Sizing verification of a 4kWp retrofitted grid-connected photovoltaic system: a case study in Shah Alam, Malaysia

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ABSTRACT

Electricity are commonly generated from several types of energy resources such as fossil and nuclear energy. However, due to emission of carbon dioxide from both sources, renewable energy is introduced to provide a clean and secure sustainable energy. One of the potential renewable energy application is Photovoltaic (PV) system; namely grid-connected photovoltaic (GCPV) system and stand-alone photovoltaic (SAPV) system. In this study, a mathematical approach of SEDA's GCPV sizing model is implemented to size a 4kWp of a retrofitted GCPV system by the method claimed to be the best practice mathematical design model under tropical climate Malaysia. The outcome of the sizing approach will then be evaluated with HelioScope software, one of commercial simulation tools available in current market. The final result obtained from both methods shows that the final PV array configuration is 1 x 12 (parallel x series) which is in agreement to the actual installed system.

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1. INTRODUCTION

Due to depletion sources of fossil fuels throughout the world, the renewable energy resources has been introduced based on the capability of the technology to generate a clean and secure sustainable energy [1-2]. The solar energy is converted to electrical power using solar cells that encapsulated inside a PV module [3-4]. There are two types of PV systems; namely grid-connected photovoltaic (GCPV) system and stand-alone photovoltaic (SAPV) system [1-5]

Generally sizing of the PV system can be undertaken by way of mathematical model, simulation and artificial intelligent method [6-16]. In sizing GCPV system, the mathematical model method typically involves PV-to-inverter sizing ratio [17-22]. Upon the sizing, the operation of the GCPV system must be safe to user while obtaining maximum harvesting of solar energy as well as to estimate the best combination of PV array with grid inverter.

To date, various selection of PV modules are obtainable in current market; results in difficulties for the system designers to choose the best combination of PV modules and inverter in the system sizing [15]. In addition, there are many sizing models available worldwide such as mathematical, simulation and artificial intelligent. For the cases in Malaysia tropical climate, SEDA's GCPV system design model is claimed to be the best practice mathematical-based design model [23]. Although, there are selection of computer simulation tools for the design of GCPV system available in the market, only few comparison have been undertaken based on the GCPV array configurations obtained from the proposed sizing model with the available simulation tool. This study presents sizing verification of retrofitted GCPV system on tiles roof under tropical Malaysia. The objectives were:

a. To size a 4kWp of retrofitted GCPV system using SEDA's GCPV sizing model.
b. To evaluate GCPV sizing model of SEDA's method with commercial HelioScope software.

2. RESEARCH METHOD

The GCPV system being evaluated in this study is located in Shah Alam (Lat:3.1°N, Long:101.5 °E). The GCPV system specifications are as listed in Table 1. There are two methods of sizing the respective GCPV system: GCPV sizing model of SEDA method and Helioscope Simulation method. These two methods are required to obtain the final PV array configuration of the installed system. Figure 1(a) shows the flow of sizing model as proposed by SEDA, meanwhile Figure 1(b) shows the flow of sizing model using Helioscope Simulation method.

Table 1. GCPV System Specification

Subjects	Descriptions
Type of system	Grid-connected
Nominal power	4kWp
Array configuration	1 x 12 (parallel x series)
Type of PV module	Poly-crystalline
PV module tilt angle and orientation	20° facing South
Mounting type	Retrofitted

