Design and Implementation of a Solar Power System on Grid SDN 023905 BIN JAI using PVSYST Software

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ABSTRACT:
Electricity is an indispensable requirement for modern society, and with the advancement of technology, the adoption of renewable energy sources, such as Solar Power Plants (PLTS), has been on the rise. PLTS harness the virtually limitless and abundant power of solar energy. The successful construction and operation of a Solar Power Plant necessitates meticulous planning to ensure optimal functionality. In our research aimed at PLTS development, we have chosen an on-grid operating system for installation on the roof of SDN 023905 Binjai. This decision aligns with our goal to reduce the reliance on conventional electrical sources at SDN 023905 Binjai, which currently receives its entire electrical supply from PLN. The proposed PLTS will boast a capacity of 1.2kWp, comprising four 300Wp solar panels connected in series, alongside a 1.2 kW to 3 kW inverter. Our comprehensive analysis validates the feasibility of this plan, as it yields a Performance Ratio (PR) of 84%, surpassing the minimum PR benchmark of 70%. From a financial perspective, the project entails an initial investment cost of IDR 31,555,222, with a remarkably swift payback period occurring within the first year and month of the PLTS's 20-year operational lifespan.

KEYWORDS: PLTS, On Grid, Energy, Performance Ratio.

1. INTRODUCTION

Renewable energy is a valuable resource in terms of sustainability because it can reduce greenhouse gases worldwide [1]. The use of solar power plants (PLTS) has a long-term advantage of around 20-25 years. Solar panels can also be applied as a power generator that can be used to supply electrical energy to remote areas or villages far from power sources. [2] Based on the information above, the use of this Solar Power Plant can be utilized and applied at SDN 023905 Binjai. Because the need for electrical energy at SDN 023905 Binjai is still fully supplied by the State Electricity Company (PLN). The use of solar power plants is very useful for buildings or households that supply a lot of electrical energy and is very useful for remote villages that are far from sources of electricity from the National Electric Company. Based on the information above, in this study, the authors will plan on grid the most optimal PLTS on-grid at SDN 023905 Binjai if it is maximally and optimally managed can help reduce the supply and cost of electrical energy from the State Electricity Company, so that during the day the electrical energy used fully uses energy from the PLTS directly, while at night the energy used fully use energy from PLN. In addition, in the Binjai area, there are still no schools or buildings that use the PLTS system, so the presence of PLTS at SDN 023905 Binjai can be a reference for the community to become more familiar with renewable energy and develop the benefits of environmentally friendly renewable energy, especially this PLTS. In this planning, analysis uses the PVSYST 7.2 software to calculate the on-grid at SDN 023905 Binjai as well as selecting the inverters right.

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2. LITERATURE REVIEW

2.1. Solar Energy

Is electromagnetic radiation emitted from the sun to the earth which is composed of photons or particles that are converted into a source of electricity. The energy that comes from the sun's electromagnetic radiation reaches the earth's surface. The average value of Earth's solar radiation is 1,353 W/m and represents the solar constant. The intensity of solar radiation in Indonesia per day lasts for 4 to 5 hours [3]. Photovoltaic technology is the utilization of solar radiation energy converted into electrical energy through PLTS. This technology is made using semiconductor materials called solar cells. Photovoltaic technology is known to be environmentally friendly and has high efficiency. However, to design it requires an installation area that is large enough to capture solar light. To produce 100mW of power requires a land area of 60-70 hectares or if it is assumed that the sunlight generated throughout Indonesia has an area of 2 million km2is 4.8 kWh/m2/ day equal to 112,000 GWp distributed. In Indonesia, currently, the use of solar energy is around 10MWp, so there is still a lot of need, and new power plants are being built in Indonesian territory to be able to produce electricity. [4]

2.2. Solar Power Plant

Solar Power Plant is a renewable power plant that utilizes electromagnetic radiation originating from sunlight and absorbed by solar cells (photovoltaic technology) followed by the process of converting solar photon radiation to a power source. PLTS performance is related to environmental conditions, temperature, solar modules, and weather as well as the value of the intensity of sunlight [5].

