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Assessment of Conventional and Improved SAPV Sizing Methods Using Statistical Indicator

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Abstract

Photovoltaic (PV) system sizing installation tools have played an important role in order to avoid undersizing or oversizing of system components which lead to inaccurate initial costing. In addition, the system is usually designed to fulfill the specific load demand, which close to its point of utilization. This paper presents an assessment of a conventional method (CM) and an improved standalone photovoltaic sizing method (ISAPVSM) by employing statistical evaluations i.e. RMSE, MBE and MAPE .The findings show that the improved sizing method gives lower LCOE and optimum components configuration for SAPV system.

Keywords:*Optimal Sizing, Stand Alone, Photovoltaic, Validations, Renewable Energy.*

1. Introduction

Malaysia is located in equatorial zone, between 100˚ to 120˚ in east longitude and between 1˚ to 7˚ in north latitude. The country is still in urbanization process, and based on [1], the level of electrification in Malaysia's rural area in 2012 is still not exceeded 96%. In addition, past researches indicated that electricity demand and country's population have been increasing regularly for past decades [2].

However, surging oil prices, the decrease of fossil fuel sources and its effects on environment have become major concerns. Thereby, renewable energy has been explored to be alternative energy resources. Among all possible renewable energy available in Malaysia, photovoltaic (PV) generation is the most promising, since Malaysia receives abundance sunshine throughout the year.

Unfortunately, solar energy is underutilized, due to high initial cost and the requirement of large space area. The system is also unpredictable, since the energy is fluctuated throughout the day. Due to that, the generated energy will not match with the load required. Therefore, in most cases, battery is used as backup supply at night and during cloudy days. It is important to use an efficient method to design stand alone photovoltaic (SAPV) system, so the system will not over/undersized.

The authors in [3-6]used conventional methods to design the SAPV system in order to fulfill an average daily load demand. Also they used simple calculations to determine the number of PV panels, batteries, charge controller and inverter ratings.

This paper presents a new design method to improve the published conventional technique [3], for a similar hypothetical case of typical load usage in Malaysia's residential area. Then, both methods will be evaluated using Mean Bias Error, Root Mean Square Error, and Mean Percentage Error.

2. Conventional Method (CM) of SAPV Sizing

This section discussed in detailed the calculations using conventional method in system sizing, configuration and arrangement for SAPV system, as published in [3, 7].

2.1 Estimate Load Demand

Daily DC and AC demand, E_{DC} and E_{AC}(Wh) is calculated using Eq. 1 and 2, where $\eta_{DClosses}$ *is 0.2* and $\eta_{AClosses}$is 0.35 [7].The total energy required is calculated by employingEq. 3.Then, daily system charge requirement, Q_{req}(Ah), is obtained by using Eq. 4, where V_{DCbus} is DC bus voltage (V).

$$DC_{losses} = E_{DC} * \eta_{DClosses} \quad (1)$$

$$AC_{losses} = E_{AC} * \eta_{AClosses} \quad (2)$$

$$E_{req} = AC_{losses} + DC_{losses} + E_{AC} + E_{DC} \quad (3)$$

$$Q_{req} = \frac{E_{req}}{V_{DCbus}} \quad (4)$$

2.2PV Array Sizing

Based on Q_{req} (Ah) inEq. 4, system charging current from PV array, I_{charge} (A) is calculated usingEq. 5 [7] and the month with the lowest peak sun hour (h),PSH_{lowest} is selected in designing the PV array.

$$I_{charge} = \frac{Q_{req}}{PSH_{lowest}} \quad (5)$$

Then, number of parallel string, $N_p$is calculated usingEq. 6, where $I_{SCT}$is module's current output in STC condition (A).Followed by the series-connected modules in a parallel string, $N_{mod/strg}$is calculatedusing Eq. 7, where V_{mod_rated} is the module's rated voltage and total modules (V), N_{PV}isdetermined by Eq. 8 [7]:

$$N_p = roundup\left(\frac{I_{charge}}{I_{STC}}\right) \quad (6)$$

$$N_{mod/strg} = \frac{V_{mod\_rated}}{V_{DCbus}} \quad (7)$$

$$N_{PV} = N_p * N_{mod/strg} \quad (8)$$

2.3Battery Sizing

Battery capacity required (Ah), Q_{batreq} is calculated based on Eq. 9 [6, 7], where N_c is battery's reserved days, and *DOD* is battery's depth of discharge. N_c usually set as 1- 4 days, and it is advised that battery's depth of discharge should not be over 60%. Number of batteries in series connection for a parallel string, $N_{bat_series}$is calculated using Eq. 10 where V_{bat} is individual battery voltage (V). Number of parallel connection, $N_{bat_parallel}$is calculated as Eq. 11, where Q_{bat} is individual battery capacity (Ah)[7].