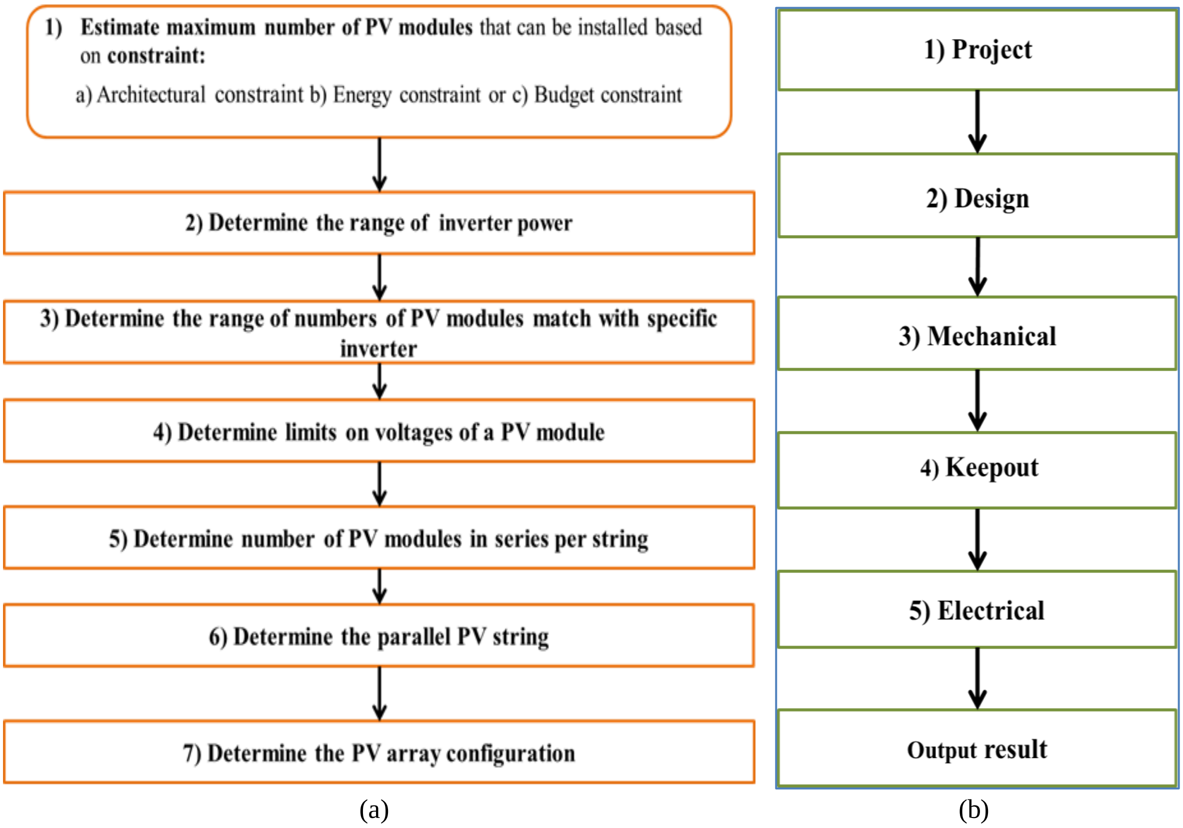


Figure 1. (a) Flow chart on GCPV sizing using SEDA's model, (b) Flow chart on GCPV sizing using simulation method of HelioScope

GCPV sizing model of SEDA method was introduced with reference to Malaysian Standard (MS) and International Standards (IEC) [23]. This sizing model required to design GCPV system in a systematic method to maximize the power output from an available roof space. The initial step of sizing is the estimation of maximum number of PV modules that can be installed based on identified constraints. The constraints can be from the aspect of architectural, energy or budget. Second step was the determination of inverter and followed by the determination of PV modules power capacity. Next, the limits in generated voltage of a PV module need to be determined. From the generated voltage of each PV module, the quantity of PV modules combined in series of each string can be obtained. The voltage must be within the input window of the inverter. Furthermore, the number of parallel PV string can be calculated by matching the maximum input current to the inverter with short circuit current from each PV string. The combination of PV modules in series and parallel strings resulted in PV array configuration.

Simulation method by using HelioScope software (Folsom Lab USA) allows the user to design photovoltaic system [24]. This web-based simulation software provides the detailed wiring diagram together with 3D model design. The software includes two powerful modeling tools: PVSyst and AutoCAD; which is helpful especially getting the quantitative and visual aided results based on the proposed designed.

There are five processes that make it differ from SEDA's method, which are project, design, mechanical, keep-out, and electrical. First step is to write the name of the project including the site location for chosen GCPV system. The HelioScope will display the visualization of the site; which is given by the maps and satellite image. Secondly, design are based on the located area for the PV array installation. Next, all information of both mechanical and electrical part must be included in the PV component databases. For the case where the site consists of any obstruction such as tree, the user can excluded the area in keep-out part. The optimized PV array configuration was determined at the end of simulation together with single line diagram of the complete system.

