Map. The map was developed by Solarex using solar radiation data measured at various locations on the globe. The map shows the average amount of solar energy, received on horizontal surfaces at different geo-locations.

Al Riza, *et al.* (2011b) has demonstrated PSH method for standalone PV system sizing without sufficient sizing results evaluation. Simulation using software i.e. TRNSYS can be carried out to evaluate the system performance. TRNSYS is one of the most complete and extensible simulation environments for the transient simulation of solar energy systems, which is developed in the University of Wisconsin. The modular structures of TRNSYS give the software tremendous flexibility and facilitate an addition of new models into the program (Shao, 2007). Al Riza, *et al.* (2011c) has developed TRNSYS model for standalone PV system for residential lighting. The model has been validated with experimental data. This paper covers the PSH method calculation procedures for standalone PV system with residential electricity load and sizing results evaluation using TRNSYS simulation. It is expected that the PSH method combined with simulation evaluation will provide reliable sizing results.

2. Methods

2.1 Sizing using PSH method

To calculate the size of the PV panel by using PSH method, first, the electricity demand per day and solar energy availability for the sites with respect to PSH have to be determined. PSH value that is used in this calculation is obtained from Global Solar Power Map. Load energy for typical Malaysian terraced house is explained in section 2.3. Then, Eq. 1 is used to calculate the PV array capacity.

$$P_{PV} = \frac{P_{load}}{PSH.\eta_{system}} \quad (1)$$

P_{PV} is PV panel nominal peak power. P_{load} is total energy demand for a day, PSH is Peak Sun Hour and η_{system} is overall system efficiency.

After total P_{PV} of PV panel is determined, the battery capacity can be calculated using Eq. 2 as follows:

$$C_{bat} = \frac{P_{load}.N_a}{DoD.V_{rated}.\eta_{system}} \quad (2)$$

C_{bat} is the battery capacity in Ampere hour (Ah) and N_a is the number of autonomy days (day with minimum solar irradiation) required consecutively. *DoD* is the depth of discharge and V_{rated} is the voltage of the system in Volts.

2.2 TRNSYS 16 Standalone PV system model

TRNSYS 16 software is used to developed standalone PV system model. The model that was developed by Al Riza, *et al.* (2011c) is used in this research to simulate the system. The model has been validated with experimental data. Fig. 1 shows the TRNSYS model of standalone PV system.

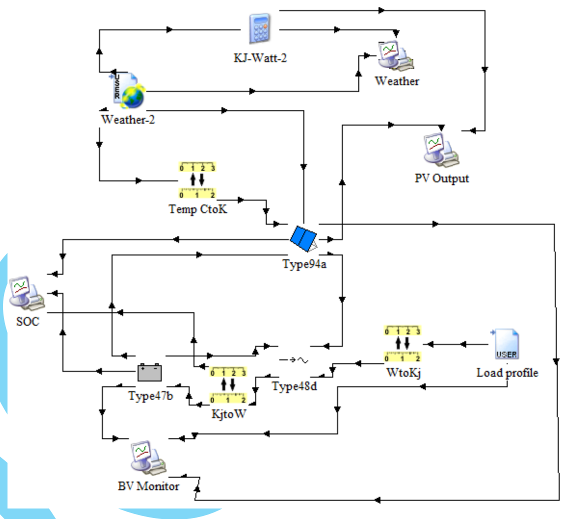

Figure 2: Standalone PV System model in TRNSYS 16

2.3 Data set for PSH calculation

The solar energy availability data can be obtained from global solar power maps for any area on the earth. The Peak Sun Hour (PSH) presented in the global solar power maps represent the worst-case seasonal PSH (hours) values that used for calculating year-round application. It can be seen in Fig. 3, that Malaysia has an average PSH value of 4-5 hours. A.W. Azhari *et al.* (2008) in their study conclude that Malaysia receives average solar radiation between 4.21 to 5.56 kWh/m^2. Fig. 4 shows the example of PSH value, which is obtained from measured data for Bandar Sri Iskandar. The data was taken on 5 May 2010, on a sunny day from morning until afternoon and for the cloudy sky in the afternoon. The total radiation for the day is 4510 Wh/m^2, which is equal to PSH value of about 4.5.