$$Q_{batreq} = \frac{Q_{req} * N_c}{DOD} \quad (9)$$

$$N_{bat\_series} = \frac{V_{DCbus}}{V_{bat}} \quad (10)$$

$$N_{bat\_parallel} = roundup\left(\frac{Q_{batreq}}{Q_{bat}}\right) \quad (11)$$

2.4Charge Controller Sizing

The voltage rating needs to be sized according to DC bus voltage. Most controllers have equal battery charge rating, I_{cc_charge} and load current rating, I_{cc_output} (A). I_{cc_charge} and I_{cc_output} are calculated as Eq. 12 and 13, where P_{DCload} is total DC load power (W) and 1.25 is set as oversized factor to provide margin for PV module current and load current [8].

$$I_{cc\_charge} = N_p * I_{sc} * 1.25 \quad (12)$$

$$I_{cc\_output} = \frac{P_{DCload}}{V_{DC}} * 1.25 \quad (13)$$

2.5Inverter Sizing

Inverter power rating , $P_{inv}$is selected using Eq. 14, where P_{ACload} is total power from AC load demand and 1.25 is set as oversized factor [8].

$$P_{inv} = P_{ACload} * 1.25 \quad (14)$$

3. An Improved SAPV SizingMethod (ISAPVSM)

This section discussed the design steps and calculations by using new improved method as depicted in Fig. 1.

3.1 Estimate Load Demand

Design process started with an estimation of hourly energy requirement,E_{req}.as stated in Eq. 3 where the hourly system charge requirement, Q_{req}(Ah), is calculated using Eq. 4. In addition to the above mentioned steps, the designer needs to identify the DC bus voltage value for system configuration. It can either be 12 VDC, 24 VDC or 48 VDC, based on load size. Higher voltage is usually preferred for bigger system [7].

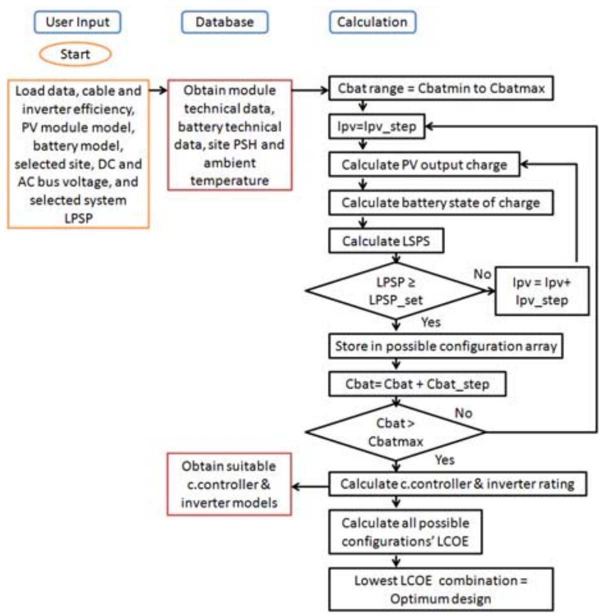

Fig. 1 Design Flowchart.