3. RESULTS AND ANALYSIS

The chosen GCPV system was installed based on budget constraint where the owner invested RM31,000.00 for the installation of solar PV system. In order to complete the mathematical approach in sizing model of SEDA's method [23], a meteorological database and other parameters of the chosen site are required. The steps of the mathematical approach and substitution of values were as shown below:

Step 1: Determine the maximum number of modules and PV array power depending on budget constraint, $P_{arraySTC}$.

$$P_{arraySTC} = \frac{Allocation}{Q_{index}} = \frac{RM\ 31{,}000}{7.75} = 4 \text{ kWp}$$

$$N_{maxMODULE} = round\ down \left[\frac{P_{arraySTC}}{P_{moduleSTC}}\right] = round\ down \left[\frac{4000\ W_p}{320\ W_p}\right] = 12\ modules$$

Where $P_{arraySTC}$ is PV array power at Standard Test Condition (STC), $Allocation$ is the budget for installed system (RM), Q_{index} is the cost index for complete PV system (RM per W_p), $N_{maxMODULE}$ and $P_{moduleSTC}$ the maximum number of module and PV module power at STC respectively

Step 2: Determine the range of inverter power compared to Steca Grid 4200W nominal AC power of inverter for real system.

$$\text{Q} \times f_2 \leq P_{invNOM} \leq \text{Q} \times f_1$$
$$12 \times 320 \times 0.9 \leq P_{invNOM} \leq 12 \times 320 \times 1.0$$
$$3456W \leq P_{invNOM} \leq 3840W$$

Where, f_1 and f_2 are design factor, P_{invNOM} is nominal AC power of inverter (W), Q is the range of inverter power (W).

The range of nominal inverter power should be within 3456W to 3840W. However, the real installed inverter has AC nominal inverter power of 4200W bigger than the maximum estimation of SEDA's method which is 3840W. The analysis of the findings shows that the installed inverter is oversized about 9% from the maximum estimation of nominal inverter power, hence there is no possibility of clamping power occurrence [25]. Thus, the inverter will operate well and has longer lifespan.

Step 3: Determine the range quantity of PV modules to match with power capacity of the inverter

$$N_R = round\ up \left[\frac{P_{invNOM}}{f_1 \times P_{moduleSTC}}\right] to\ round\ down \left[\frac{P_{invNOM}}{f_2 \times P_{moduleSTC}}\right] = 14$$

Where, N_R is the range quantity of PV modules

Step 4: Determine the range voltage of PV module to match the input voltages of inverter.

$$V_{ocMAX} = V_{ocSTC} \times \left\{1 + \left[\left(\frac{\alpha_{v_{oc}}}{100\%}\right) \times (T_{cellMIN} - T_{stc})\right]\right\} = 47.10 \text{ V}$$

$$V_{mpMAX} = V_{mpSTC} \times \left\{1 + \left[\left(\frac{\alpha_{v_{mp}}}{100\%}\right) \times (T_{cellMIN} - T_{stc})\right]\right\} = 38.15 \text{ V}$$

$$V_{mpMIN} = V_{mpSTC} \times \left\{1 + \left[\left(\frac{\alpha_{v_{mp}}}{100\%}\right) \times (T_{cellMAX} - T_{stc})\right]\right\} = 29.92 \text{ V}$$

Where, V_{ocMAX} is the maximum open circuit voltage (V), V_{mpMAX} is the maximum voltage at highest power (V),V_{mpMIN} is Lowest voltage at highest power (V), V_{ocSTC} is the open circuit voltage at STC (V), V_{mpSTC} is the voltage at highest power at STC (V),$\alpha_{v_{oc}}$ is the temperature coefficient of voltage at open circuit (%/°C), $\alpha_{v_{mp}}$ is the temperature coefficient of voltage at high power (%/°C), $T_{cellMIN}$ is the minimum cell temperature (°C), $T_{cellMAX}$ is the maximum cell temperature (°C).
Step 5: Determine the quantity of PV modules in series per string.

$$N_{sMAX} = round\ down\left[\frac{V_{maxINV} \times f_3}{V_{ocMAX}}\right] = 15\ units$$

$$N_{sMPPTmax} = round\ down\left[\frac{V_{maxINVwin} \times f_4}{V_{mpMAX}}\right] = 17\ units$$

$$N_{sMPPTmin} = round\ up\left[\frac{V_{minINVwin} \times f_6}{V_{mpMIN} \times f_5}\right] = 12\ units$$