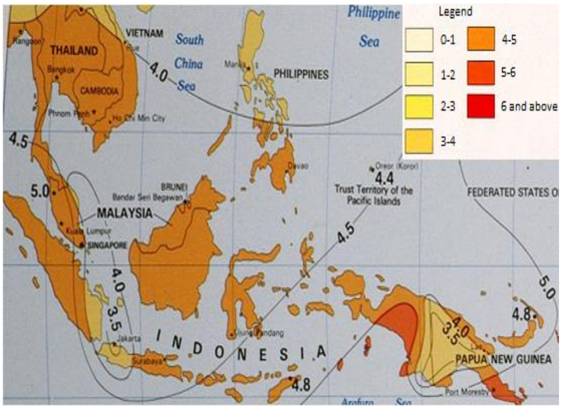

Figure 3: Global Solar Power Map for South East Asia (Solarex, 1996)

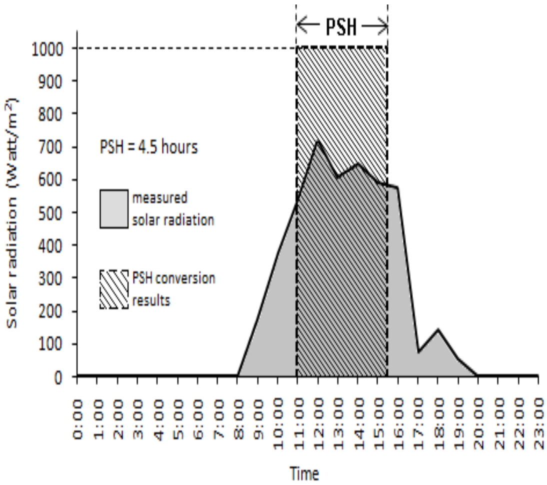

Figure 4: PSH obtained from measured data in Bandar Sri Iskandar (5 May 2010)

For electrical energy load, the data of Malaysian typical residential house is used as presented in Table 1. The type and the operation hours of each household appliance may varying due to the occupants' behavior, but their average total value, as reported from previous studies is about 6 kWh/day. Other parameters that required for PSH calculation are listed in Table 2. A *DoD* greater than 80% should be avoided. The "sweet spot" (optimum *DoD* for the greatest amount of power produced over the service life) is generally somewhere between 20% and 60% on the average. A reasonable number of autonomy days (N_a) are three (3).

Table 2: Parameters used for sizing calculation using PSH Method

No.	Parameter	Value	Unit
1	System Efficiency (η_{system}) – include connection losses, dust factor, inverter efficiency and charging efficiency	80	%
2	System Voltage (V_{rated})	24	Volts
3	DoD	50	%

2.4 Data set for Simulation

For simulation input, one year meteorological data from Ipoh Weather Station is used. The missing data is a filled using method that was proposed by Al Riza, *et al.* (2011d). Figure 5 shows full data set for the weather simulation input. The weather data consist of hourly global solar radiation on horizontal surface, ambient temperature and relative humidity data. For load profile data, data from table is processed to be a daily profile load as presented in Figure 6. It is assumed the daily load profile is constant.

