Technical study of 1.2 KWP solar plant on Tanbihul Ghoafilin
Islamic Boarding School Banjarnegara

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Abstract. The depletion of fossil energy, especially oil and gas, and international commitments in reducing emissions has prompted the government to make renewable energy a top priority to maintain energy security and independence. One of the renewable energies that have great potential in Indonesia is solar energy. Indonesia's solar energy potential reaches 207.8 GWp. However, Indonesia's current installed capacity is only 0.085 GWp or 0.04% of the total solar energy potential in Indonesia. The purpose of this study was to design and analyze the technical potential of on-grid solar plant installation at the Tanbihul Ghoafilin Islamic Boarding School with a capacity of 1.2 kWp using PVsyst 7.2 software. This Solar Plant is estimated to produce 1.7 MWh of energy in one year with a Performance Ratio of 84%.

1. Introduction

The depletion of fossil energy, especially oil and gas, the global commitments to reducing greenhouse gas emissions have encouraged the Indonesian government to continuously increase new and renewable energy to maintain energy security and independence. One of the new and renewable energies that have great potential in Indonesia is solar energy. Indonesia's solar energy potential reaches 207.8 GWp. However, Indonesia's current installed solar energy capacity is only 0.085 GWp or 0.04% of the total solar energy potential in Indonesia [1].

New and Renewable Energy is developed and optimized by changing the mindset that NRE is no longer alternative energy for fossil fuel but a national energy supply. Based on Government Regulation number 79 of 2014 on National Energy Policy Article 9 Letter f Number 1, NRE share is at least 23% in 2025 and 31% in 2050 provided that it meets the economic. NRE demand is projected to increase to 21 million TOE in 2025 and 49 million TOE in 2050. Total NRE input to a power plant is 45.5 million TOE in 2025 and 166 million TOE in 2050, with the most significant share coming from geothermal, hydro, and solar power. Primary energy from solar is 1.8 million TOE in 2025 and will increase sharply to 73 million TOE in 2050 [2].

With the potential for solar energy, which is relatively high in Indonesia and with regulatory support from the government, it is expected to be a solution to the high demand for electricity in Indonesia in the future by using solar cells as a source of electrical energy. Solar Power Plant is one application of new and renewable energy, with the sun as the primary energy source. Given the increasing number of household customers, utilizing the house’s roof as a solar power plant can be effective and efficient. So, the purpose of this research is to design and analyze the potential of rooftop solar power plants with on-grid systems in terms of engineering and economic analysis using PV Syst 7.2 software.
2. Methodology

2.1. Solar Radiation
Solar radiation is the amount of energy received by the earth per unit area per unit time whose value changes depending on several factors, such as latitude, season, and time [5]. There are four types of radiation. These are Direct Normal Irradiation (DNI) which is direct irradiation from the sun, Diffuse Horizontal Radiation (DHI) caused by scattering of atmospheric particles, and Global Horizontal Irradiation (GHI), the sum of Direct Radiation and Diffuse Radiation [7].

\[ GHI = DNI + DHI \]  \hspace{1cm} (1)

2.2. Solar Power Plant
A solar power plant is a power plant that uses sunlight as an energy source through solar cells and converts sunlight into electricity. The solar cell is a thin semiconductor material made of pure silicon and other semiconductor materials [8]. PLTS is an environmentally friendly power plant with no rotating parts, is not noisy, and does not cause hazardous waste to the environment. However, several factors affect the efficiency of solar cell output power, namely, the influence of solar radiation, solar cell temperature, solar panel orientation, and shading [9].

2.2.1. Photovoltaic Module. A Photovoltaic Module is a Solar Power Plant component composed of several solar cells arranged in such a way, either in series or parallel, to produce a specific voltage or current and set in one frame and laminated or given a protective layer. The solar cell itself is a semiconductor element that can convert solar energy into electrical energy based on the photovoltaic effect. Then the arrangement of several solar modules mounted in such a way on support is called an array.