3.2PV Array Sizing

For sizing the PV array the output must be able to meet total load demand plus extra energy to cover system losses. However, designers need to obtain the hourly PSH at the selected sitebefore sizing the PV arrays.Eq. 15is only applicable to a system that involves charge controller with MPPT and the hourly output charge generated by PV generator, Q_{pv}(Ah) is calculated as below, where I_{mp_stc} is the maximum power point current output of the module (A),N_{pv_par} is number of parallel connections in module array, η_{temp} is temperature de-rating factor, η_{wire} is cable efficiency , η_{inv} is inverter efficiency, η_{mm} is module mismatch or power tolerance, and η_{dirt} is dirt de-rating factor [9, 10].

$$Q_{pv}(t) = PSH(t) * I_{mp\_stc} * N_{pv\_par} * \eta_{temp} * \eta_{wire} * \eta_{inv} * \eta_{mm} * \eta_{dirt} \quad (15)$$

3.3Battery Sizing

To estimate battery state of charge (SOC), Q_{bat} in amp-hour analysis is shown as Eq.16[11, 12]Existence of charge controller will prevent battery to overcharge/over-discharge. Hence, when battery is fully charged or its' capacity reaches maximum DOD; the SOC is modeled as Eq. 17.

$$Q_{bat}(t) = Q_{bat}(t-1) + \left(I_{pv\_Ah}(t) - I_{load}(t)\right) \quad (16)$$

$$Q_{bat}(t) = Q_{bat}(t-1) \quad (17)$$

3.4Charge Controller Sizing

I_{cc_charge} and I_{cc_output} are calculated as previous Eq.12 and 13[8]. Then, the number of charge controller required in the system, is determined using Eq. 18, 19 and 20, as follows [13]:

$$P_{pv\_max} = P_{stc} * N_{pv} \quad (18)$$

$$P_{cc\_max} = V_{DCbus} * I_{cc\_charge} \quad (19)$$

$$N_{cc} = \frac{P_{pv\_max}}{P_{cc\_max}} \quad (20)$$

where$P_{stc}$is the maximum power output for a solar panel under solar radiation of 1000W/m^2(W),N_{pv} is number of PV panel in an array, and N_{cc} is number of charge controller.

3.5Inverter Sizing

Inverter power rating , P_{inv} is selected using Eq. 14 as stated in section 2.5, where $P_{ACload}$is total power from AC load demand and 1.25 is set as oversized factor [8].

3.6Loss of Power Supply Probability

To calculate LPSP, the equation below is used:

$$LPSP = \frac{\sum_t^T Powerfailuretime}{T} \quad (21)$$

3.7Levelized Cost of Energy

LCOE is calculated by dividing producing electricity annualized cost, $LCC$with total useful electrical energy generated, E_{PV}[4].

$$LCOE = \frac{LCC_{1year}}{E_{PV}} \quad (22)$$

4. Case Study

The performance and the accuracy of the sizing results were evaluated by calculating the Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE). MBE and RMSE[7]are generally used in comparing new developed model and the former model to the actual model. Low value of RMSE ad MBE is desirable. However, for MBE and MPE, each over-estimated data will cancel any under-estimated data.

The expression for MBE, RSME and MPE are as presented by Eq. 22, 23 and 24.

$$MBE = \frac{\left[\sum_{i=1}^{N}\left(Q_{new} - Q_{conv}\right)\right]}{N} \qquad (22)$$

$$RMSE = \sqrt{\left(\frac{\sum_{i=1}^{N}\left(Q_{new} - Q_{conv}\right)^2}{N}\right)} \qquad (23)$$

$$MPE = \left[\sum\left(\frac{Q_{conv} - Q_{new}}{Q_{req}} * 100\right)\right] / N \qquad (24)$$

whereQ_{new} is supply charge conventional method, as calculated using expression below:

$$Q_{new/conv} = Q_{pv} + Q_{bat\_discharging} \qquad (25)$$

5. Case Study

5.1Load Profile

A typical house load profile for rural area in Malaysia is used as a case study andtabulated in Table I.The hourly load profile is as illustrated in Fig. 2 with an assumption that the daily energy requirement remains the same throughout the year [11].

Table 1: Margin specifications

Appliance	Voltage (V)	Power (W)	Daily Usage (h)	Energy (Wh)
Fluorescent Lamp 1	230	20	10	200
Fluorescent Lamp 2	230	40	4	160
TV	230	60	5	300
Refrigerator	230	50	24	1200
Radio Cassette	230	10	11	110
Ceiling Fan	230	60	2	120
Desk Fan	230	25	5	125
Total		265		2215

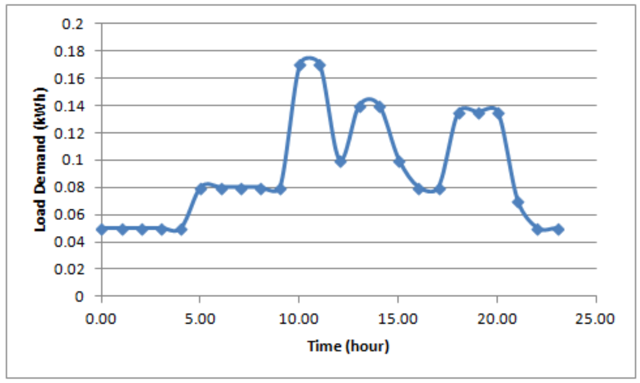

Fig. 2Hourly Load Profile.

