Standalone Photovoltaic System Cost Optimization for Matantimali Village Central Sulawesi

Bandiyah Sri Aprillia, I Made Hendry Keswara, Jangkung Raharjo, Mohamad Ramdhani, Kharisma Bani Adam and Efri Suhartono

1School of Electrical Engineering, Telkom University, Bandung, Indonesia

Abstract. Electricity is very limited in Matantimali village where it is located on the slopes of Gawalise, Marawola District, Sigi Regency, Central Sulawesi Province. In this village, the state electricity company (PLN) can only provide electricity during the day from 06:00 to 18:00. During night, the diesel generator becomes the main energy source for the village providing electrical energy from 18:00 until 06:00. However, the use of diesel generators contradicts with the government commitment to generate environmentally-friendly power generation. This study aims to analyse and to optimize the price of off-grid solar systems which will be implemented in the village of Matantimali as a potential replacement of the existing diesel based electric energy. We find in this study that 11 PV units with a total power of 3,686 Wp, two 2400 W powered inverter, and a 16-unit battery cover are the required specification for optimal power of 1300 V A load. The Off-grid solar panel installation system creates annual cost savings of IDR 3,543,397 compared to the use of conventional electricity using diesel generators and PLN.

1. Introduction
Increasing global energy demand is one of the biggest challenges experienced by modern society. To meet this demand, nearly 80% of our energy consumption comes from fossil fuels (gasoline, coal and natural gas). However, these energy sources are non-renewable. The most dangerous aspects related to its use are air pollution and rising global temperatures [1].

Matantimali Village, located in Marawola Sub district, Sigi Regency, Central Sulawesi Province, is on the Gawalise Mountains at an altitude of 1,500 meters above sea level. The location of the village is very far from the city resulting in very limited availability of electricity. PLN can only provide electricity during the day, from 06:00 to 18:00. During the off hours, the community’s solution is to use diesel generators to obtain electricity.

Renewable energy is an alternative method to generate electricity. Among renewable energy choices, solar energy can directly convert solar radiation energy into electrical energy [2]. Therefore, the electrical energy produced by solar power stations connected to the network is very dependent on solar radiation [3]. In solar power systems, solar panels can be connected on-grid or off-grid [4,5]. In the Off-grid system, solar panels are connected to batteries as storage media or energy banks [5,6]. Whereas on the On-grid system require solar panels to be connected to the PLN grid and can be regulated according to their energy requirements load.

The integration of hybrid renewable energy in remote and rural areas can supply the needed power needs and reduce emissions. Hence solar, wind, hydro and biomass energy, as well as hybrids,
can effectively electrify rural areas [7]. To maintain the level of hybrid energy storage in meeting peak loads during the use of biomass, wind, and solar energy sources during periods of low or no solar radiation or during periods of low wind it is strongly recommended to use storage media [8]. The integration of hybrid power plants sourced from renewable energy (solar panels) and conventional power (diesel generators) sourced from fuel is also one of the beneficial solutions to meet the needs of daily electricity loads in remote areas such as Sirilogui Village, located in the District of North Siberut, Mentawai Islands Regency [9]. However, the use of generators is very contradictory to the government’s commitment to generate environmentally friendly power because the generators used are based on fossil fuel (biodiesel) and if the generator is damaged, then the village has no electricity at night.

Based on BPPT data, BMG of Matantimali Village has solar radiation intensity reaching 5,512 Wh/m². Therefore, the appropriate method to generate power for the village would be a photovoltaic solar power station. This research aims to design an off-grid photovoltaic system with the lowest possible cost planning. The results of this study are expected to be considered appropriate electrification designs for the village of Matantimali, Central Sulawesi, Indonesia

2. Research Methodology
Research methodology during the study is shown in Figure 1 as follows:

![Figure 1. Research Methodology](image)

Figure 1 describes the research method carried out by the author. Starting from studying literature and looking for references from books, journals, etc. The survey was conducted at the location to
collect data and to analyse the intensity of solar radiation at the location of the house that will be reviewed in this study. Before simulation and analysis, we must first analyse the electricity needs of one house in the village of Matantimali. After analysing the electricity requirements, it is continued by designing the optimum off-grid PV system.

2.1. System Design
Broadly speaking, the system design contains data of daily electricity load (kWh), location in the form of a map, and also the cost and specifications of components.

![Figure 2. System Design](image)

Figure 2 shows the design of a solar electric energy installation system consisting of solar panels, converters and batteries to meet load requirements. The solar panel functions as a DC input connected to the battery and the voltage on the battery is converted to AC voltage by the inverter to meet load requirements.

