Analysis of Hybrid Configuration Solar Power Plant Design at Water Treatment Plant

T P Driarkara, M A Budiansyah, G Alviningsih and A R Utomo
Department of Electrical Engineering, Universitas Indonesia, Depok, Indonesia

E-mail: arutomo@eng.ui.ac.id

Abstract. Human life needs are essentially supported by the need for electrical energy currently faced with environmental issues. Power plants in Indonesia 57.2% still use coal fuel as their primary fuel. The electrical load needed is undoubtedly a critical concern on energy. The existing water treatment plant is still completely dependent on the existing power generation system. We can utilize the available space at the water treatment plant to design a solar-powered electricity generation system. Later, the system with 800 PV modules and 290 batteries that produce 1106.175 MW of power will be able to support the daily electricity needs of water treatment plant.

1. Introduction
Energy remains an essential thing that supports the needs of human life. Energy has become a vital requirement even in encountering other primary needs. However, we are confronting with the issue of conventional energy which delivers a significant impact on the earth. In Indonesia itself, based on available data, 57.22% of the electricity generation still uses conventional coal fuel as its primary fuel. Anticipating the impact on the environment increasingly destructive, then we require a way to suppress it. Many parties have been competing in finding answers to this problem by initiating the idea of clean energy or energy that consumes resources that are not environmentally damaging, renewable natural resources. By utilizing renewable natural resources such as wind, water and the sun, it can help us in answering the issues and problems posed by conventional fuels. One idea is utilizing solar and unlimited energy to be used as an energy generator by utilizing photovoltaic or PV [1-5].

Many studies and methods can be carried out in the preparation of PV so that it can work optimally. With load data and component specifications and supporting information, we can determine how we can arrange PV to provide output that suits our needs. What's more, PV installation can also be useful in locations or places that have problems with renewable natural resources such as water and air, but the sun could be the solution to these problems because the sun will continue to radiate photons during the day. With this, we can apply PV to institutions or fields of providers of human life needs, like water treatment company, as an alternative or additional energy [6-12].

2. Solar Power Plant Design

2.1. Average Derating Factor.
In calculating an ideal PV system, several factors can reduce system reliability. This factor is identified as the derating factor. Derating factors consist of several considerations varying from PV efficiency, to shading and PV components. Each derating factor has its standard range and value. Based on data
obtained from PVWATTs, and adjusting to the components and specifications that we owned, we can obtain the derating factor value by calculating the average value of each factor that influences the efficiency of the PV system. The average of each value contains 2% so that each factor is worth 0.98.

| Table 1. Average Derating Factors. |
|------------------------------------|
| Derating factors                   |
| System Availability 0.98           |
| Sun-Tracking 1                    |
| Age 1                             |
| Shading 1                         |
| PV 0.95                           |
| Inverter 0.984                    |
| Mismatch 0.98                     |
| Overall Derating Factor 0.9849    |

The derating factor values obtained can be used in the calculation in order to search PV power on arrays by comparing Peak Power with the average value of the derating factor.

2.2. Hybrid System

One other type of configuration is a hybrid system. Hybrid system represents a network of solar power plants that however require battery components as supporting energy and also remain connected to existing utility networks. This configuration can, in other words, use PV as a supporting supplier as well as a primary supplier. In fact, with this configuration, electricity companies also gain mutual benefits if the PV system owners are willing to sell the more energy they produce.

![Figure 1. Hybrid System Configuration.](image)

On the other hand, this configuration can also ensure that there is still electrical energy coming in even when PV cannot work due to weather factors and other things. When PV in a sustained period of time is unable to generate electricity, the local network will however conduct electricity from the existing electricity energy utility network. In addition, the amount of battery needed also does not need to be as much as when we install the hybrid configuration because the battery is solely responsible for storing energy reserves and excess energy. It can be suggested that the required battery can adjust without having to maximize system requirements.

Suitable batteries are required according to the calculation of the load and energy capacity generated by PV so that when sunlight is not available due to weather or night, energy can still be transmitted. Calculations from the battery itself require specifications of the battery and its ability to maintain the energy release process and we can determine how long the system can survive without sunlight.
3. Methodology
In the process of calculating the compilation of solar-powered electricity generation systems, several factors are required. The first thing to conclude is to calculate the daily load of water treatment plant. By referring to the existing load and area, the amount of PV can be used so that we can calculate the other supporting components such as inverters and batteries needed and the number of PV modules that can be connected to these inverter components.