2.3. Working Principle of Solar Power Plants

The working principle of solar power plants is that from solar energy, the energy emitted from sunlight will be absorbed by solar modules (photovoltaic) triggering photons to move towards electrons and producing voltages and electric currents [6]. Solar energy can be converted into a source of electricity using solar modules composed of semiconductor materials. Solar panels can capture solar radiation, and produce energy of motion which can release electrons into the conduction band and then produce an electric current. This motion/kinetic energy continues to increase in line with the increasing intensity of sunlight. The greatest intensity of solar radiation is captured by the earth during the day which is capable of producing solar energy which is captured around 120,000 Tera watts. The type of metal used certainly affects the performance of the solar cell. [7]

2.4. Off Grid PLTS System

In the Off Grid-Tie System, sunlight is converted into DC voltage through the Solar Module, which is pure DC voltage that comes out of the solar module. Then the pure DC voltage uses a DC to DC regulation module which is called a DC regulator. The DC regulator aims to regulate DC storage in the battery. Then the output voltage from the DC regulator is converted to AC voltage using an inverter to produce a sinusoidal voltage. From the output of the inverter AC voltage is rectified using a rectifier or called a converter. So that the DC load can feel the pure DC wave voltage. Other sources of electricity that come from PLN are not connected, but the DC source that is used comes from the battery.[8] A Centralized Solar Power Generation System (Off-Grid) is a power plant that utilizes solar light but is not connected to the PLN network or a generation source that only uses solar energy through the help of solar panels or photovoltaic so that it produces electrical energy from the Off-Grid itself even at generally used in areas that cannot be reached by electricity sources from the PLN network such as rural areas. [9]

2.5. PLTS On Grid System

This method is in principle combining PLTS on other power grids, for example through the PLN power grid.[10] The equipment that greatly affects performance in this type of operation is the inverter, with the function of converting the DC electric power produced by the PLTS into AC electric power that is in sync with the standard electricity installed (utility grid).solution Green for urban communities such as offices, industrial buildings, or community housing.[11] This method utilizes solar modules to produce electricity that is environmentally friendly and avoids the effects of greenhouse gases/emissions. As the name suggests, the PLTS On Grid System, or grid-connected PV, thus the system is always connected to the PLN network and maximizes the utilization of PV energy in producing electricity as optimally as possible. In PLTS, the On Grid does not use batteries but is connected to the grid as the energy medium. In PLTS On Grid meter, EXIM will record how much energy is saved to the PLN electricity network which will be determined at the end of the month to reduce the client's electricity costs according to the arrangements of the nearest electricity supplier. One of the characteristics of the On Grid is the counter islanding that is installed on the inverter which makes the PLTS not produce power when the power goes out. [12]

2.6. PLTS Hybrid System Hybrid

Is PLTS a system that connects at least two generators, the generators that are often used are PLTS generators, micro-hydro, and wind power. Indonesia tends to utilize PLTS-Microhydro, PLTS-Genset, and PLTS Wind Power. However, this PLTS-Genset is used more often. The combination of Hybrid PV-Genset will limit generator working hours (for example the first 24 hours of work to 4 hours each day, more specifically during peak load conditions) so that work and executive financial plans are more productive, while PLTS is used to supply base loads, so speculation is not needed what a start. PLTS Hybrid has the criteria of increasing the service hours of the existing (existing) system, especially during the day, reducing the operating hours of the existing (existing) PLTD, using a battery with a capacity according to the operating pattern. Hybrid systems can be designed to have a larger capacity than the existing system because they use batteries. Batteries are not only energy storage; they are also useful for stabilizing the output of PLTS. [13]

Solar cells or Photovoltaics are electronic components with the function of converting solar energy into electrical energy, this energy conversion is produced by a process called the photovoltaic effect [14]. Where the photovoltaic effect is the release of positive and negative charges in solid particles through solar radiation. So, the output in the form of voltage and current is directly affected by the high intensity of the solar radiation [15]. The most common solar cells are cells obtained from transparent silicon and the manufacturing cost decreases over time with high-quality improvements. This solar cell itself has a lifespan of more than 25 years [16]. The purer the silicon atoms, the better the solar cell converts sunlight into electrical energy (photoelectric effect). What's more, in studies of research facilities, the productivity can be as high as 44% under ideal circumstances [17].