2.2. Solar Panel Installation Design

![Figure 3. Photovoltaics Installation Design](image)

Figure 3 shows the solar panel installation design in a house located in the village of Matantimali. Solar panels would be installed on the roof of the house with 2 inverters. Green dots are used to represent trees around the solar panels.
2.3. Residential load profile in Matantimali Village

Electricity load study is a method used to calculate daily energy consumption. Electrical energy consumption in Table 1 is obtained by listing electrical loads (load groups, type of load, load power rating) and making a load profile as shown in Figure 4 which contains daily load period.

Table 1 shows the daily use of household electricity in Matantimali Village from 00:00 to 23:00.

| No | Time | Loads | Total (W) |
|----|------|-------|-----------|
| 1  | 00.00| Lights 10 x 5 = 50 | 50 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | **Total: 350** | **Total: 350** |
| 2  | 01.00| Lights 10 x 5 = 50 | 50 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | **Total: 350** | **Total: 350** |
| 3  | 02.00| Lights 10 x 5 = 50 | 50 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | **Total: 350** | **Total: 350** |
| 4  | 03.00| Lights 10 x 5 = 50 | 50 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | **Total: 350** | **Total: 350** |
| 5  | 04.00| Lights 10 x 5 = 50 | 50 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | **Total: 350** | **Total: 350** |
| 6  | 05.00| Lights 10 x 5 = 50 | 50 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | **Total: 350** | **Total: 350** |
| 7  | 06.00| Lights 10 x 5 = 50 | 50 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | **Total: 350** | **Total: 350** |
| 8  | 07.00| Lights 10 x 5 = 50 | 50 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | Rice Cooker 400 x 1 = 400 | 400 |
|    |      | **Total: 400 + 750** | **Total: 1150** |
| 9  | 08.00| Lights 10 x 5 = 50 | 50 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | Rice Cooker 400 x 1 = 400 | 400 |
|    |      | Handphone Chargers 5 x 1 = 5 | 5 |
|    |      | **Total: 50 + 300 + 400 + 5** | **Total: 755** |
| 10 | 09.00| Lights 10 x 5 = 50 | 50 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | Rice Cooker 400 x 1 = 400 | 400 |
|    |      | Handphone Chargers 5 x 1 = 5 | 5 |
|    |      | TV 60 x 1 = 60 | 60 |
|    |      | **Total: 50 + 300 + 400 + 60** | **Total: 815** |
| 11 | 10.00| Lights 10 x 5 = 50 | 50 |
|    |      | Handphone Chargers 5 x 1 = 5 | 5 |
|    |      | TV 60 x 1 = 60 | 60 |
|    |      | **Total: 50 + 5 + 60** | **Total: 115** |
| 12 | 11.00| Lights 10 x 5 = 50 | 50 |
|    |      | Fans 45 x 1 = 45 | 45 |
|    |      | Handphone Chargers 5 x 1 = 5 | 5 |
|    |      | TV 60 x 1 = 60 | 60 |
|    |      | **Total: 50 + 45 + 5 + 60** | **Total: 160** |
| 13 | 12.00| Lights 10 x 5 = 50 | 50 |
|    |      | Fans 45 x 1 = 45 | 45 |
|    |      | Handphone Chargers 5 x 1 = 5 | 5 |
|    |      | TV 60 x 1 = 60 | 60 |
|    |      | **Total: 50 + 45 + 5 + 60** | **Total: 160** |
| 14 | 13.00| Lights 10 x 5 = 50 | 160 |
|    |      | Kipas 45 x 1 = 45 | 45 |
|    |      | Handphone Chargers 5 x 1 = 5 | 5 |
|    |      | TV 60 x 1 = 60 | 60 |
|    |      | **Total: 160 + 60 + 5** | **Total: 760** |
| 15 | 14.00| Lights 10 x 5 = 50 | 400 |
|    |      | Kipas 45 x 1 = 45 | 45 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | Handphone Chargers 5 x 1 = 5 | 5 |
|    |      | TV 60 x 1 = 60 | 60 |
|    |      | **Total: 400 + 360** | **Total: 760** |
| 16 | 15.00| Lights 10 x 5 = 50 | 350 |
|    |      | Refrigerators 300 x 1 = 300 | 300 |
|    |      | Handphone Chargers 5 x 1 = 5 | 5 |
|    |      | TV 60 x 1 = 60 | 60 |
|    |      | **Total: 350 + 60 + 5** | **Total: 415** |
Data of a day’s worth of electricity consumption was obtained to calculate the daily energy consumption which was then arranged in table 1.

