Technical analysis feasibility solar power plant on-grid system design in Junior High School 3 Purwodadi

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Abstract. Indonesia's commitment to reduce greenhouse gases by 29 % by transforming into uses of renewable energy 23 % in 2025 has been written on Paris Agreement 2015. The increasing growth rate of energy demand each year becomes a new problem for Indonesia, if Indonesia is still dependent on fossil energy. The energy demand in Indonesia in 2020 is 268 TWh and it is estimated that it will be 364 TWh in 2025. Indonesia is located on the equator and has very large solar potential. Data from National Energy Council (DEN) shows that solar power potential in Indonesia is 207.9 GW, while the current installed in Indonesia has only reached 100 MW or 0.05% of the total. The need for early awareness becomes a priority to support the creation of awareness of the importance of renewable energy. This study was conducted to assess the potential of solar power on SMP N 3 Purwodadi. The study uses PV Syst 7.1 software with variation of photovoltaic panels ranging from 1040 wp to 1350 wp to get annual generated electric power. Results of this study showed that installation of solar power on SMPN 3 Purwodadi generated electrical power from 1516 kWh to 2205 kWh.

1. Introduction
The growth of electricity demand is getting higher from year to year. In line with Indonesia's economic and population growth, it is projected that in 2050 the demand for electrical energy will grow at 1,455 TWh with a production of 1,600 TWh [1]. The supply of energy that remains dominated by fossil energy will have a long-term impact on air cleanliness and carbon footprint emissions. Indonesia's dependence on using fossil fuels to meet national energy needs does not support Indonesia to use 25% of new renewable energy by 2025.

The National Energy Council noted that in 2018 Indonesia's power generation capacity was 64.5 GW, 56.4% of which came from coal. The dominance of the use of energy generation with coal and oil is very high, with 64% of electrical energy generated from the fossil fuel sector in 2020. It is projected that by 2050 Indonesia's energy will be supplied by 50% from coal, 26% from gas and oil, and 24% from new renewable energy (NRE). Indonesia has abundant potential energy sources from renewable energy of around 417.8 GW, with details of 17.9 GW from ocean, 23.9 GW geothermal, 32.6 GW bioenergy, 60.6 GW wind, 75 GW hydro, and 207 GW solar. The largest potential for renewable energy comes from solar energy at 207.8 GWp. However, the utilization of electrical energy sources uses NRE when it is only 10.4 GWp or 2.5% of its potential [2-3]. The need for education about the importance of transforming the use of energy from fossil fuels to new and renewable energy is a problem concerning
the awareness of all people. In Australia, 92% of electric power generation is provided by coal or gas, the balance is from renewable sources [4].

The existence of government policies to support the transformation and movement towards new and renewable energy as written in the Minister of Energy and Mineral Resources Regulation No. 49 of 2018 is proof that the government supports its citizens to install PLTS themselves. Minister of Energy and Mineral Resources Regulation No. 49 of 2018 provides a policy for users to use PLTS to power their own customers and sell the excess power. Early education about the importance of new and renewable energy is a solution so that people are not selfish in using electrical energy and provide an understanding of the importance of clean energy. Therefore, the purpose of this research is to analyze the technical feasibility of rooftop solar power plant systems using PVSyst 7.1 software as a tool.

2. Material and Methods

2.1. Solar irradiation
Solar irradiance is the energy emitted on a surface with an area of 1 m$^2$ (W/m$^2$). In general, solar irradiance can be seen from the source. Direct Normal Irradiance is the irradiance that is directly received by a panel or surface with respect to the closest distance to the sun. The Global Horizontal Irradiance (GHI) is the sum of the direct and indirect radiation on the horizontal surface. Global Tilted Irradiance (GTI) is the total radiation received by the surface with a specified angle and a specified azimuth angle. In the context of GTI solar panels are also affected by shadows [5].