The PV module used is the polycrystalline PV module with a maximum capacity of 350 Watts. Table 2 shows the specification of the used PV module.

| Table 2. PV Module’s Specification. |
|------------------------------------|
| Model                             | Polycrystalline                  |
| Max Power at STC                  | 350 W                            |
| Optimum Operating Voltage (Vmp)   | 36.4 V                           |
| Optimum Operating Current (Imp)   | 9.62 A                           |
| Open Circuit Voltage (Voc)        | 43.5 V                           |
| Short Circuit Voltage (Isc)       | 10.6 A                           |
| No. of Cells                      | 60                               |
| Dimension                         | 1700 x 1016 x 40 mm              |
| Module Efficiency                 | 20.3 %                           |

Temperature Characteristic

|                           | 44± 3° C                        |
|                           | -0.30% /°C                      |
|                           | -0.24% /°C                      |
|                           | 0.04% /°C                       |

For the inverter, it has 320 to 800 Volts capacity for DC and nominal power of 20 kW. Table 3 shows the specification of the used inverter module.

| Table 3. Inverter’s Specification. |
|------------------------------------|
| Input (DC)                         |                                |
| Max. Vdc Input                     | 1 kV                            |
| Min. Vdc Input                     | 150 V                           |
| MPP Voltage Range                  | 320 V – 800 V                   |
| Max. PV Input Current              | 33 A                            |

Output (AC)

| Nominal AC Power                  | 20 kW                           |
| Max. AC Apparent Power            | 20 kVA                          |
| Max. AC Output Current            | 29 A                            |
| Number of String                  | 6                               |
| Nominal Grid Frequency            | 50 Hz/60Hz                      |
| Max. Efficiency                   | 98.4 %                          |

This research used lead-acid batteries with a 12 Volt nominal voltage and a capacity of 375 Ah. Table 4 shows the specification of the used battery.
Table 4. Battery’s Specification.

| Model                  | Lead-Acid |
|------------------------|-----------|
| Rated Capacity @20 Hour| 375 Ah    |
| Nominal Voltage        | 12 V      |
| Dimension              | 552 x 337 x 310 mm / 78 kg dry – 104 kg wet |

4. Sizing Components.

4.1. Calculate the Area Needed
By adjusting the needs of water treatment plant, the calculation begins by calculating the area available with the equation.

\[
\text{Array Lenght} = \frac{L_{\text{roof}}}{L_{\text{module}}} \\
\text{Array Width} = \frac{W_{\text{module}}}{W_{\text{roof}}} \\
\text{Max. System Capacity} = N_{\text{max module}} \times P_{\text{MPP}}
\]  

(1) \(\text{Array Lenght} = \frac{L_{\text{roof}}}{L_{\text{module}}} \) 
(2) \(\text{Array Width} = \frac{W_{\text{module}}}{W_{\text{roof}}} \) 
(3) \(\text{Max. System Capacity} = N_{\text{max module}} \times P_{\text{MPP}}\)

4.2. Calculate the Components Needed
This research can get the number of inverters by comparing the power of the generator system with the maximum capacity of the inverter.

\[
N_{\text{inverter}} = \frac{P_{\text{system}}}{P_{\text{max inverter}}} \\
N_{\text{min module}} = \frac{P_{\text{inverter}}}{P_{\text{max module}}}
\]  

(4) \(N_{\text{inverter}} = \frac{P_{\text{system}}}{P_{\text{max inverter}}} \) 
(5) \(N_{\text{min module}} = \frac{P_{\text{inverter}}}{P_{\text{max module}}} \)

The number of modules that we can connect must be between the vulnerable minimum and maximum values of the inverter voltage, so we need to re-examine the number of components we use using the existing principle. The calculation of the number of inverter components at maximum and minimum temperatures is needed by assuming the temperature parameters in the tropics range from 20°C to 75°C.

\[
V_{\text{DC, max}} = V_{\text{OC, STC}} + (T_{\text{max}} - T_{\text{STC}}) \times V_{\text{OC, temp. coeff}} \times V_{\text{OC, STC}}
\]  