There are three main types of photovoltaic modules according to their material. Monocrystalline Photovoltaic, Polycrystalline Photovoltaic, and Thin Cells Photovoltaic. Monocrystalline has been a favorable option due to its high efficiency in producing energy. While thin cells are not that popular because of their low efficiency [15]

\[ (\text{maximum PV efficiency}) = \frac{P_{\text{max}}(\text{Maximum Power Output})}{E(\text{Incident Radiation}) \times A(\text{Area of Collector})} \]  \hspace{1cm} (2)

2.2.2. Inverter is a tool that converts direct current (Direct Current) into alternating current (Alternating Current). Inverter in Solar Power Plant used as a power control system. The inverter converts the direct current (DC) generated by the solar module into alternating current (AC) electricity, which will control the quality of the electrical power issued to be sent to the load or power grid. Inverters may be classified into three broad types [8]:
- The stand-alone inverter is designed for a remote off-grid power system with battery backup where the inverter draws its DC power from batteries charged by PV array and converts it to AC power. When available, many stand-alone inverters also incorporate integral battery chargers to replenish the battery from an AC source. Usually, these do not interface with the utility grid and are not required to have anti-islanding protection.
- Grid-tie inverter is designed to shut down automatically upon loss of utility supply for safety reasons. They do not provide backup power during utility outages. This kind of which match phase with a utility-supplied sine wave [8].
2.3. Simulation Design
In this research, PVSyst software is used to determine the performance of a solar power plant and as a tool for conducting technical analysis. Flow chart of the study can be seen in Figure 1 below.

![Figure 1. Research Flowchart.](image)

2.4. Research Location
This research was conducted at the Tanbihul Ghofilin Islamic Boarding School building in Bawang, Banjarnegara, Indonesia Latitude 7.4003° and Longitude 109.6258° as illustrated in Figure 2.

![Figure 2. Research Locations Tanbihul Ghofilin Islamic Boarding School.](image)

2.5. Data Collection
The research location is latitude -7.4002 and longitude 109.6273, which has an average annual solar insolation of 4.66 kWh/m2/day. Moreover, the average yearly solar insolation, wind speed at the research site is 2.46 m/s, temperature data, and the diffuse radiation can be obtained at NASA Predictions of Worldwide Energy Resources (NASA POWER). Some of the data above can be used to
process data regarding the potential for utilizing solar energy into PLTS at the research site. Table 1 shows data of insolation, temperature, diffuse radiation and wind speed in Banjarnegara.

Table 1. Insolation, temperature, diffuse radiation, and wind speed in Banjarnegara

| Month   | Total Radiation (kWh/m²/day) | Diffuse Radiation (kWh/m²/day) | Temperature (°C) | Wind Speed (m/s) |
|---------|-----------------------------|--------------------------------|------------------|------------------|
| January | 4.78                        | 2.55                           | 26               | 1.7              |
| February| 4.91                        | 2.71                           | 26               | 1.7              |
| March   | 4.52                        | 2.39                           | 26.4             | 1.5              |
| April   | 5.05                        | 2.45                           | 26.5             | 1.09             |
| May     | 4.69                        | 2.12                           | 27               | 1.39             |
| June    | 4.55                        | 2.15                           | 26.1             | 1.59             |
| July    | 4.8                         | 2.27                           | 25.9             | 1.8              |
| August  | 5.08                        | 2.34                           | 25.9             | 2.1              |
| September| 5.32                        | 2.66                           | 26.1             | 2.1              |
| October | 5.37                        | 2.8                            | 26.9             | 1.79             |
| November| 4.62                        | 2.85                           | 26.4             | 1.3              |
| December| 4.6                         | 2.78                           | 26.3             | 1.49             |
| Average | 4.86                        | 2.51                           | 26.29            | 1.63             |

2.6. Module Orientation
Photovoltaic module orientation in this research is plane tilt 30° with azimuth 10°. Orientation of this module adjusts to their building rooftop. The orientation of photovoltaic module is given in Figure 3.

2.7. Solar Power Plant Component
The main components to be determined are solar panels and inverters. The solar panel component has ten alternative options with one inverter. Alternative solar panels are solar panels with polycrystalline (Table 2) and monocrystalline (Table 3) types, each of which has a power of 1200 Wp. While the
alternative for the inverter to be chosen is the Solis mini 1500 4G inverter which has a capacity of 1500 Watts with a maximum efficiency of 97.2%. The alternative components for the TablePV mini-grid that will be included in the PVsyst 7.2 software to be simulated in the PV mini-grid plan are as in Table 4.