5.2Components Price

Solarbuzz[14] provided a complete average monthly pricing for components related to solar industry such as module, inverter, battery, charge controller and solar electricity prices, up until March 2012. The SAPV system components prices are shown in Table 2 below, after conversion into Malaysian currency.

Table 2: SAPV System Components

System Components	Unit	Price
Module	MYR/Wp (≥125 W)	7.5554
Battery	MYR/Output Wh	0.703
Charge Controller	MYR/A	19.565
Inverter	MYR/ W	2.3458
Support Structure & Installation cost	MYR/Wp	4

6. Results and Analysis

The sizing results obtained from an improved method is illustrated in Fig. 3. The optimum configuration obtained based on the lowest LCOEis a 1.4kWp PV array, 130 Ah battery, 54.3A for the minimum rating of charge controller and 340W for the minimum rating of inverter. The results are also compared with published results that used conventional sizing method in [3], as shown in Table 3.

It can be seen that, the improved method giveshigher PV capacity (1.4 kWp) whencompare to the conventional method. This is due to the ISAPVSM includes all possible derating factors in the calculation. Moreover, theconventional results used average daily meteorological data, where it unable to analyze the fluctuation effect in solar irradiance profile toward system sizing. Meanwhile, in[3], the insufficient energy generated is covered by

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having a battery. On the other hand, the battery capacity obtained from this improved method is almost similar to several published papers[11, 15], and much smaller compared to [3]. In the economic analysis, the system's LCOE of the improved method is MYR 1.05/kWh, which is much lower, compared to conventional method, which is RM 1.76/kWh.

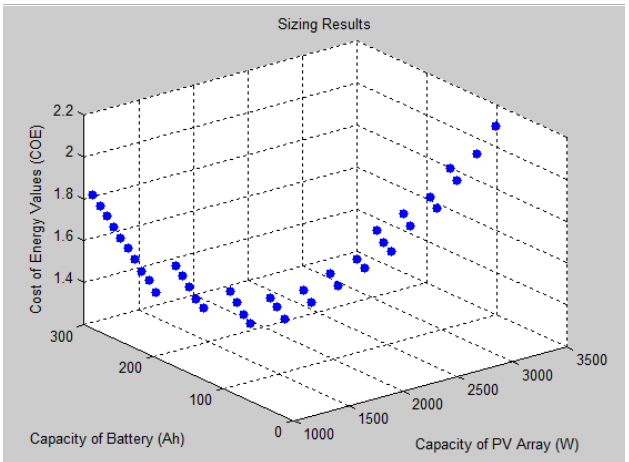

Fig. 3Sizing Results by using an improved sizing method

Table 3: Comparison between CM and ISAPVSM

Improvements	Conventional[3] Nordin, N.	Improved Method
Optimum Design	Ppv=1120Wp; Cbat=500 Ah;	Ppv=1400Wp; Cbat=130Ah; LPSP=0.01
Consider PV & battery connection	√	√
Include temperature effect	√ - Using 0.85 as average value for total derating factors	√
Include ηinv		√
Include ηdirt		√
Include ηwire		√
Include ηmm		√
Using Hourly Analysis	X-monthly	√
PV generator (W)	1120	1400
Capacity Battery (Ah)	500	150
Rating Charge Controller (A)	43.4	54.25
Rating Inverter (W)	331.25	331.25
Max DOD in performance analysis	50%	80%
LPSP	X-not involved	1%
Initial Cost (RM)	23234.27	20,873.37
LCOE (RM/kWh)	1.76	1.05

The performance of the optimized ISAPVSM system isassessed by using statistical indicator, i.e. MBE, RMSE, and MPE. The assessment summary is as in Table 4 below. By comparing the charge supply in the improved SAPV sizing methodto conventional method, the value of MBE, RMSE and MPE are 1.2554, 2.3473 and -8.8653 respectively. From the test, it can be seen that the charge supplied by system in the improved method is higher compared to the conventional method.