(6) \(V_{\text{DC, max}} = V_{\text{OC, STC}} + (T_{\text{max}} - T_{\text{STC}}) \times V_{\text{OC, temp. coeff}} \times V_{\text{OC, STC}}\)

\[
V_{\text{MP, min}} = V_{\text{MPP, STC}} + (T_{\text{min}} - T_{\text{STC}}) \times V_{\text{MP, temp. coeff}} \times V_{\text{MPP, STC}}
\]  

(7) \(V_{\text{MP, min}} = V_{\text{MPP, STC}} + (T_{\text{min}} - T_{\text{STC}}) \times V_{\text{MP, temp. coeff}} \times V_{\text{MPP, STC}}\)

The maximum and minimum voltage must be between the inverter operating input voltage limits. This is so that the inverter can work in optimal conditions.

\[
N_{\text{min max}} = \frac{V_{\text{DC(max/min)}}}{V_{\text{OC(max/MPP,min)}}}
\]  

(8) \(N_{\text{min max}} = \frac{V_{\text{DC(max/min)}}}{V_{\text{OC(max/MPP,min)}}}\)

The maximum and minimum vulnerability in the number of inverters intended for each string can be used as a backup at any time to overcome possible damage or any maintenance problems that occur.

4.3. Sizing Battery
Based on the battery data used, we need to find the Power value on the PV Array by comparing the average energy required per day with the average factor of the derating factor efficiency. The average energy needed is divided by the amount of sunlight to irradiate, assuming 5 hours per day.

\[
W_{\text{peak}} = \frac{P_{\text{daily avg.}}}{T_{\text{sun}}} \\
P_{\text{PV Array}} = \frac{W_{\text{peak}}}{\eta} \\
E_{\text{rough}} = P_{\text{PV Array}} \times DoA
\]  

(9) \(W_{\text{peak}} = \frac{P_{\text{daily avg.}}}{T_{\text{sun}}} \) 
(10) \(P_{\text{PV Array}} = \frac{W_{\text{peak}}}{\eta} \) 
(11) \(E_{\text{rough}} = P_{\text{PV Array}} \times DoA\)

A safe energy value is required so that the battery condition is maintained from damage caused by usage in the amount of rough energy. Safe energy \(E_{\text{safe}}\) can be determined by dividing rough energy with the Maximum Allowable Deep of Discharge (MoDD) of 85%.

\[
E_{\text{safe}} = \frac{E_{\text{rough}}}{\text{MoDD}}
\]  

(12) \(E_{\text{safe}} = \frac{E_{\text{rough}}}{\text{MoDD}}\)
\[ Total\_Capacity\_{Battery} = \frac{E_{safe}}{V_{Battery}} \]  
\[ N_{Battery} = \frac{Total\_Capacity\_{Battery}}{Capacity\_{Battery}} \]  
\[ N_{Series\_Battery} = \frac{V_{System}}{V_{Battery}} \]  
\[ N_{Parallel\_Battery} = \frac{N_{Battery}}{N_{Series\_Battery}} \]

5. Data and Analysis

Average total daily load from water treatment plant was found to be 5,447,357,143 kWh. This data, moreover, became a reference load for the arranging of a PV system. Table 5 shows the load demands of water treatment plant.

Table 5. Load Data of Water Treatment Plant

| Mon  | Tue  | Wed  | Thu  | Fri  | Sat  | Sun  |
|------|------|------|------|------|------|------|
| 5558.8 | 5691 | 5288 | 5445.6 | 5852.1 | 5189.2 | 5106.8 |
| Average | 5447.357143 kWh |

On the existing area which is 50 m x 16 m, by leaving 1 m on the edge of the roof and 0.36 m between each series module, each building can accommodate 25 PV modules in parallel connection and 16 PV modules in series connection which leads to 400 PV modules in total. According to calculation above, in order to fully support the load, we need one more area to install the system which led to using two rooftop area on water treatment plant’s site.

14 inverters are needed in this solar power generation system to meet existing loads. Each inverter can be connected with 58 PV modules. If it determined based on the values of $V_{oc\_max}$ and $V_{MPP\_min}$, we can obtain that at least 10 inverters were used and a maximum of 19 inverters. This determines that the 14 modules needed are the ideal number for the system to be designed because they are between the maximum and minimum intervals.

