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Standalone Photovoltaic System Sizing using Peak Sun Hour Method and Evaluation by TRNSYS Simulation

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Abstract- This paper presents sizing and evaluation of a standalone photovoltaic system for residential load. Peak Sun Hour method is used to determine photovoltaic panel and battery capacity, then the sizing results are tested and evaluated using hourly time-step transient simulation model by using TRNSYS 16.0. The results show for typical Malaysian terraced house that has about 6 kWh daily electricity load, the photovoltaic system requirement consists of 1.9 kWp photovoltaic panel and 2200 Ah battery capacity for a 24V system.

Keywords Photovoltaic system, sizing, peak sun hour, transient simulation.

1. Introduction

Photovoltaic (PV) systems, either on-grid and standalone system have been widely used for various types of applications around the world. In a standalone PV system, sufficient solar panels and battery capacity are required to ensure reliability of the system [1]. PV systems sizing can be carried out using deterministic and stochastic methods [2]. 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 [3].

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 [4].

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 [3]. 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 [5]. The map shows the average amount of solar energy, received on horizontal surfaces at different geo-locations.

Al Riza, *et al.* [6] 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. Al Riza, *et al.* [7] 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. Materials and Method

2.1. Sizing using PSH Method

To calculate the size of the PV panel by using PSH method, 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.

$$P_{PV} = \frac{P_{load}}{PSH.\eta_{system}}$$

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:

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

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. Simulation setting and dataset

TRNSYS 16 software is used to develop standalone PV system model. The model that was developed by Al Riza, *et al.* [7] 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.

To run the simulation meteorological data and load data are required. 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 values that are used for calculating year-round application. From Global Solar Power Map that is developed by Solarex it is obtained that Malaysia has an average PSH value of 4-5 hours [5]. Also [8] tells us that, Malaysia receives average solar radiation between 4.21 to 5.56 kWh/m^2.

For electrical energy load, the data of Malaysian typical residential house are used as presented in Table 1. The type and the operation hours of each household appliance may vary due to the occupants' behavior, but their average total value, as reported from previous studies is about 6 kWh/day. Other parameters required for PSH calculation are System Efficiency (η_{system}) – include connection losses, dust factor, inverter efficiency and charging efficiency, System Voltage (V_{rated}) and Depth of Discharge (*DoD*). 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) for residential PV system are three (3).

For simulation input, one year meteorological data from Ipoh Weather Station are used. The missing data are a filled using method that was proposed by Al Riza, *et al.* [9]. Figure 2 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 are processed to be a daily profile load and the daily load profiles were assumed to be constant.

Table 1. Residential House Energy Consumption (adapted from [10, 11 and 12]).

No	Item	Power (Watt)	Qty	Operation Hours	Wh/ day	%
1	Lamp 1	18	3	12	648	23
2	Lamp 2	18	3	6	324	
3	Lamp 3	18	2	2	72	
4	Lamp 4	40	2	4	320	
5	Ceiling Fan	80	2	6	960	16
6	Refrigerator	85*	1	24	2040	34
7	Television	100	1	6	600	10
8	Misc.	-	-	-	1000	17
	TOTAL				5964	