2.4. System Specification

| Components    | Specification |
|---------------|---------------|
| Inverter      | DC 2400 W     |
| PV            | 340 Wp        |
| Battery       | 12V/100Ah     |

Table 2 shows PV system specifications used in this research. Components used consist of inverter, PV, and batteries.

2.5. Solar Panel Requirements Calculation

The solar panels are designed with 100% of the load requirements. The solar panel calculations needed are as follows:

\[
\text{Total solar panel energy} = 100\% \times 1.3 \times \text{Total power in one day}
\]

\[
= 100\% \times 1.3 \times 9,640
\]

\[
= 12,532 \text{ Wh/day}
\]

(1)

Note: Percent supply of solar panels = 100%

Note: 1.3 is obtained from a one – power factor.

\[
\text{Wp is required} = \frac{\text{Total solar panel energy}}{\text{Solar panel generator factor}} = \frac{12,532}{3.4}
\]

\[
= 3,686 \text{ Wp}
\]

(2)

The number of solar panels = \( \frac{3,686}{340} = 10.841 \approx 11 \text{ pcs} \)

(3)

2.6. Components Prices

Component prices are adjusted to the specifications needed to make costs within reason and in accordance with system requirements.
Table 3. Price Table and Component Specification

| Components  | Specifications | Prices Per-Components (IDR) | Amount | Total Price (IDR) |
|-------------|----------------|-----------------------------|--------|-------------------|
| Inverter    | 2400 W         | 6,675,000                   | 2      | 13,350,000        |
| Solar Panels| 340 Wp         | 2,280,000                   | 6      | 25,080,000        |
| Batteries   | 12 V ; 100 Ah  | 3,685,194.45                | 4      | 14,740,777.80     |
| Total       |                |                             |        | 53,170,777.8      |

Component prices consisting of: inverter, solar panels, and batteries are searched in accordance to the system requirements. The total cost required is IDR 37,615,777.8.

Total electric load in one year = 9,640 x 1 year = 9,640 x 366 days = 3,528.24 kWh/year (4)

Total power needed = 3,528.24 kWh/year x 100% x 1.3 = 4,586.712 kWh/y (5)

Total power = Total electricity load in one year – Total power needed in PV = 1,058.472 kWh/year (6)

Power pricing of PLN = IDR 1600/kWh

Cost of Energy (each unit) = (Total Power x Price of PLN power)/Total power needed in PV = (1,058.472 x 1600)/4,586.712 = IDR 369.230/kWh.

2.7. PLN and Diesel Generator Costs

Matantimali Village is a village that uses PLN and diesel generators as a daily electricity supply with a total load of 1300 VA. PLN supplies from 06.00 until 18.00. During those 12 hours according to the data that has been obtained, the power load is 5.83 kWh using the PLN electricity network. So, it can be calculated:

The cost of PLN electricity in one day = price of 1 kWh x load power consumption = IDR 1600 x 5.83 = IDR 9,328.

1 year = 366 days. So, in one year the cost that must be spent for electrical energy from PLN supplies is IDR 9,328 x 366 = IDR 3,414,048.

Whereas from 18:00 to 6:00 the village of Matantimali uses a generator to generate electricity. Generators used have 80% efficiency of the maximum power load installed in each house. Then the generator needed for a load of 1300 VA or 1300 Watt is a generator that has 2500 Watt power. The generator uses biodiesel fuel. So the price that can be issued by heating 12 hours on the generator can be calculated:

2500 Watt generator power = 2.5 kWatt.

Fuel used for 12 hours = diesel consumption per kilowatt hour x generator power in kilowatt x heating time = 0.21 x 2.5 x 12 = 6.3 liters.

Price of Bio Solar = IDR 9,400

So, the price of generator fuel issued in 1 day = fuel used for 12 hours’ x the price of generator fuel (biodiesel) = 6.3 x 9,400 = IDR 59,220 / day.
1 year = 366 days
Therefore, the cost of generator fuel in one year is IDR 59,220 x 366 = IDR 21,674,520.

**Table 4.** Conventional Electricity Cost Calculation

| Supply                  | Period | Load or Fuel | Yearly Cost    |
|-------------------------|--------|--------------|----------------|
| Diesel Generators       | 12 hour| 6.3 Liter    | IDR 21,674,520 |
|                         |        |              |                |
| Total                   |        |              | IDR 25,088,568 |

3. RESULT AND DISCUSSION

HOMER application was used to simulate the installation of a circuit that has been made and to calculate the Net Present Cost (NPC) and the cost of power per kWh (COE). The results of the HOMER simulation are arranged to have a possibility on the NPC and COE values. NPV and COE are affected by the intensity of sunlight and the fraction of renewable energy used.