Cells Monocrystalline are generally composed of a single silicon rod with a cylindrical shape, after which it is sliced small so that it has a wafer and is about 200-250 µm thick, and to minimize reflection losses or reflections on the upper surface, micro-grooves are formed. (microgrooves). The main advantages of this type of monocrystalline are its better efficiency compared to the others (14-17%), durability, or strength (effective for up to twenty years of usage). [18]

Polycrystalline is composed using silicon rods which are then melted and formed using parallel pipes, then Waffers generally have a rectangular shape and are 180 – 300 micrometers thick. This type was made with the intention of reducing production costs, so as to get solar cells that have a lower cost, but the resulting efficiency is 12-14%. [18]

Technology, namely solar modules, will be based on thin film. crystal). Raw materials wafer, in the manufacture of solar modules with thin layers, can minimize the cost of making solar cells because they use no more than 1% of silicon raw material in their manufacture. In its manufacture, the method that tends to be used is plasma-enhanced chemical vapor deposition (PEVCD) made from hydrogen and hydrogen gas. [19]

An inverter is an electronic equipment with the function of converting DC current into AC current in accordance with the requirements of the equipment used. By converting DC current from solar cells into AC current for electricity purposes which incidentally uses AC current. [20]

PLN which already has PLTS installations in its circuit can export the excess electricity produced by PLTS to the PLN network and is different from getting/importing electricity from the PLN network when the PLTS cannot meet the customer's electricity needs. PLN consumers who use the net metering kWh meter Exim in their electrical installation, replacing the installed conventional kWh meter. Its use is no different from the usual kWh meter from PLN. The additional feature is being able to read imported kWh from PLTS to PLN which is also known as net metering [21].

3. METHOD

3.1. Research Stage

1. The author conducts a literature study/study of the literature in order to better understand and understand the basis of the material and the steps to support the research.

2. The author formulates the essence of the problem that will be used as an idea for writing this thesis. 3. The author collects data by visiting the places that will be examined and meeting related parties who will be interviewed to record the necessary data.

4. Carry out interviews or interviews with the Principal of SDN 023905 Binjai and experts related to the object of this research.

5. Carry out writing by conveying ideas on problems that occur in the object of concern.

3.2. Research Location

The location object chosen as the research and data collection site is SDN 023905 Binjai which is located at Jl. Independence Pioneers No. 238, Pepper Gardens, Kec. North Binjai, Binjai City, North Sumatra 20744 with coordinates 03°38'00", 098°29'26.

3.2. Data Used

1. Primary Data

Data that can be taken directly from asking the school directly such as daily load data at SDN 023905 Binjai

2. Secondary Data

Data obtained in the form of archival data related to Global Horizontal Irradiation (GHI) data and temperature at the research location taken from the Pvsyst 7.2 meteonorm.

3.3. Software Used

1.PVSYST 7.2

2.Microsoft Excel

3.Microsoft word

4.Microsoft Power Point

3.4. Data Processing and Analysis

If all the data is collected, data processing will be carried out to find the purpose and results of writing this thesis. The calculation results that have been obtained will be analyzed to find out how much WP power is needed to meet the power requirements at SDN 023905 Binjai as well as the number of solar modules and inverters needed using PVSYST 7.2 Software.

4. RESULTS AND DISCUSSION

The following is the daily load usage data at SDN 023905 Binjai which is taken directly from asking the school directly regarding the daily load used, then the usage of the load data can be obtained, namely:

Table 1. Daily load at SDN 023905 Binjai

NO	Loads at SDN 023905	Number of Loads	Duration of use per day	Powe (W)	All Power (W)	Energy (WH)
1	Light	27	5	18	486	2430
2	Dispenser	1	3	350	350	1050
3	Fan	2	3	130	260	780
4	Computer	2	3	95	190	570
5	Printer	1	1	15	15	15
6	wifi	1	24	18	18	432
7	Water Machines	1	3	125	125	375
8	Speaker	1	1	24	24	24
	TOTAL			775 W	1.468 W	5.676 kWh

Based on Table 1, the daily load data at SDN 023905 Binjai above we can conclude that the power used in a day is 775 watts with a total power of 1,468 watts and a total energy of 5,676 kWh.