2.2. Solar Power Plant
Solar Power Plant is a power generation system whose energy comes from solar radiation, through the conversion of photovoltaic cells. Photovoltaic systems convert solar radiation into electricity. The higher the intensity irradiation that hits the photovoltaic cell, the higher the electrical power it produces [6]. Solar PV can be divided as module material from as:

1. Monocrystalline
Monocrystalline solar cells are also known as single crystal cells. Monocrystalline cells are made of a very pure form of silicon, making them the most efficient material for converting sunlight into energy. Monocrystalline has the highest efficiency at 15-20%.

2. Polycrystalline
The first solar panels were based on polycrystalline silicon also known as polysilicon (p-Si) and multicrystalline silicon (mc-Si). The raw silicon is melted and poured into a square mold, which is cooled and cut into square wafers. The efficiency of polycrystalline-based solar panels is typically 13-16% due to the lower purity of silicon.[7]

the number of solar panels needed is obtained using the formula:

$$J_m = \frac{P_m}{\eta_{PV} \times P_{MPP} \times TCF}$$

where:

$J_m$ = Number of arrays
$P_m$ = Output Power (Wp)
$\eta_{PV}$ = efisiensi panel (%)
$P_{MPP}$ = Rated Out Panel PV (Wp)

2.3. Technical Analysis
Array yield (YA)
Array yield is the output DC energy generated by the PV array (EA, DC) against the output power rating of the array.

$$Y_A = \frac{E_{ADC}}{P_o}$$

$Y_A$ = Array Yield (kWh/kWp/day)
EADC = Output DC Generated (kWh)
Po = Rated PV Output (kWp)

Final yield (YF)
The total AC energy produced by the PV system daily, monthly, or even yearly divided by the power output of the installed PV. It is measured based on the inverter output supplied to the PV array under STC conditions of 1000 W/m² solar irradiance and 25 C temperature. The formula is as follows

\[ Y_F = \frac{E_{AC}}{P_o} \]

YF = Final Yield (kWh/kWp/ha)
EAC = Output AC Generated (kWh)
Po = Rated PV Output (kWp)

Reference Yield (YR)
The total irradiance at the plane angle HT divided by the reference PV irradiance G (1kW/m²). used to indicate the number of hours at the reference irradiance.

\[ Y_R = \frac{H_T}{G_o} \]

YR = Reference Yield
HT = Sun Irradiance on panel (kWh/m²)
Go = Reference Sun Irradiance (kWh/m²)

Performance Ratio (PR)
The performance ratio is the ratio of the final yield to the reference yield. The performance ratio shows how much total system losses are when changing the input DC power to AC power [8-9].

\[ PR (%) = \frac{Y_F}{Y_R} \]

This research uses PVSyst 7.1 software to predict electrical energy generated from solar panels. Research flowchart is given in Figure 1. Irradiance data and temperature data are collected using the external website PVGIS. Objects of the research are comparing variations of photovoltaic panels that will be chosen to be implemented on SMPN 3 Purwodadi. Photovoltaic panels are positioned fixed tilted at 15° and 70° on azimuth. R
2.4. Location

The location of the research is SMP N 3 Purwodadi, Grobogan is illustrated in Figure 2. Astronomically located at coordinates -7.09573255118786, 110.90828737832165.
2.5. Irradiance and Temperature

Table 1. Irradiance and Temperature data

| Month    | GHI (kWh/m²) | DHI (kWh/m²) | Temperature (°C) |
|----------|--------------|--------------|------------------|
| January  | 4.79         | 2.62         | 25.63            |
| February | 5.50         | 2.48         | 26.29            |
| March    | 5.93         | 2.25         | 26.33            |
| April    | 5.11         | 2.26         | 26.23            |
| May      | 4.76         | 2.03         | 26.64            |
| June     | 5.37         | 1.81         | 26.96            |
| July     | 5.80         | 1.79         | 27.88            |
| August   | 6.20         | 1.89         | 28.66            |
| September| 6.75         | 2.15         | 28.70            |
| October  | 6.45         | 2.41         | 28.13            |
| November | 5.59         | 2.61         | 27.70            |
| December | 4.69         | 2.49         | 25.75            |
| Average  | 5.58         | 2.23         | 27.07            |

Table 1 describes data above average Global Horizontal Irradiance is 5.58 kWh/m² and average temperature is 27.07 °C, [PVGIS TMY]

2.6. Photovoltaic and Daily Load

PV datasheets are needed to estimate solar power production, as available in Table 2. Daily load data needed to project the required PV system estimates. Based on the results of the site survey directly obtained data on the use of loads at the site are given in Table 3, while daily load profile is described in Figure 3.