**Table 5.** HOMER Application Standalone PV System Simulation Results

| Components                          | HelioScope (PV) | Battery (unit) | Converter (Inverter) (KW) | NPC (IDR) | COE (IDR) | Operational Cost (IDR/year) | Installation Cost (IDR) | Rent Fraction (%) | Initial Cost (IDR) |
|-------------------------------------|-----------------|----------------|---------------------------|-----------|-----------|-----------------------------|-------------------------|------------------|-------------------|
| Total                               | 11              | 16             | 4.8                       | 325 M     | 4,775     | 11.9 M                      | 97.4 M                  | 100              | 25,080,000        |

Table 5 shows the Off-Grid system configuration in the house located in Matantimali village using the HOMER application. The configuration results obtained by the system can meet 100% of the electrical needs with daily electricity load consumption of 9,640 Wh/day with the installation of 11 units of PV configuration with 3,686 Wp, inverter powered 2400 W, and batteries 16 units in total and an expense procurement cost of up to IDR 90,700,000. Off-grid installation systems will cover the expensive costs of the electrical energy gains in PV. Based on calculation, the total cost to be paid for 25 years for the installation of the Off-Grid system is IDR 325,000,000. The batteries are used to store electricity as much as 16 units. The greater the profit (greater Rent Friction), the lower the operational costs of the system, but the higher the present total net cost (NPC), therefore the higher the operational costs.

Table 6 shows the Off-grid system installation by calculating the NPC and COE on the solar panel installation in yearly usage and the total annual cost amounts to IDR 21,465,170.

**Table 6.** Pricing Comparison with Conventional Method

| System               | Total cost in IDR/Year | Total Cost | Savings in IDR/Year |
|----------------------|------------------------|------------|---------------------|
| Solar Panel Installations | 21,465,170             | 21,465,170 |                     |
| PLN                  | 3,414,048              | 25,088,568 | 3,543,397           |
| Diesel Generators    | 21,674,520             |            |                     |
Table 6 shows the comparison of Off-grid system installations with conventional electrical energy in annual usage. The total profit can be obtained reaching IDR 3,543,397 per year with the configuration of the standalone PV system.

4. CONCLUSION
The power requirements of 1300VA in Matantimali Village can be fulfilled with the Off-grid solar power system. Based on the analysis results of the configuration of 11 PV units with 3,686 Wp power, two 2400 W power inverter, and 16 units of batteries would produce optimum results. Our proposed the Off-grid solar panel installation system will save the amount of IDR 3,543,397 per year compared to conventional electricity in the form of diesel generators and PLN grid.

References
[1] Nicoletti G 2015 A technical and environmental comparison between hydrogen and some fossil fuels Energy Conversion and Management. 89 p 205-213.
[2] Ozoegwu C, C Mgbemene and P A Ozor 2017 The status of solar energy integration and policy in Nigeria Renewable and sustainable energy reviews. 70 p 457-471.
[3] Aprillia B S, C Ekaputri and M R Z Fahmi Solar Cell Output Optimization using Light Convergence Method.
[4] Aprillia B S and M A F Rigoursyah 2020 Design On-Grid Solar Power System for 450 VA Conventional Housing using HOMER Software.
[5] Al Nabulsi A and R Dhaouadi Efficiency optimization of a DSP-based standalone PV system using fuzzy logic and dual-MPPT control. IEEE Transactions on Industrial informatics 2012 8(3) p 573-584.
[6] Zubi, G., Dufo-López, R., Pasaoglu, G., & Pardo, N. (2016). Techno-economic assessment of an off-grid PV system for developing regions to provide electricity for basic domestic needs: A 2020–2040 scenario. Applied Energy, 176, 309-319.
[7] Hossain F M 2015 Impact of renewable energy on rural electrification in Malaysia: a review. Clean Technologies and Environmental Policy. 17(4) p 859-871.
[8] Balamurugan P, S Ashok and T Jose 2009 Optimal operation of biomass/wind/PV hybrid energy system for rural areas International Journal of Green Energy 6(1) p 104-116.
[9] Sari D P and R Nazir 2015 Optimalisasi desain sistem pembangkit listrik tenaga hybrid diesel generator-photovoltaic array menggunakan HOMER (studi kasus: Desa Sirilogui, Kabupaten Kepulauan Mentawai) Jurnal Nasional Teknik Elektro. 4(1).