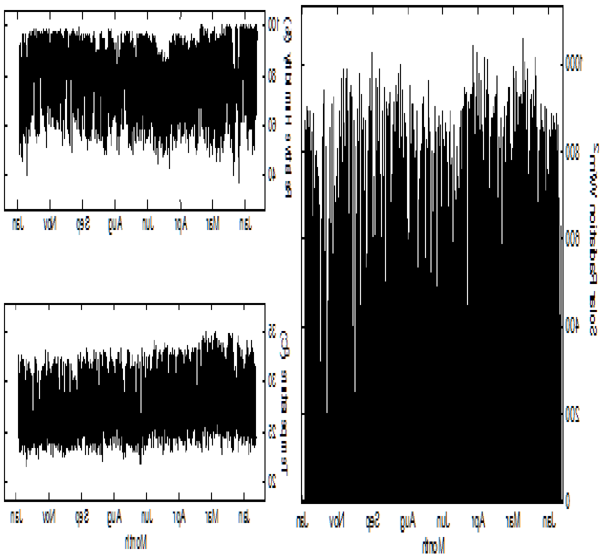

Figure 5: Weather data input for the simulation

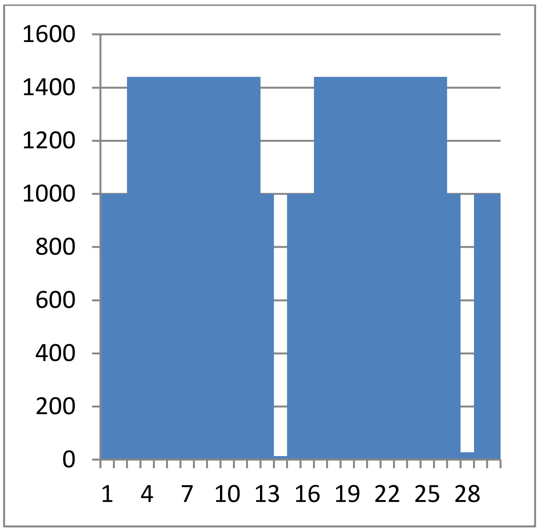

Figure 6: Daily load profile of photobioreactor

3. Results and discussions

3.1 Sizing Results

Fig. 7 shows PV panel sizing curve. From Fig. 7, it is observed that the higher solar energy availability (by mean of PSH) will results smaller PV panel requirement. In a lower PSH value, the PV panel requirement will increase more significantly with load increasing rather than in higher PSH value. For the location at Bandar Seri Iskandar, PSH value of 4.5 was chosen based on the available data.

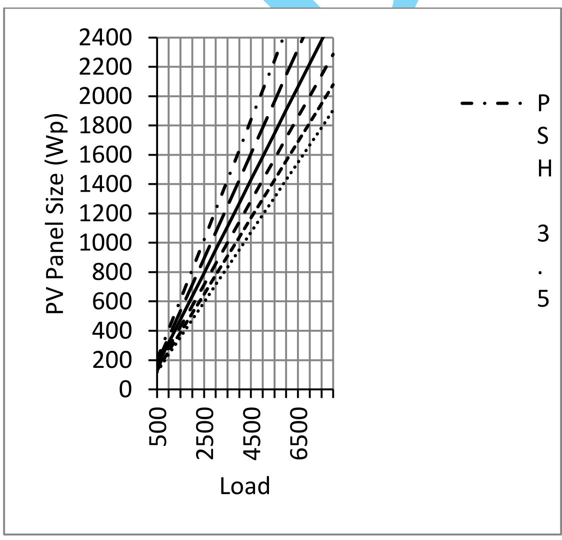

Figure 7: PV panel sizing curve

Battery capacity calculation has been carried out using deterministic method. Fig. 8 shows sizing curve of battery capacity with variation of number of autonomy days (N_a). Then, after both PV panel and battery sizing curve were obtained, the configuration can be determined. From the calculation above, for a typical house in Malaysia that has a constant load of about 6 kWh/day, with system efficiency 80%, the PV panel required for the system is 1900 Wp with battery storage of about 2200 Ah for a 24V system.

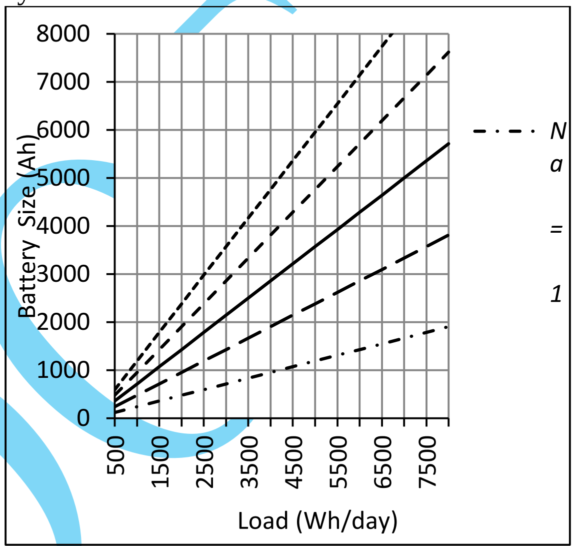

Figure 8: Battery sizing curve

3.2 Simulation Results

From the sizing results the selected configuration of the PV system is 1700 Wp PV panel and 1900 Ah battery in a 24 Volts system. Selected PV-Battery capacity configuration for the system then uploaded in the TRNSYS model to be simulated. Most of the system parameters for each component of the model are the same value with model that was developed by Al Riza (2011a), but some value is changed due to different in the design of the PV system. The PV panels configuration used in the system can be vary depend on the installation space and condition. In the simulation each module peak power value is 215Wp with configuration explained in Table 3. The list of parameters values that were changed described in Table 3.