Data on the temperature at SDN 023905 Binjai was obtained from the official website https://globalsolaratlas.info/ by entering the coordinate values according to the coordinates at SDN 023905 Binjai, you can obtain *temperature* and solar radiation as follows:

	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	kWh/m²/day	kWh/m²/day	°C	m/s	[-]	%
January	4.60	2.45	27.0	1.69	4.068	82.6
February	5.40	2.79	27.4	1.79	4.584	80.8
March	5.27	2.83	27.9	1.80	4.309	79.8
April	5.47	2.56	27.7	1.70	3.940	82.8
May	4.89	2.65	28.1	1.70	3.884	81.5
June	4.77	2.27	27.7	1.81	4.024	81.8
July	4.87	2.51	27.8	1.80	3.881	80.0
August	4.77	2.67	27.6	1.79	4.126	81.3
September	4.53	2.79	26.8	1.80	4.053	84.5
October	4.15	2.49	26.9	1.59	4.195	84.2
November	4.32	2.46	26.6	1.70	3.761	86.0
December	3.84	2.45	26.8	1.69	3.750	84.9

Fig. 1. Data on temperature and solar radiation at SDN 023905 Binjai.

Based on Fig. 1 on solar radiation above, we can conclude that the lowest solar radiation was 3.84 kWh/m2/day in December, while the highest solar radiation was 5.47 kWh/day m2, thus the average solar radiation is 4.74 kWh/m2/day. Based on Figure 4.1 we can also conclude that the temperature is 26.6$^{\circ}C$ in November, while the temperature is 28.1 $^{\circ}C$ in May, and temperature the average 27,3 $^{\circ}C$.

4.3. Technical Analysis of PLTS Planning

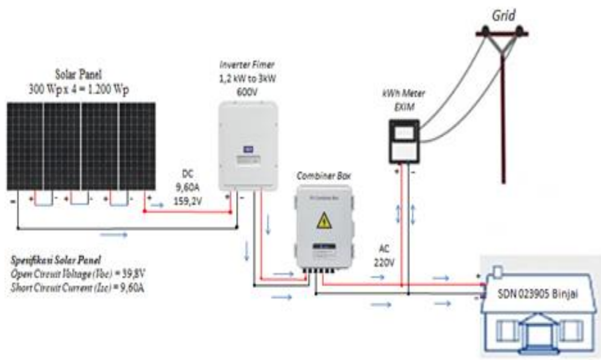

Fig. 2. System *On Grid.*

From the picture above this PLTS, it can be interpreted that sunlight will be absorbed by the solar module, which is absorbed by the solar module in the form of a DC current so that it flows to the inverter so that it is converted into AC current then flows to the distribution panel which will later supply the load then if no load is supplied then it will flow to the kWh Meter EXIM which will later read how much power has been supplied to PLN or received from PLN, then the power is channeled to the PLN network, so Likewise, if the power required is less than the power supplied by the PLTS, then the power that will be supplied from the PLN network will be used which is channeled through the EXIM kWh meter which will read how much power is received via the PLN network.

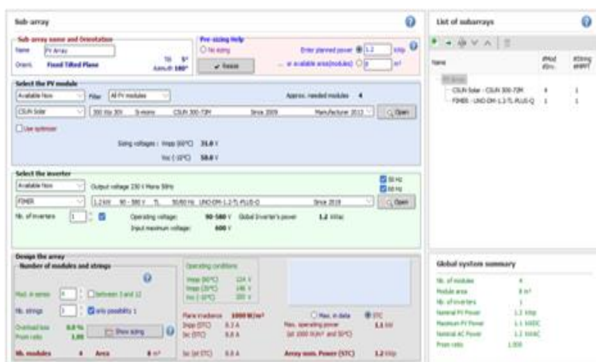

Fig. 3. PLTS System *On Grid* Using *PVSYST 7.2.*

From Fig. 3, namely the design of the on-grid, it can be seen that the planning of the on-grid solar modules monocrystalline brand CSUN with a capacity each module is 300Wp and will be installed on a roof with a slope of 5o and facing south, in this plan 1 FIMER brand inverter with a power capacity of 1.2 kW to 3 kW in one inverter.