Table 4: Assessment by using Statistical Indicator

Methods	MBE	RMSE	MPE
Improved Method	1.2554	2.3473	-8.8653

7. Conclusions

Solar Energy has great potential as one of the alternative energy in Malaysia. SAPV system sizing by using conventional methods have a lot of weakness and tend to give an oversized results. Hence, an improved method was proposed, to improve existing technique. Based on economic analysis, the LCOE obtained by the new method is lower than the conventional method, which is MYR 1.5/kWh. In addition, the statistical tests were performed to analyze the improved sizing method in the systems' performance compared to conventional method.

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References

[1] H. Borhanazad, S. Mekhilef, R. Saidur, and G. Boroumandjazi, "Potential application of renewable energy for rural electrification in Malaysia," *Renewable Energy,* vol. 59, pp. 210-219, 2013.

[2] (28 October 2014). *The Malaysian Economy in Figures 2013*. Available: http://www.epu.gov.my/en/the-malaysian-economy-in-figures-2013

[3] N. D. Nordin and H. A. Rahman, "Design and economic analysis in stand alone photovoltaic system," in *Energy*

Conversion (CENCON), 2014 IEEE Conference on, 2014, pp. 152-157.

[4] J. Abdulateef, K. Sopian, W. Kader, B. Bais, R. Sirwan, B. Bakhtyar*, et al.*, "Economic analysis of a stand-alone PV system to electrify a residential home in Malaysia," in *the 10th IASME/WSEAS International Conference on Heat Transfer, Thermal Engineering and Environment (HTE'12). Istanbul, Turkey*, 2012.

[5] A. Kumra, M. Gaur, R. Kumar, C. Malvi, and R. Gupta, "SIZING OF STANDALONE PHOTOVOLTAIC SYSTEM FOR COTTAGE INDUSTRY IN A REMOTE RURAL AREA IN INDIA."

[6] A. Nafeh, "Design and Economic Analysis of a stand-alone PV system to electrify a remote area household in Egypt," *Open Renewable Energy Journal,* vol. 2, pp. 33-37, 2009.

[7] M. Hankins, *Stand-alone Solar Electric Systems: The Earthscan Expert Handbook for Planning, Design and Installation*: Earthscan, 2010.

[8] S. I. Sulaiman, T. K. A. Rahman, I. Musirin, and S. Shaari, "Sizing grid-connected photovoltaic system using genetic algorithm," in *Industrial Electronics and Applications (ISIEA), 2011 IEEE Symposium on*, 2011, pp. 505-509.

[9] R. Dufo-López, J. M. Lujano-Rojas, and J. L. Bernal-Agustín, "Comparison of different lead–acid battery lifetime prediction models for use in simulation of stand-alone photovoltaic systems," *Applied Energy,* vol. 115, pp. 242-253, 2014.

[10] S. I. Sulaiman, T. K. A. Rahman, I. Musirin, S. Shaari, and K. Sopian, "An intelligent method for sizing optimization in grid-connected photovoltaic system," *Solar Energy,* vol. 86, pp. 2067-2082, 2012.

[11] W. Shen, "Optimally sizing of solar array and battery in a standalone photovoltaic system in Malaysia," *Renewable Energy,* vol. 34, pp. 348-352, 2009.

[12] J. Li, W. Wei, and J. Xiang, "A Simple Sizing Algorithm for Stand-Alone PV/Wind/Battery Hybrid Microgrids," *Energies,* vol. 5, pp. 5307-5323, 2012.

[13] J. Abdulateef, "Simulation of solar off-grid photovoltaic system for residential unit."

[14] S. Buzz. (2012, 1 December 2014). *Module Pricing*. Available: http://www.solarbuzz.com/facts-and-figures/retail-price-environment/module-prices

[15] T. Khatib, A. Mohamed, K. Sopian, and M. Mahmoud, "A new approach for optimal sizing of standalone photovoltaic systems," *International Journal of Photoenergy,* vol. 2012, 2012.

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