Table 3: Parameter setting for components of TRNSYS model

No.	Component	Parameter	Value	Unit
1.	PV Panel (94a)	Module short-circuit current ref.	8.48	Amperes
		Module open-circuit voltage ref.	36.56	V
		Module voltage at mpp	29.34	V
		Module current at mpp	7.5	Amperes
		Number of cells wired in series	10	-
		Number of modules in series	1	-
		Number of modules in parallel	9	-
2.	Battery (47b)	Cell energy capacity	16.7	Ah
		Number of cell in series	11	-
		Number of cell in parallel	12	-

PV array output (Watt)

Simulation has been carried out for selected configuration (1900 Wp PV panel and 2200 Ah battery capacities at 24V system voltage). The simulation control card was adjusted to simulate the system in hourly time step for one year (8760 hour). Fig. 4.46 shows simulation results for PV panel output power in Watts. The parameters in PV panel component model were adjusted as that of experimental PV panel datasheet. The total nominal Watt peak of PV panel is 500Wp. In actual condition the output always below 500 Watts because hourly average solar radiation never reach 1000 W/m^2 and the PV panel temperature always above 25^{o}C during the day in the presence of solar radiation. A zoom in graphic is shown in Fig 4.47.

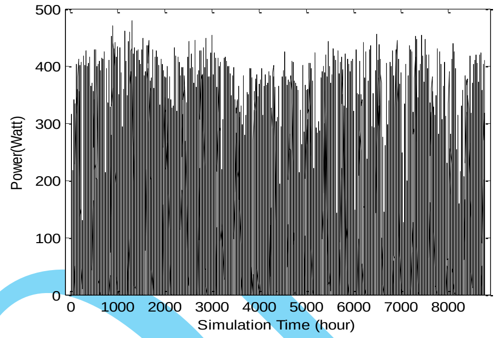

Figure 9: Simulation results: PV array output (Full simulation)

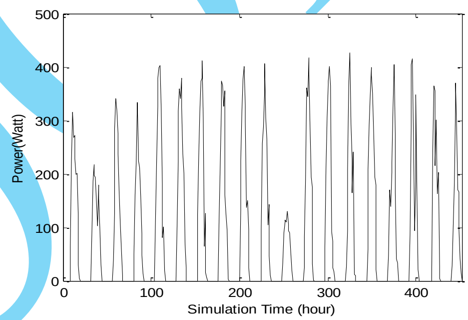

Figure 10: Simulation results: PV panel output power

The load input setting to the simulation model is shown in Fig. 4.48. Fig. 4.49 shows power input (+) and output (-) to and from the battery. The power input is fluctuated dependent on solar radiation value while the power output is constant during the night. Fig. 4.50 shows more detail of power input and output.

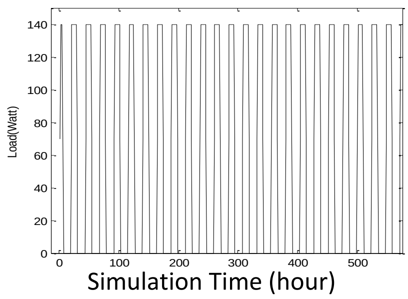

Figure 11: Load setting in the simulation

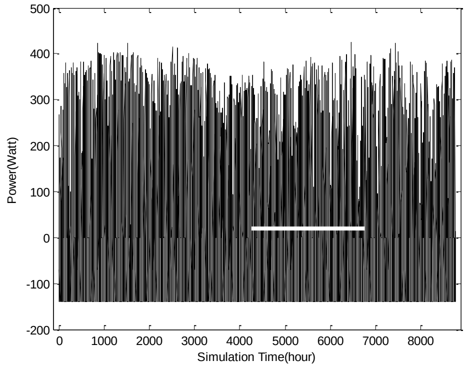

Figure 13: Simulation results: Power input and Output (Full simulation)

It is observed from Fig. 4.50, the system cannot fully supply energy to the load during the night for several days. Points A and B are the days when the system cannot fully supply the load. Points C and D are an example when the load is totally supplied by the PV system. The total load that is supposed to be supplied by the system is 511000 Wh. From the simulation results, it can be calculated that total load that is supplied by the system is 500130.44 Wh. Therefore, the Loss of Power Supply is = 511000 Wh - 500130.44 Wh = 10869.55 Wh. The calculated LPSP value of the system from the simulation results is 0.02 while the LPSP design is 0.001. The difference in performance results by mean of LPSP between design value (using daily-based data) and using simulation (hourly data) is because of the different model of the component, different time-step and considered parameters. However, the minimum SOC can be configured to lower value, and then the load would be supplied totally by the system.