4.4. Solar Panel Specifications

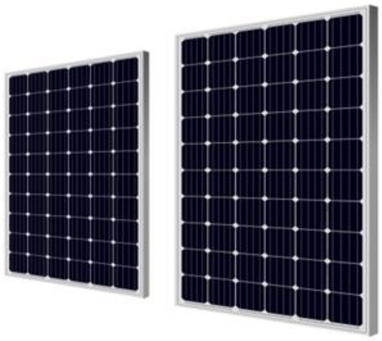

Fig. 4. Solar Panel 300 WP CSUN *Monocrystalline.*

Table 2. Solar panel specifications.

Rated Power (Pmax)	300Wp
Max. Power Voltage (Vmpp)	32.2V
Max. Power Current (Lmpp)	9.31A
Open Circuit Voltage (Voc)	39.8V
Short Circuit Current (Isc)	9.60A
Max. System Voltage	1500V
Cell Efficiency	18.48%
Positive Power Tolerance	±3%
Dimension	1640x992x35mm
Weight	18.3Kg

4.5. Inverter Specifications

Fig .5. Inverter UNO-DM-1.2/2.0/3.0 TL-PLUS-Q.

Table 3. Detection time for each trial.

Model No.	UNO-DM-1.2-TL-PLUS-Q	UNO-DM-2.0-TL-PLUS-Q	UNO-DM-3.0-TL-PLUS-Q
Warranty			
Product Warranty (Min)	5 Years	5 Years	5 Years
Input Data(DC)			
Max. DC Power	1.5 kW	2.5 kW	3.3 kW
Max. DC Voltage	600 V	600 V	600 V
Rated DC Voltage	185 V	300 V	300 V
Min. DC Voltage to Start Feed In	120 V	150 V	150 V
Max. DC Current	10 A	10 A	10 A
MPP(T) Voltage Range	90~580 V	90~580 V	90~580 V
No of MPP Trackers	1	1	1
DC Inputs	1	1	1

4.6. Determining the Number of PV Modules

To determine the number of PV modules, beforehand you must know how much PV power capacity must be installed, it can be calculated by equation 2.1:

$$PWatt\ Peak = \frac{\text{Konsumsi Beban Harian}}{\text{Lama Penyinaran Matahari}} = \frac{5.676\ \text{Wh}}{5\ \text{h}}$$

$$= 1.135{,}2\ W \approx 1.200\ Wp \approx 1{,}2\ kWp$$

So, the capacity of the PLTS to be built at SDN 023905 Binjai is 1.2 kWp.

The solar panels used in this plan have a Pmpp specification of 300 Wp per panel. So that the number of solar panels that will be needed by PLTS, if the desired capacity is 1.2 kWp can be calculated by equation 2.2, namely:

$$\text{Number of Solar Panels} = \frac{\text{Pwatt peak}}{\text{Pmpp}}$$

$$= \frac{1200\ \text{Wp}}{300\ \text{Wp}}$$

$$= 4\ Panel$$

So, the number of solar panels needed to build a PLTS *on grid* with a capacity of 1.2 kWp in this plan is 4 panels.

After knowing the number of panels to be made, it is necessary to know that the number of panels to be installed is sufficient to be installed on the roof of SDN 023905 Binjai. With the data that has been obtained, the *array* of SDN 023905 Binjai has a roof area that is quite large, namely 23.4 m x 17.5 m so that it can be made as a PLTS placement where the area of the PV *array* is around $8m^2$. After the calculation of the area of the SDN 023905 Binjai array, and it is necessary to calculate the amount of area to be used for module installation, the calculation of the area of the module area to be used, is then calculated in equation 2.4-2.6:

a. Total module length = Module length x 1 series
   = 1640 mm x 1 seri
   = 1.640 mm
   = 1.6 m ≈ 2m

b. Total module width = Module Width x 4 modules
   = 992 mm x 4 modules
   = 3.968mm
   = 3.9 m ≈ 4m

c. Total area = Total Length x Total Width
   = 2m x 4m
   = $8m^2$

So it can be seen from the results of calculating the area of the module area on the roof of SDN 023905 Binjai that it can be used as a place to place PLTS because the area is sufficient.

Then to measure the slope of the PLTS will be determined using equation 2.7-2.9 with data taken from the coordinates of SDN 023905 Binjai (03°38'00, 098°29'26) obtained as follows:

$\alpha = 90° - lat + \delta$
$= 90° + 3{,}38° - 23{,}45°$
$= 69{,}93°$

$\beta = 90° - \alpha$
$= 90° - 69{,}93°$
$= 20{,}07°$

So from the results of calculations by knowing the coordinates of SDN 023905 Binjai, it is obtained that the maximum tilt angle of the solar panel is 20,07°.