Where N_{sMAX} is the highest number of PV modules, V_{maxINV} is the highest input voltage of inverter (V), f_3 is the safety margin (decimal), $N_{sMPPTmax}$ and $N_{sMPPTmin}$ are the highest and the least quantity of PV modules at MPPT respectively, $V_{maxINVwin}$ and $V_{minINVwin}$ are the maximum and least input MPPT voltage of inverter respectively (V), f_3, f_4, f_5, f_6 are safety margin (decimal),
Step 6: Determine the quantity of PV modules in parallel per string

$$N_{pMAX} = round\ down\left[\frac{I_{dcMAXinv} \times f_7}{I_{sc\_string\_stc}}\right] = 1$$

Where, N_{pMAX} is the maximum quantity of PV modules in parallel per string, $I_{dcMAXinv}$ is the peak current to the inverter (A), $I_{sc\_string\_stc}$ is the short circuit current of string (A), f_7 is safety margin (decimal).
Step 7: Determine the final configuration based on values from step 5 and step 6.

$$N_t = N_p \times N_s = 1 \times 12 = 12 \text{ modules}$$

Where, N_t is total modules of PV array, N_p is the quantity of PV modules connected in series per string, N_s is the quantity of PV modules attached in parallel.

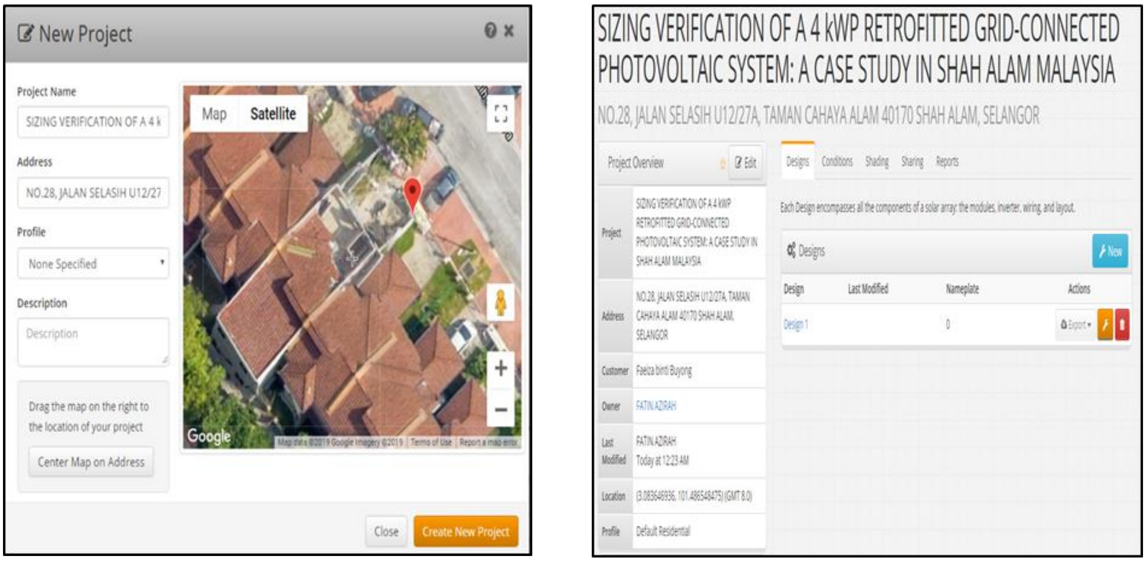
The simulation conducted using HelioScope software aiming to determine the final PV array configuration according to selected modules and inverter.

The steps of the simulation were as shown below:
Step 1: The name of the project together with address of the chosen site was created in HelioScope. The site appeared as in Figure 2(a).
Step 2: 'Design' section was created by inserting several introductory site details as shown in Figure 2(b).
Step 3: Mechanical part begins in this steps where the user or designer set the area for the installation of the PV system. The PV modules related information was inserted as shown in Figure 3.

At this stage, the values for row, module and frame spacing together with the orientation of module either horizontal or vertical have been inserted.
Step 4: 'Keep-out' section was where the user placed a tree or obstruction available at the site because both could contribute to shading as shown in Figure 4. Thus, it can affect the overall performance of the system.