Table 2. Photovoltaic Module Alternatives 1 to 5

| Specification               | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 | Alternative 5 |
|-----------------------------|---------------|---------------|---------------|---------------|---------------|
| Photovoltaic type           | Polycrystalline | Polycrystalline | Polycrystalline | Polycrystalline | Polycrystalline |
| Maximum Power (Pmax)        | 100 Wp        | 120 Wp        | 150 Wp        | 200 Wp        | 300 Wp        |
| Open Circuit Voltage (Voc)  | 21.6 V        | 21.6 V        | 21.6 V        | 43.2 V        | 43.4 V        |
| Short Circuit Current (Isc) | 6.46 A        | 7.72 A        | 9.7 A         | 6.5 A         | 9.72 A        |
| Maximum Voltage (Vmp)       | 17.2 V        | 17.2 V        | 17.2 V        | 34.4 V        | 36.2 V        |
| Maximum Current (Imp)       | 5.81 A        | 6.98 A        | 8.72 A        | 5.81 A        | 8.28 A        |
| Module Efficiency           | 13.17%        | 14.29%        | 14.81%        | 14.40%        | 15.46%        |
| Dimension (mm x mm)         | 1062 x 715    | 1244 x 675    | 1500 x 675    | 1400 x 992    | 1956 x 992    |

Table 3. Photovoltaic Module Alternatives 6 to 10

| Spesifikasi                  | Alternative 6 | Alternative 7 | Alternative 8 | Alternative 9 | Alternative 10 |
|------------------------------|---------------|---------------|---------------|---------------|----------------|
| Photovoltaic type            | Monocrystalline | Monocrystalline | Monocrystalline | Monocrystalline | Monocrystalline |
| Daya Maksimum (Pmax)         | 100 Wp        | 150 Wp        | 200 Wp        | 300 Wp        | 400 Wp        |
| Open Circuit Voltage (Voc)   | 21.6          | 21.6          | 43.2          | 44.4          | 49.44         |
| Short Circuit Current (Isc)  | 6.46 A        | 9.7 A         | 6.09 A        | 8.99 A        | 10.86 A       |
| Maximum Voltage (Vmp)        | 17.2          | 17.2          | 35.2          | 36.7          | 40.36         |
| Maximum Current (Imp)        | 5.81 A        | 8.72 A        | 5.69 A        | 8.17 A        | 9.92 A        |
| Module Efficiency            | 15.47%        | 14.81%        | 15.67%        | 15.46%        | 19.83%        |
| Dimension (mm x mm)          | 1195 x 541    | 1500 x 675    | 1580 x 808    | 1956 x 992    | 2025 x 996    |

Based on the variations of the components above, the solar power plant that will be simulated has ten alternative configurations which can be seen in Table 5 as follows.
Table 4. Inverter Specification.

| Specification          | Rating       |
|------------------------|--------------|
| DC Input               |              |
| Maximum Array Power    | 1800 W       |
| Maximum DC Voltage     | 600 V        |
| Starting Voltage       | 60 V         |
| Maximum Input Current  | 11 A         |
| MPPT Voltage Range     | 50-500 V     |
| AC Output              |              |
| Rated Output Power     | 1500 W       |
| Maximum Output Power   | 1700 W       |
| Nominal Grid Voltage Range | 220/230 V |
| Maximum Output Current | 8.1 A        |
| Maximum Efficiency     | 97.2%        |

Table 5. Components Configurations of Solar Power Plant.

| Variation | Solar Panel                  | Inverter                      | Array Configuration          |
|-----------|------------------------------|-------------------------------|------------------------------|
| 1         | Polycrystalline 100 Wp Voc (21.6 V) Isc (6.46 A) | 1500W Inverter Max Vin (600 V) Max Iin (11 A) | 12 modules installed in series Voc (259.2 V) Isc (6.46 A) |
| 2         | Polycrystalline 120 Wp Voc (21.6 V) Isc (7.72 A) | 1500W Inverter Max Vin (600 V) Max Iin (11 A) | 10 modules installed in series Voc (216 V) Isc (7.72 A) |
| 3         | Polycrystalline 150 Wp Voc (21.6 V) Isc (9.7 A) | 1500W Inverter Max Vin (600 V) Max Iin (11 A) | 8 modules installed in series Voc (172.8 V) Isc (9.7 A) |
| 4         | Polycrystalline 200 Wp Voc (43.2 V) Isc (6.5 A) | 1500W Inverter Max Vin (600 V) Max Iin (11 A) | 6 modules installed in series Voc (259.2 V) Isc (6.5 A) |
| 5         | Polycrystalline 300 Wp Voc (43.4 V) Isc (9.72 A) | 1500W Inverter Max Vin (600 V) Max Iin (11 A) | 4 modules installed in series Voc (173.6 V) Isc (9.72 A) |
| 6         | Monocrystalline 100 Wp Voc (21.6 V) Isc (6.46 A) | 1500W Inverter Max Vin (600 V) Max Iin (11 A) | 12 modules installed in series Voc (259 V) Isc (6.46 A) |
| 7         | Monocrystalline 150 Wp Voc (21.6 V) Isc (9.7 A) | 1500W Inverter Max Vin (600 V) Max Iin (11 A) | 8 modules installed in series Voc (172.8 V) Isc (9.7 A) |
| 8         | Monocrystalline 200 Wp Voc (43.2 V) Isc (6.09 A) | 1500W Inverter Max Vin (600 V) Max Iin (11 A) | 6 modules installed in series Voc (259.2 V) Isc (6.09 A) |
| 9         | Monocrystalline 300 Wp Voc (44.4 V) Isc (8.99 A) | 1500W Inverter Max Vin (600 V) Max Iin (11 A) | 4 modules installed in series Voc (177.6 V) Isc (8.99 A) |
| 10        | Monocrystalline 400 Wp Voc (49.44 V) Isc (10.86 A) | 1500W Inverter Max Vin (600 V) Max Iin (11 A) | 3 modules installed in series Voc (148.32 V) Isc (10.86 A) |