4.7. Determining Inverter Capacity

Determining the inverter can be seen based on the required power capacity. Inverter capacity calculation can be calculated by equation 2.3 as follows:

$Inverter$ Capacity = Number of solar panel x panel capacity
= 4 $panel\ x$ 300 Wp
= 1.200 $Watt \approx$ 3.000 $Watt$

The capacity of the inverter used in this plan is 3 kW, because the inverter used must be able to accommodate the total current and voltage that comes out of the array and then enters the inverter. When using 1.2 kW it cannot accommodate the total current and voltage that comes out of the array. From Figure 4.7 above it can be seen that the inverter that we use can accommodate the total current and voltage that comes out of the array leading to the inverter with a total current obtained of 12.5 A with the maximum current capacity of the inverter being 14.5 A, then the total voltage obtained is 16 V with the maximum voltage capacity of the inverter is 600 V.

4.8. Calculating the Power Output of PLTS

The losses (losses) of the PLTS system are assumed to be 15% because all the system equipment used is new **(Bien, Kasim, & Wibowo, 2008:41 in his book Mark Hankins, 1991: 68),** then the amountice loss as calculated by equation 2.10 as follows:

Pi = The amount power used × (100% − 15%)
= 1.200 $watt$ × 85%
= 1.020 W ≈ 1,020 kW

The result of reducing losses in solar panels based on the capacity of the installed panels is 1,020 kW. The energy generated from solar modules is related to the lowest and highest solar radiation data. If the data used is the lowest solar radiation of 3.84 contained in Table 4.1, the energy produced by the panel can be calculated by equation 2.11 as follows:

$Pout$ = Pi × minimal solar radiation
= 1,020 kW × 3,84 h
= 3,91 kWh

So, the energy produced when the sun's radiation is lowest is 4.2 kWh. If using the highest solar radiation data, namely 5.47 kWh contained in table 4.1, it can be calculated by equation 2.13 as follows:

$Pout$ = Pi × maximum solar radiation
= 1,020 kW × 5,47 h
= 5,57 kWh

So, the energy produced during the highest solar radiation is 5.57 kWh. If you want to calculate the energy produced on average per year, then the radiation data used is the average radiation, or called Peak Sun Hour (PSH) with a value of 4.83 in Table 4, it can be calculated by equation 2.21 as follows:

$Pout$ = $Pi \times PSH$
= 1,020 kW × 4,74 h
= 4,83 kWh

$Energi\ yield$ = $energ$y $output\ x$ 365 days
$Energi\ yield$ = 4,83 kWh $\boldsymbol{x}$ 365 days
= 1.762,95 kWh/Tahun

Table 4. Calculation Results of PLTS Power Output Based on Solar Radiation and *Energy Yield*

Radiasi Matahari Terendah (kWh)	Radiasi Matahari Tertinggi (kWh)	Radiasi Matahari Rata-Rata (kWh)	Eyield (kWh/Tahun)
3,91	5,57	4,83	1.762,95

4.9. Calculating Performance Ratio (PR)

Performance Ratio (PR) is a parameter of system quality produced from energy annually. If the system's PR value is around 70-90% then the system can be categorized as feasible. The following is the calculation to determine the *performance ratio* of this PV mini-grid system:

PR = $\frac{\text{EYield}}{\text{EIdeal}}$ $E\ ideal$ = P arraySTC $x\ H\ tilt$
$H\ tilt = PSH\ x$ 365 = (4,74 h x $\frac{1000\ \text{W}}{\text{m2}}$) x 365 Days
= 1.730,1 kWh/m^2

$Energi\ ideal$ = solar module power specifications x number of modules $x\ Htilt$
Energi Ideal = 300Wp x 4 modul x 1730,1 $\frac{\text{h}}{\text{tahun}}$
= 2.076.120 $\frac{\text{wh}}{\text{tahun}}$

So that the PR is obtained, equal to:

$$PR = \frac{EYield}{EIdeal}\ PR = \frac{1.762,95\ kWh/tahun}{2.076,120\ kWh/tahun} = 0,849 \approx 84\%$$

So, from the results of the performance ratio calculation above, a ratio of 84% is obtained, and the system is categorized as feasible to use.