Step 5: The electrical design has been completed by connecting and stringing the inverter with wires. In this part, the model and number of inverter needed to be connected to the chosen PV array according to actual system has been inserted as shown in Figure 5.

Step 6: Single line diagram for the GCPV system design by using commercial HelioScope software was shown. Thus, the final PV combination is 1 x 12 (similar to sizing model of SEDA's method) as shown in Figure 6.



(a) (b)

Figure 2. (a) Project initialization, (b) Project overview

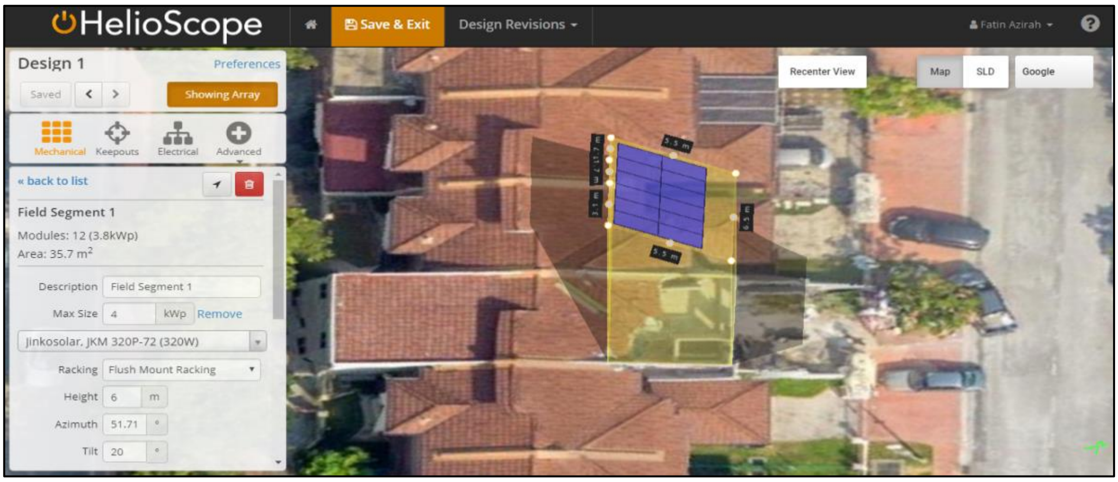


Figure 3. Information on mechanical part of Helioscope

Figure 4. Keep-out part of HelioScope

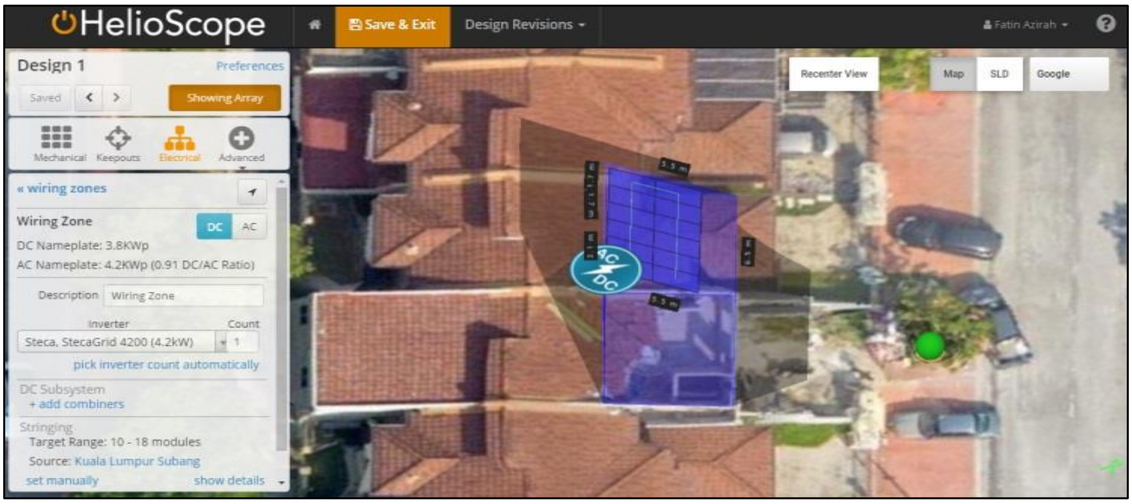


Figure 5. Electrical installation

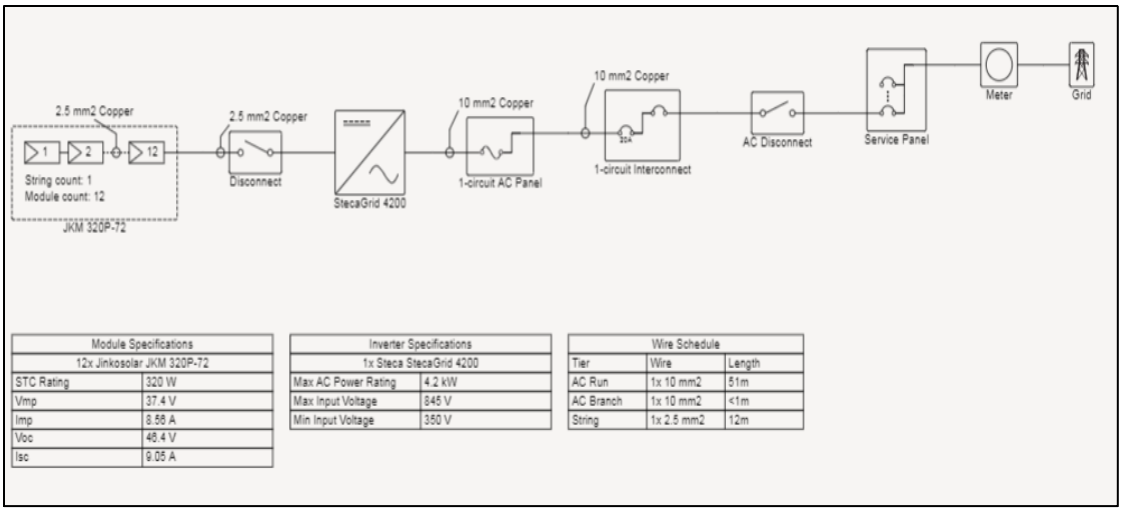


Figure 6. Single line diagram (final PV array combination)

4. CONCLUSION

This paper presents the sizing of a 4 kW_p retrofitted GCPVsystem using SEDA's sizing model. This sizing was based on money invested by the customer with total of RM 31,000 for a complete GCPV system. The sizing was verified by matching the output array of JinKO ($320W_p$) modules with the input of StecaGrid 4200W involving voltages and currents of both electrical devices. The calculations based on sizing model of SEDA method shows that the final configuration of PV array is 1×12 (parallel $\times$ series) in which similar to the actual installed system. This study also evaluated GCPV sizing model of SEDA method with