2.8. Estimated Daily Load Profile

The estimated daily load at the research site at the MTs Tanbihul Ghofilin Building was done by manual observation. The study site has an installed capacity of 7.7 kVA. The load at the research site has a weekly cycle divided into working days for six days (Table 6) and loads on weekends for a day (Table 7). The following will show the daily load profile at the research site.
Table 6. Daily Use Load on Weekdays.

| Load                                | Amount | Power (watt) | Energy (Wh) | Use time     |
|-------------------------------------|--------|--------------|-------------|--------------|
| Right building class lamp           | 36     | 15           | 5400        | 07.00 - 17.00|
| Left building class lamp            | 36     | 15           | 5400        | 07.00 - 17.00|
| Mid building class lamp             | 24     | 15           | 3600        | 07.00 - 17.00|
| Stairs LED Lamp                     | 9      | 8            | 1008        | 17.00 - 07.00|
| Toilet LED Lamp                     | 6      | 15           | 900         | 07.00 - 17.00|
| Corridor TL Lamp                    | 33     | 15           | 6930        | 17.00 - 07.00|
| Corridor LED Lamp                   | 6      | 8            | 672         | 17.00 - 07.00|
| LCD Projector                       | 4      | 220          | 3520        | 08.00 - 12.00|
| Fan                                 | 30     | 30           | 6300        | 10.00 - 17.00|
| Laptop Computer                     | 30     | 30           | 6300        | 10.00 - 17.00|
| **TOTAL**                           |        |              | **40030**   |              |

Table 7. Daily Use Load on Weekends.

| Load                                | Amount | Power (watt) | Energy (Wh) | Use time     |
|-------------------------------------|--------|--------------|-------------|--------------|
| Right building class lamp           | 36     | 0            | 0           | -            |
| Left building class lamp            | 36     | 0            | 0           | -            |
| Mid building class lamp             | 24     | 0            | 0           | -            |
| Stairs LED Lamp                     | 9      | 14           | 1008        | 17.00 - 07.00|
| Toilet LED Lamp                     | 6      | 0            | 0           | -            |
| Corridor TL Lamp                    | 33     | 14           | 6930        | 17.00 - 07.00|
| Corridor LED Lamp                   | 6      | 14           | 672         | 17.00 - 07.00|
| LCD Projector                       | 4      | 0            | 0           | -            |
| Fan                                 | 30     | 0            | 0           | -            |
| Laptop Computer                     | 30     | 0            | 0           | -            |
| **TOTAL**                           |        |              | **8610**    |              |

2.9. Technical Analysis

The technical analysis carried out will discuss the design capabilities of the Solar power plant to determine the specifications of the components used, the orientation of the solar panels, and the capacity that the PV mini-grid can provide. The power generated by PLTS is influenced by various factors, namely solar radiation at the PLTS location, the slope and orientation of the solar panels, the presence or absence of sunlight, the temperature of the area where the PLTS is located, and the components used in the manufacture of PLTS. It is estimated that photovoltaic efficiency decreases with lifetime due to the degradation of the solar module and the age of the components used. The quality of a solar power plant can also be shown by its performance ratio. The efficiency ratio is usually expressed as a percentage of the total power generated by the system as a result of losses compared to when the system was operating under STC conditions. Solar plant system losses include solar panel efficiency, temperature, and inverter efficiency [10].
3. Result and Analysis

Data on the factors that affect the PVSyst 7.2 software simulation results are needed. These factors include the geographical location of the solar power plant, data on solar potential at that location, regional temperature, radiation distribution, wind speed, specifications of the components used, the orientation of solar panels, and estimated daily loads at the site. After the simulation is complete, the place will display the amount of electric potential generated by the solar plant. Some values represent the amount of electrical energy generated, the amount supplied to the load, and the amount provided to the grid. In addition, it can also be seen a diagram of solar plant losses and the value of the performance ratio, which is displayed in graphical form. In this study, a household-scale solar power plant was designed at the Tanbihul Ghoﬁlin Islamic Boarding School.