Table 2. PVDatasheet

| Brand      | Pmax (Wp) | Installed (Wp) | Voc (V) | Vmp (V) | Isc (A) | Imp (A) | Efficiency |
|------------|-----------|----------------|---------|---------|---------|---------|------------|
| JA SOLAR 540 | 540       | 1080           | 49.6    | 41.64   | 13.86   | 12.97   | 20.90%     |
| JA SOLAR 450 | 450       | 1350           | 49.7    | 41.52   | 11.36   | 10.84   | 20.20%     |
| AUSTA 440   | 440       | 1320           | 49.6    | 41      | 11.33   | 10.74   | 19.81%     |
| Canadian 410 | 410       | 1230           | 47.6    | 39.1    | 11.06   | 10.49   | 18.60%     |
| Canadian 390 | 390       | 1170           | 48.2    | 40.4    | 10.17   | 9.66    | 19.70%     |
| LONGI 375   | 375       | 1125           | 41.4    | 34.6    | 11.6    | 10.84   | 20.60%     |
| LONGI 365   | 365       | 1095           | 41.1    | 33.9    | 11.28   | 10.77   | 19.50%     |
| Canadian 350 | 350       | 1050           | 46.6    | 39.2    | 9.52    | 8.94    | 17.64%     |
| Maysun 330  | 330       | 1320           | 41.3    | 33.8    | 10.31   | 9.77    | 18.00%     |
| Hanfei 300  | 300       | 1200           | 39.8    | 30      | 11.2    | 10      | 18.00%     |
### Table 3. Daily Load

| Load  | Quantity | Power (W) | Power Total (W) | Duration (h) | Energi (Wh) | Hours of use |
|-------|----------|-----------|----------------|--------------|-------------|--------------|
| Lamp  | 34       | 12        | 408            | 13           | 4836        | 00.00-05.00, 17.00-23.00 |
| AC    | 15       | 840       | 12600          | 6            | 75600       | 09.00-14.00  |
| LCD   | 6        | 282       | 1692           | 7            | 11844       | 08.00-14.00  |
| Fan   | 12       | 64        | 768            | 5            | 3840        | 10.00-14.00  |
| Computer | 36  | 300       | 10800          | 8            | 86400       | 08.00-15.00  |
| Pump  | 2        | 300       | 600            | 3            | 1800        | 07.00, 12.00, 15.00 |

#### 3. Result and Discussions

Simulations have been performed to obtain generated energy from photovoltaic panels. PV panel variation generated different electrical power. Technical analysis on this research used PVSyst to forecast generated electrical power.

**3.1. Generated Power**

Forecasting scenarios of energy generated from solar power then obtained the ability of each PV to generate electrical energy using PVGIS TMY meteorological data. Weather and temperature factors are external factors that affect the ability of solar power to produce electrical energy [10]. The presence of solar power at the research site can save electricity generated by solar power and the excess production is sold to the grid.

Based on table 4 and figure 4, the obtained solar panels that produce the greatest power is JA Solar 450 Wp with an annual generated power 2207.15 kWh. The least generated energy is JA Solar 540 wp with an annual generated energy 1517.5 kWh. From the table, it can be seen that the power generated by the solar panel is the greater the capacity from the panel, the greater the energy generated.