Note: *Average power

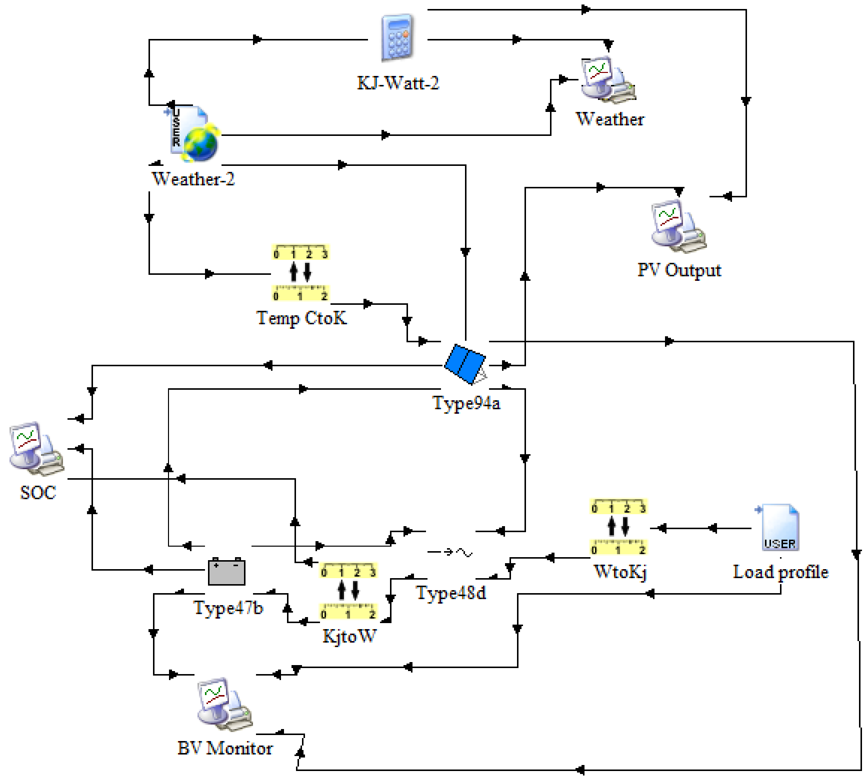

Fig. 1. Standalone PV System model in TRNSYS 16.

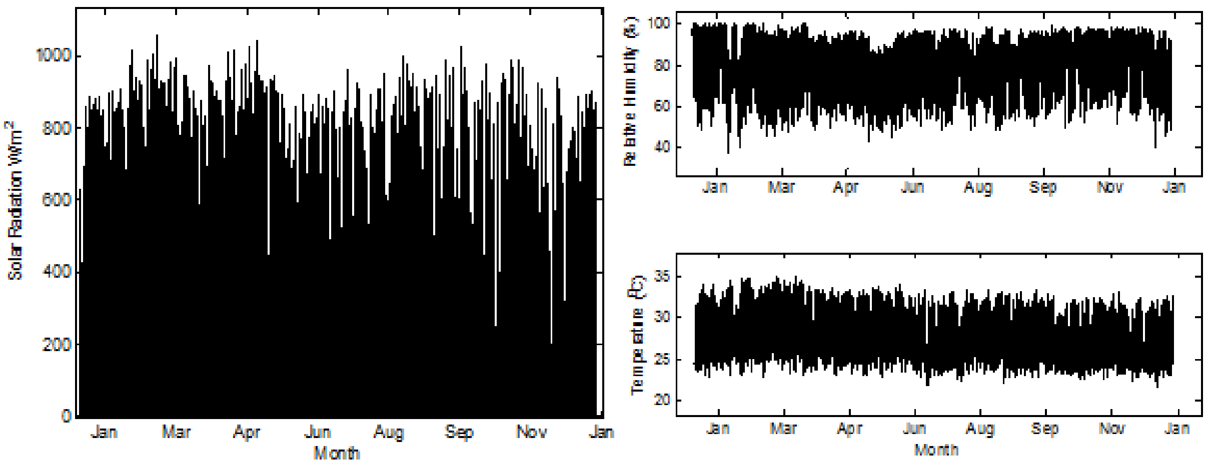

Fig. 2. Weather data input for the simulation.

3. Results and Discussion

3.1. Sizing using PSH Method

Fig. 3 shows PV panel sizing curve. It is found that the higher solar energy availability (by mean of PSH) will result in 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 values of 4.5 was chosen based on the available data.

Battery capacity calculation has been carried out using deterministic method. Fig. 4 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.