The simulation results on PVSyst 7.2 on the planning of on-grid solar plant variation of 1 to 10 will obtain a diagram as shown in Figure 4 below.

![Figure 4. Loss Diagram Alternative 1.](image)

Based on table 7, the production of solar array electrical energy in STC conditions through simulation of variation 10 has the most significant value of 2041 kWh per year. Compared to other variations, while variation 4 has the most negligible value with 2023 kWh. The difference in the electrical energy value of the array under STC conditions is due to the difference in solar panel efficiency and the surface area of each solar panel used. As in the example, variation 1 has an efficiency of 13.17% with an area of 9.1 m², which produces electrical energy output of an array of 2024 kWh under STC conditions, while variation 2 has an efficiency of 14.29% with an area of 8.4 m² which has an array output electrical energy of 2026 kWh under STC conditions. This can be said that the greater the efficiency of the solar panel and the wider the surface area of the panel, the better. Efficiency is influenced by the type of solar panel used. In general, monocrystalline panel types have greater efficiency than polycrystalline types. This is because the primary material for the manufacture of panels is more significant in concentration on mono-crystalline panels than poly-crystalline types so that the efficiency is greater [13]. Still, at nominal power, monocrystalline solar panels generally have a smaller surface area than polycrystalline.
The same method was used on the other variations, and loss diagrams will also be obtained for variations from 2 to 10. The results of the simulation can be seen in the Table 8.

Table 8. Result of PVsyst 7.2 simulation on Solar Power Plant system on grid 1-10 Variations.

| Variations | Array nominal energy at STC efficiency (kWh) | Array virtual energy at MPP (kWh) | Available Energy at Inverter Output (kWh) | Performance Ratio (%) |
|------------|---------------------------------------------|----------------------------------|------------------------------------------|-----------------------|
| 1          | 2024                                        | 1693.6                           | 1657.1                                   | 79.8                  |
| 2          | 2026                                        | 1715.6                           | 1679.0                                   | 80.8                  |
| 3          | 2024                                        | 1646.8                           | 1609.6                                   | 77.5                  |
| 4          | 2023                                        | 1637.0                           | 1600.8                                   | 77.0                  |
| 5          | 2031                                        | 1686.5                           | 1649.4                                   | 79.4                  |
| 6          | 2024                                        | 1697.8                           | 1661.3                                   | 80.0                  |
| 7          | 2024                                        | 1646.8                           | 1609.6                                   | 77.5                  |
| 8          | 2030                                        | 1685.0                           | 1648.5                                   | 79.3                  |
| 9          | 2025                                        | 1673.4                           | 1636.9                                   | 78.8                  |
| 10         | 2040                                        | 1795.6                           | 1742.5                                   | 83.9                  |

The yearly energy output produced on this solar plant at the end of inverter output, with the most negligible value 1600.8 kWh using variation 4, and up to 1742.5 kWh is the topmost value using variation 0. Therefore, the performance ratio of solar power plants with the most negligible value is variation 4 with 77.8%, and the highest performance ratio is variation 10 with 84%.

Figure 5. Comparison PR between Polycrystalline and Monocrystalline
Based on Figure 5, Solar power plants that use monocrystalline solar panels tend to have a higher Performance Ratio, ting polycrystalline solar panels. This is because the Monocrystalline Photovoltaic module has slightly better efficiency than a polycrystalline module.

4. Conclusion
The solar power generation system designed in this study is a grid-connected generating system (on-grid). The planning of this solar power plant has ten variations, each of which has a power of 1200 Wp and an inverter of 1500 W. The electrical energy generated from household-scale rooftop solar panels designed at this research location ranges from 1608 to 1742 kWh with a performance ratio ranging from 77.0% – 83.9%. Based on the performance ratio obtained, the possible, variation based on the simulation results in this study is variation 10, with the highest performance ratio value of 83.9%.

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