commercial HelioScope software. The parameters namely PV module model and inverter model, tilt angle and azimuth angle were substituted in the simulation software and all the parameters used were based on actual installed system. Final results obtained showed that the optimum combination of PV array is 1×12 (parallel $\times$ series) in which similar to the result using sizing model of SEDA. Thus, the sizing of the installed GCPV system is verified via SEDA method and HelioScope software.

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REFERENCES

[1] Nordin, N. D.and Rahman, H. A. "Pre-installation Design Simulation Tool for Grid-connected Photovoltaic System Using Iterative Methods," *Energy Procedia,* vol. 68, pp. 68-76, 2015.

[2] Alsadi, S. and Khatib., T. "Photovoltaic Power Systems Optimization Research Status: A Review of Criteria, Constrains, Models, Techniques, and Software Tools, " *Appl. Sci*., vol. 8(10), 2018.

[3] Sulaiman, S. I., *et al*. "An intelligent method for sizing optimization in grid-connected photovoltaic system, " *Solar Energy,* vol. 86(7), pp. 2067-2082, 2012.

[4] Abdul Aziz, N. I., *et al*. "Optimal sizing of stand-alone photovoltaic system by minimizing the loss of power supply probability, " *Solar Energy*, vol. 150, pp. 220-228. 2017.

[5] Muhammad-Sukki, F., *et al*. "An evaluation of the installation of solar photovoltaic in residential houses in Malaysia: Past, present, and future, " *Energy Policy*, vol. 39(12), pp. 7975-7987. 2011.