Weather factors affect the production of electrical energy. In the month of January all variations of solar panels produce the lowest energy because January is in the season of rain. In the month of September experiencing the highest production of electrical energy because September is on dry season

**3.2. Heat Losses**

The temperature in the environment affects the ability of solar panels to produce electrical energy. The hotter the environment, the solar panels will also become hot. Temperature changes in solar panels of 1°C affect the efficiency of 0.5%. Annual ambient and array temperature is available in Table 5.
## Table 4. Generated Annual Electrical Energy

| Month   | JA Solar 540 | JA Solar 450 | AUSTA 440 | Canadian 390 | LONGI 375 | LONGI 365 | Canadian 350 | Maysun 330 | Hanfei 300 |
|---------|---------------|---------------|-----------|---------------|-----------|-----------|---------------|------------|------------|
| January | 107.85        | 157.5         | 155.92    | 142.73        | 136.43    | 132.44    | 129.52        | 121.14     | 151.6      | 135.42     |
| February| 112.68        | 164.29        | 163.07    | 148.61        | 141.96    | 137.77    | 134.8         | 126.25     | 158.18     | 140.63     |
| March   | 135.79        | 198.01        | 196.88    | 178.88        | 170.93    | 165.76    | 162.36        | 152.11     | 190.85     | 168.95     |
| April   | 116.54        | 169.81        | 168.44    | 153.65        | 146.74    | 142.52    | 139.42        | 130.49     | 163.53     | 145.54     |
| May     | 115.17        | 167.7         | 166.13    | 151.83        | 145.06    | 140.93    | 137.78        | 128.72     | 161.35     | 143.92     |
| June    | 127.17        | 184.57        | 183.13    | 167.26        | 159.75    | 155.22    | 151.81        | 141.87     | 177.78     | 158.27     |
| July    | 138.54        | 200.63        | 199.77    | 181.62        | 173.5     | 168.58    | 165.03        | 154.19     | 193.72     | 171.74     |
| August  | 147.03        | 212.77        | 212.33    | 192.29        | 183.64    | 178.49    | 174.79        | 163.38     | 205.65     | 181.36     |
| September| 147.87       | 214.63        | 214.6     | 193.68        | 184.96    | 179.77    | 176.09        | 164.69     | 207.68     | 182.45     |
| October | 144.45        | 209.9         | 209.52    | 189.48        | 180.98    | 175.9     | 172.31        | 161.11     | 202.87     | 179.01     |
| November| 119.43        | 174           | 173.19    | 157.46        | 150.5     | 146.19    | 143.05        | 133.78     | 168.06     | 149.2      |
| December| 103.98        | 151.7         | 150.23    | 137.49        | 131.45    | 127.59    | 124.78        | 116.68     | 146        | 130.52     |
| TOTAL   | 1517.5        | 2207.51       | 2196.21   | 1998.98       | 1910.9    | 1857.16   | 1818.74       | 1702.41    | 2136.27    | 1897.01    |

**Figure 4. Graphic Annual Generated Energy**

It can be seen in table 5 that temperature changes on the panels throughout the year affect the efficiency of the solar panels. The highest temperature in the month of September and the lowest temperature in the month of January.

The average temperature on the solar panel is close to the STC temperature on the solar panel losses due to solar heat contribute the most to the generation of solar energy as described in Table 6. The biggest power losses occur in solar panels with the JA Solar 540 brand. Temperature coefficient is the ratio between energy generated by PV array and array power losses affected by heat. The larger the temperature coefficient the better PV panels are. Largest PV panel temperature coefficient is JA SOLAR 450 and the lowest is JA Solar 540.
### Table 5. Annual Ambient and Array Temperature

| Month   | Temperature (°C) | PV Array Temperature (°C) |
|---------|------------------|----------------------------|
| January | 25.63            | 41.79                      |
| February| 26.29            | 44.83                      |
| March   | 26.33            | 47.86                      |
| April   | 26.23            | 45.01                      |
| May     | 26.64            | 44.66                      |
| June    | 26.96            | 48.4                       |
| July    | 27.88            | 51.29                      |
| August  | 28.66            | 53.48                      |
| September| 28.70           | 54.94                      |
| October | 28.13            | 51.87                      |
| November| 27.70            | 47.5                       |
| December| 25.75            | 42                         |
| Average | 27.07            | 47.78                      |