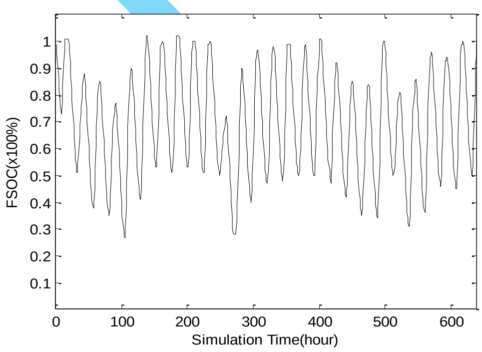

Figure 14: Simulation results: Power input and Output

Fig. 4.51 and 4.52 show simulation results for battery voltage. During the day, the battery voltage is increased due to the charging process. High voltage indicates high charging power. During the night, the battery voltage is decreasing linearly due to the constant loading. TRNSYS simulation output also presents Fractional State of Charge (FSOC) prediction. Fig. 4.53 and 4.54 shows the simulation results of FSOC. The upper limit of FSOC is one (100%) it is when the battery is fully charged. The lower limit of battery FSOC is 0.3 (30%), the controller will cut off supply to the load if the battery FSOC is lower than this value.

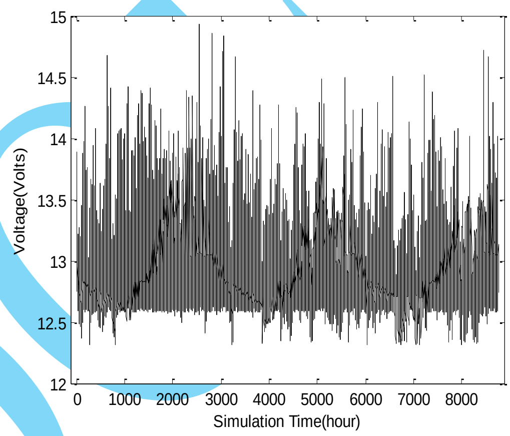

Figure 4.52: Simulation results: battery voltage monitoring (Full Simulation)

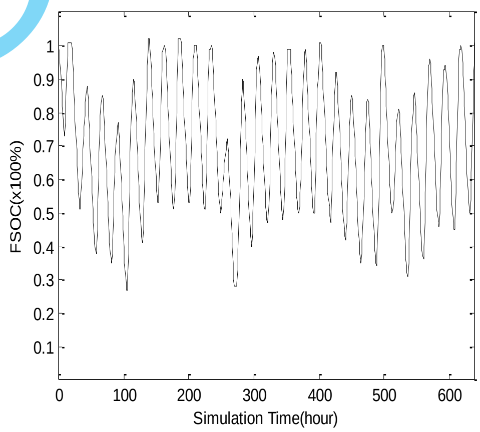

Figure 4.53: Simulation results: Battery SOC

Fig. 4.54 presents the full year simulation results of FSOC. It can be observed that the battery FSOC range during the year is between the limit, the average FSOC of the battery is 0.7. The higher operation range of FSOC will results the longer lifetime of the battery.

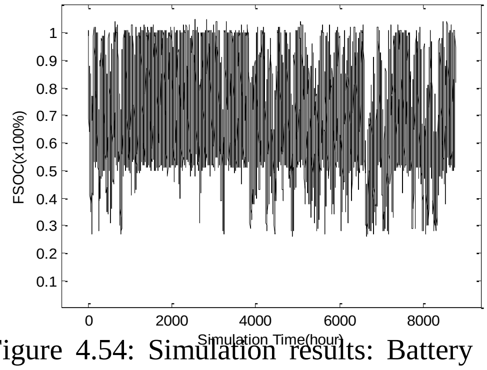

Figure 4.54: Simulation results: Battery SOC (Full simulation)

4. Conclusion

Sizing and simulation of PV system has been carried out in this research. PSH deterministic method is used as the sizing method. The sizing result is tested using TRNSYS simulation model. PSH method is used to determine PV panel and battery capacity, then the sizing results is tested and evaluated using TRNSYS model. The results shows for small scale photobioreactor daily electricity load of 1440 Wh, the PV system requirement is consist of 500 Wp PV panel and 500 Ah battery capacity for 12V system.

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