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 Volt system. Selected PV-Battery capacity configuration for the system is then uploaded in the TRNSYS model to be simulated. Most of the system parameters for each component of the model are of same value as in the model developed by Al Riza [4], but some values are changed due to different design of the PV system. The PV panels configuration used in the system can vary depending on the installation space and condition. In the simulation each module peak power value is 215 Wp with configuration explained in Table 3. The list of parameters values that were changed are described in Table 3.

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. 5 shows power input (+) and output (-) to and from the battery. The power input fluctuates depending on solar radiation value while the power output is constant during the night. 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 is 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.

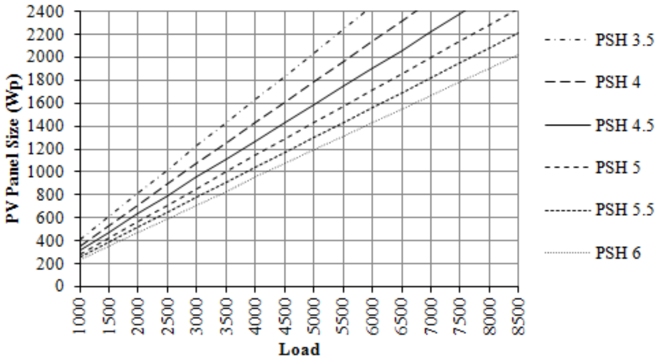

Fig. 3. PV panel sizing curve.

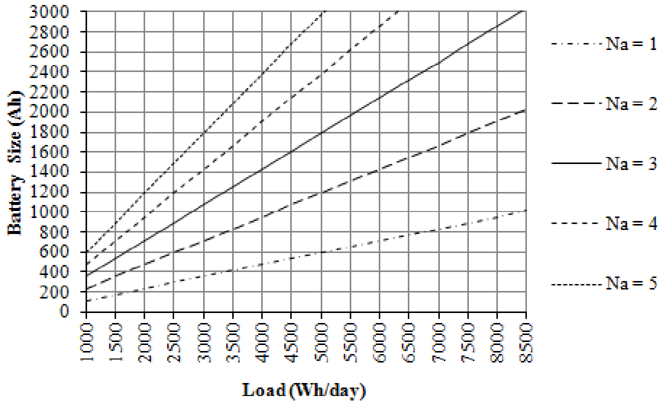

Fig. 4. Battery sizing curve.

Table 2. Parameters setting for components in 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	-

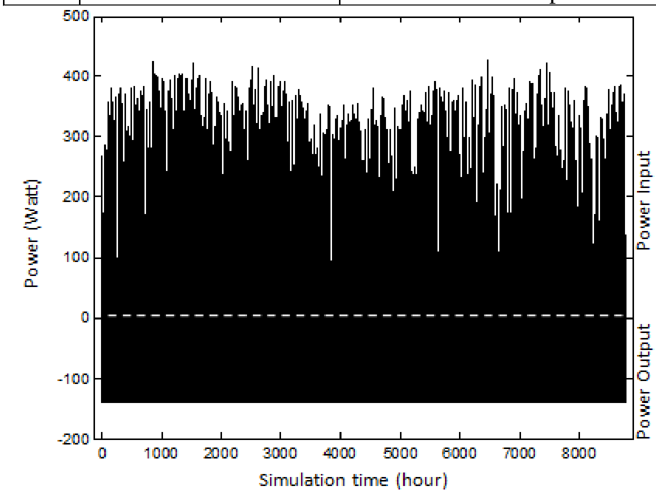

Fig. 5. Simulation results: Power input and output (full year simulation).