### Table 6. Heat Losses

| NO | Brand      | Array | Annual Array Losses | Temperature Coefficient |
|----|------------|-------|---------------------|-------------------------|
| 1  | JA SOLAR 540| 1589.8| 120.096             | 0.921                   |
| 2  | JA SOLAR 450| 2311.9| 150.12              | 0.932                   |
| 3  | AUSTA 440  | 2299.2| 146.784             | 0.933                   |
| 4  | Canadian 410| 2089.8| 136.776             | 0.931                   |
| 5  | Canadian 390| 1996.2| 130.104             | 0.932                   |
| 6  | LONGI 375  | 1938.8| 125.1               | 0.932                   |
| 7  | LONGI 365  | 1897.8| 121.764             | 0.933                   |
| 8  | Canadian 350| 1774.8| 116.76              | 0.931                   |
| 9  | maysun 330 | 2229.4| 146.784             | 0.931                   |
| 10 | Hanfei 300 | 1976.3| 133.44              | 0.929                   |

### 3.3. Technical Analysis

The results of analysis of the actual measured performance and comparison with the predicted performance using PVSYST are presented in Table 7. The power generated by the PV array received to be used at the load depends on the PV efficiency and the performance ratio of the panels. From the table, the highest final yield is obtained at LONGI 375 at 1654.48 kWh/kWp and the lowest at JA Solar 540 at 1404.17 kWh/kWp. Final yield shows that every 1 kWp produces kWh. The biggest performance ratio is Austa 440 at 82.44% and the lowest is JA Solar 540 at 69.67%. The highest array efficiency on Longi 375 is 17.60% and the lowest is on Canadian 350 14.79%
Table 7. System Technical Analysis

| No | Brand       | Applied (Wp) | Generated (kWh) | YF (kWh/kWp) | YR (kWh/kWp) | PR Ratio | Array Efficiency |
|----|-------------|--------------|-----------------|--------------|--------------|-----------|-----------------|
| 1  | JA SOLAR 540 | 1080         | 1516.6          | 1404.17      | 2015.5       | 69.67%    | 15.26%          |
| 2  | JA SOLAR 450 | 1350         | 2205.42         | 1633.71      | 2015.5       | 81.06%    | 17.14%          |
| 3  | AUSTA 440   | 1320         | 2193.2          | 1661.52      | 2015.5       | 82.44%    | 17.12%          |
| 4  | Canadian 410 | 1230         | 1994.87         | 1621.93      | 2015.5       | 80.47%    | 15.64%          |
| 5  | Canadian 390 | 1170         | 1905.8          | 1628.97      | 2015.5       | 80.82%    | 16.64%          |
| 6  | LONGI 375   | 1125         | 1851.07         | 1645.48      | 2015.5       | 81.64%    | 17.60%          |
| 7  | LONGI 365   | 1095         | 1811.84         | 1654.56      | 2015.5       | 82.09%    | 16.80%          |
| 8  | Canadian 350| 1050         | 1694.21         | 1613.72      | 2015.5       | 80.07%    | 14.79%          |
| 9  | maysun 330  | 1320         | 2127.35         | 1611.57      | 2015.5       | 79.96%    | 16.37%          |
| 10 | Hanfei 300  | 1200         | 1887.01         | 1572.51      | 2015.5       | 78.02%    | 14.90%          |

4. Conclusion
In this study the performance analysis of an on grid solar photovoltaic plant installed at Junior High School 3 Purwodadi is carried out. Comparison of generated power, final yield, system efficiency and solar panel performance ratio. Results in the conclusion that the larger the installed one, it is not certain to have the best technical performance. Power losses due to temperature are quite large because the ambient temperature and the temperature of the solar panels are different. In this study, the most efficient system in terms of performance and capability of solar panels is Longi 375 at 17.60%. The system that produces the largest annual power is the JA solar panel 450 wp of 2207.51 kWh. The panel that has the highest performance ratio is Austa Solar of 82.44%.

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