In order for the system to be designed to use hybrid configurations, battery bank is needed so it can be used when PV cannot provide electrical energy. The battery calculation is done by finding a safe energy value of 1,301.38196 kWh with power on the PV Array and rough energy of 1,106,175 kWh. Assuming the sun irradiates PV for a maximum of 5 hours per day with a DoA value of 24 hours (1 day).

The total capacity of the battery is 108,448.9467 Ah. Based on the calculations that have been done, it is discovered that the total battery needed is as much as 289,195 units with rounding to 290 units provided that the battery is installed in series of two pieces and parallel as many as 145 units.

In this condition, the energy supplied by the grid will temporarily cover the loads while PV recharges the battery. The designed PV system is expected to be able to support the load demands of water treatment plant every day accompanied by a note that sunlight can still illuminate the PV module. Table 6 shows the number of components needed to make a Solar Power Plant.

6. Conclusion

To fulfill the load demands of water treatment plant every day, the required area represents twice the size of the present building. The system can be established with an area of 50m x 16m building and requires two buildings. With a total of 800 PV modules, 14 inverter modules and 290 batteries. The system can be established with hybrid configurations. The battery designed can provide for the need for a one full day without the assistance of PV.
Table 6. Number of Components Needed.

| PV Module          |          |
|--------------------|----------|
| Total Series       | 16 x 2   |
| Total Parallel     | 25 x 2   |
| Total Module       | 400 x 2  |
| Nominal Power      | 140 kWp x 2 |

| Inverter           |          |
|--------------------|----------|
| Number of Inverter | 14       |
| Operating Voltage  | 320 – 800 V |

| Battery            |          |
|--------------------|----------|
| Total Series       | 2        |
| Total Parallel     | 145      |
| Total Batteries    | 290      |
| Total Capacity     | 108448.4967 Ah |

References

[1] IEEE Std. 2003 IEEE Standard for Interconnecting Distributed Resources With Electric Power Systems 1547-2003.
[2] Ben K 2010 Distribution System ModelsPower System Studies and Modeling PV Inverters Utility/Lab Workshop on PV Technology and Systems Tempe Arizona, pp. 8-9.
[3] Foley G 1995 Photovoltaic Applications in Rural Areas of the Developing World World Bank Technical Paper 304, Energy Series 1995.
[4] Tiandho Y, Sunanda W, Afriani F, Indriawati A and Handayani T P 2018 Accurate model for temperature dependence of solar cell performance according to phonon energy correction Latvian Journal of Physics and Technical Sciences 55 15-25
[5] Hemakshi B, Gaurang S, An Analysis of One MW Photovoltaic Solar Power Plant Design International Journal of Advanced Research in Electrical Electronics and Instrumentation Engineering 3 6969.
[6] Kenny R P, Friesen, G, Chianese D, and Dunlop E D 2003 Energy Rating of PV Modules: Comparison of Methods and Approch, 3rd World Conference on Photovoltaic Energy Conversion May 2003.
[7] Chianese D, Cereghetti N, Rezzonico S and Travaglini G 2001 Power and energy production of PV modules 17th EPVSEC.
[8] Yang B, Li W, Zhao Y and He X 2010 Design and analysis of a grid-connected photovoltaic power system IEEE Trans. Power Electron. 25 pp. 992-1000.
[9] Paravalos C, Koutroulis E, Samoladas V, Kerekes T, Sera D and Teodorescu R 2014 Optimal design of photovoltaic systems using high time-resolution meteorological data IEEE Trans. Ind. Informat. 10 pp. 2270-2279.
[10] Kerekes T, Koutroulis E, Sera D, Teodorescu R and Katsanevakis M 2013 An optimization method for designing large PV plants IEEE J. Photovolt.3 pp. 814-822.
[11] Siemens 2010 PSS®E: Transmission System Analysis and Planning. [Online] Available at: http://www.energy.siemens.com/hq/en/services/power-transmission-distribution/power-technologies-international/software-solutions/pss-e.htm [Accessed 20 April 2019]
[12] Handayani T P, Hulukati S A, Jaya R, Tiandho Y, Abdullah R 2019 The prototype of solar-powered building lighting IoT IOP Conference Series: Materials Science and Engineering 486 012079

Acknowledgement
This research is funded by a research grant of HIBAH PITTA B 2019 No. NKB-0694/UN2.R3.1/HKP.05.00/2019 from Universitas Indonesia.