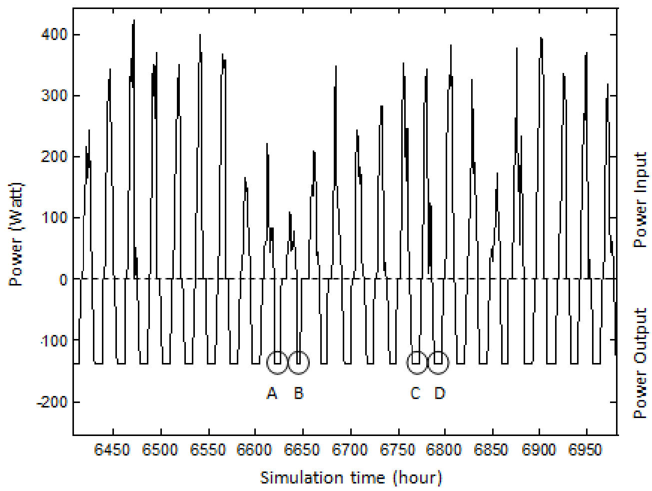

Fig. 6. Simulation results: Power input and output (loss of power supply spot).

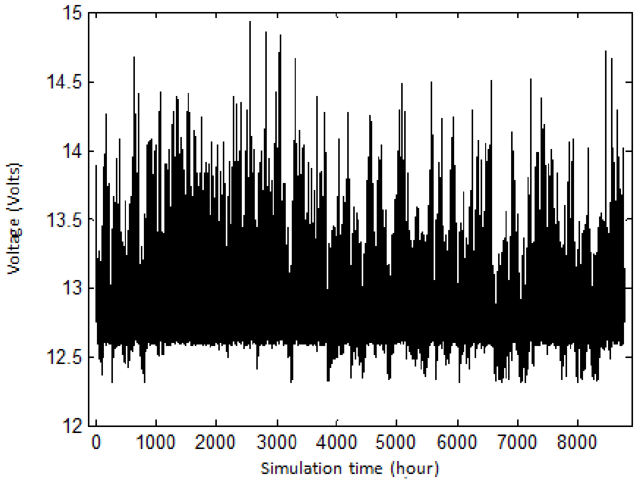

Fig. 7. Simulation results: battery voltage monitoring (Full Simulation).

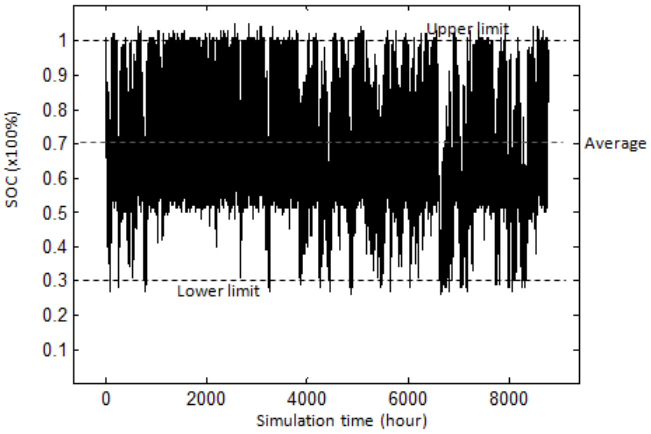

Fig. 8. Simulation results: Battery SOC (Full simulation).

Fig. 6 provides an analysis of power input and output. It is observed from Fig. 7, 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.

Fig. 7 shows 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. 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. Fig. 8 presents the full year simulation results of FSOC. It can be observed that the battery FSOC range during the year is between the limits. The average FSOC of the battery is 0.7. The higher operation range of FSOC will result the longer lifetime of the battery.

4. Conclusion

Sizing and simulation of PV system have been carried out in this research. PSH deterministic method is used as the sizing method. The results shows for typical Malaysian terraced house that has about 6 kWh daily electricity load, the PV system requirement consists of 1.9 kWp PV panel and 2200Ah battery capacity in a 24V system. In this research the sizing result was tested using TRNSYS simulation model. Simulation results show small value of LPSP that means the system performance meet the design expectation. Eventhough deterministic method does not corporate the stochastic nature of solar radiation and PV system, if the parameters in the PSH method are determined properly it will results proper size of PV system.

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