[6] Mansur TMNT, *et al*. "Performance analysis of self-consumed solar PV system for a fully DC residential house, " *Indonesian Journal of Electrical Engineering and Computer Science*.; vol. 8(2), pp. 391-398, 2017.

[7] Mansur TMNT, *et al*. "Sizing and cost analysis of self-consumed solar PV DC system compared with AC system for residential house, " *Indonesian Journal of Electrical Engineering and Computer Science.* vol.10(1), pp 10-18. 2018.

[8] Reyasudin Basir Khan M, *et al*. "Optimal grid-connected PV system for a campus microgrid, " *Indonesian Journal of Electrical Engineering and Computer Science*. vol. 12(3), pp. 899-906, 2018.

[9] Bin Rosselan MZ, *et al*. "Sizing optimization of large-scale grid-connected photovoltaic system using cuckoo search, " *Indonesian Journal of Electrical Engineering and Computer Science.* vol. 8(1), pp. 169-76. 2017.

[10] Irwan YM, *et al*. "Design the balance of system of photovoltaic for low load application,". *Indonesian Journal of Electrical Engineering and Computer Science.* vol. 4(2), pp. 279-85. 2016.

[11] Heine K, *et al.* "A simulation approach to sizing batteries for integration with net-zero energy residential buildings," *Renewable Energy*. vol. 139(c), pp. 176-85. 2019.

[12] Rahmanian B, *et al.* "Application of experimental design approach and artificial neural network (ANN) for the determination of potential micellar-enhanced ultrafiltration process," *Journal of Hazardous Materials*. vol. 187(1–3): pp. 67-74, 2011.

[13] Yang D, *et al.* "Optimal sizing of a wind/solar/battery/diesel hybrid microgrid based on typical scenarios considering meteorological variability," *IET Renewable Power Generation*, vol. 13(9), pp. 1446-1455, 2019.

[14] Zhang F, *et al.* "Optimal sizing of ESS for reducing AGC payment in a power system with high PV penetration, " *International Journal of Electrical Power and Energy Systems*. vol. 110, pp. 809-818. 2019.

[15] S. I. Sulaiman, *et al.* "An intelligent method for sizing optimization in grid-connected photovoltaic system, " *Solar Energy*. vol. 86(7), pp. 2067-2082, 2012.

[16] Mora Segado P, *et al.* "Models to predict the operating temperature of different photovoltaic modules in outdoor conditions, " *Progress in Photovoltaics: Research and Applications*. vol. 23(10), pp. 1267-1282, 2014.

[17] Wang, H., *et al*. "Optimum inverter sizing of grid connected photovoltaic systems based on energetic and economic considerations,". *Renewable Energy,* vol. 118, pp. 709-717. 2017.

[18] Chen, S. L., *et al*. "Determining the optimum grid-connected photovoltaic inverter size, " *Solar Energy,* vol. 87, pp. 96-116, 2013.

[19] Burger, B. R., R. "Inverter sizing of grid-connected photovoltaic systems in the light of local solar resource distribution characteristics and temperature, " *Solar Energy*, vol. 80, pp. 32-45. 2006.

[20] Macedo, W. and N Zilles, R. " Operational results of grid-connected photovoltaic system with different inverter's sizing factors (ISF) " *Progress in Photovoltaics: Research and Applications,* vol. 15, pp. 337-352. 2007.

[21] Louma, J. K. and J Murray, K. "Optimal inverter sizing considering cloud enhancement, " *Solar Energy*, vol. 86(1), pp. 421-429, 2012.
[22] Jafarabadi, R., *et al.* (2019). "Global optimum economic designing of grid-connected photovoltaic systems with multiple inverters using binary linear programming," *Solar Energy*. vol. 183, pp. 842-850, 2019.
[23] SEDA Malaysia Grid-Connected Design Course. Purajaya, Malaysia: Sustainable Energy Development Authority Malaysia, 2014.
[24] HelioScope. (2017). HelioScope Retrieved from https://help.helioscope.com/category/132-getting-started.
[25] Hussin, M. Z., *et al.* "Design installation and testing results of 1 kWp amorphous-silicon FS GCPV system at UiTM, Malaysia,". *In IEEE International Conference on Control System, Computing and Engineering,* pp. 83-88, 2012.

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