4.10. Initial Investment

Table 5. Initial Investment Cost of PLTS at SDN 023905 Binjai.

No	Komponen	Jumlah	Satuan	Harga Satuan	Total Harga
1.	Solar Panel *CSUN Monocrystalin* 300 Wp	4	Pcs	Rp. 2.350.000	Rp. 9.400.000
2.	*Inverter FIMER*	1	Pcs	Rp. 9.755.222	Rp. 9.755.222
3.	Panel Cable	50	Meter	Rp. 10.000	Rp. 500.000
4.	*Combiner Box*	1	Set	Rp. 1.650.000	Rp. 1.650.000
5.	*Mounting* (Support Pen Rack)	1	Set	Rp. 9.600.000	Rp. 9.600.000
6.	kWh Meter *Exim*	1	Pcs	Rp. 450.000	Rp. 450.000
	TOTAL				Rp. 31.555.222

4.11. Maintenance and Operational Costs

Investment for maintenance and operations per year in PLTS is calculated to range from 1% to 2% of all initial investment costs (Santiari: 2011). The percentage consists of costs for solar panel cleaning activities, the maintenance budget and component inspection. In this study, maintenance and operational costs (M) are set at 1% of the total initial investment cost. Because Indonesia only has 2 seasons, including the rainy and dry seasons, compared to other countries which have 4 seasons, the maintenance and operational costs tend to be higher. The cost per year is:

$$\begin{aligned} M &= 0,01 \times Total\ biaya\ investasi \\ &= 0,01 \times 31.555.222 \\ &= Rp.\ 315.552\ /tahun \end{aligned}$$

4.12. Calculating the Life Cycle Cost of PLTS

The PLTS that will be built in this study is expected to operate for 20 years. It is known that the life of this project refers to the guarantee given by the solar panel manufacturer. The discount rate (i) used to calculate the present value in this study is 4.25%. The discount rate is determined from Bank Indonesia's lending rate in September 2022, which is an average of 4.25% (BI, 2022). The present value of the PLTS maintenance and operational costs (Mpw) for a 20-year project life with a discount rate of 4.25% is calculated using the following equation $P = [\frac{(1+i)^n - 1}{i\ (1+i)^n}]$

$$Mpw\ (M\ 4,25\%\ 20\ Years) = Rp.\ 315.552\ [\frac{(1+0,0425)^{20}-1}{0,0425\ (1+0,0425)^{20}}]$$

$$\begin{aligned} &= Rp.315.552\ [\frac{(1,0425)^{20}-1}{0,0425\ (1,0425)^{20}}] \\ &= Rp.315.552\ [\frac{2,29890631 - 1}{0,0425\ (2,29890631)}] \\ &= Rp.315.552\ [\frac{1,29890631}{0,0977035182}] \\ &= Rp.\ 4.195.064 \end{aligned}$$

So, from the calculation above, the PV mini-grid life cycle cost (LCC) for a 20-year project life can be calculated using the following equation:

$$\begin{aligned} LCC &= C + Mpw \\ &= Rp.\ 31.555.222 + Rp.\ 4.195.064 \\ &= Rp\ 35.750.286 \end{aligned}$$

4.13. Calculating the Energy Cost of a PLTS

The Energy Cost (*Levelized Cost of Energy*) of a PLTS, is determined from the life cycle cost (LCC), the return on investment factor (CRF), and the annual kWh of production. The payback factor for converting all life cycle cost cash flows into a series of annual costs is calculated using the following equation.

$$\begin{aligned} CRF &= \frac{i\ (1+i)^n}{(1+i)^n - 1} \\ &= \frac{0,0425\ \ (1+0,0425)^{20}}{(1+0,0425)^{20} - 1} \\ &= \frac{0,097}{1,298} \\ &= 0,0747 \end{aligned}$$

The annual kWh production value is as follows.

$$\begin{aligned} \text{Annual kWh Production} &= kWh\ \text{daily production} \times 365 \\ &= 4,83\ kWh \times 365 \\ &= 1.762,95\ kWh \end{aligned}$$

Obtaining the annual production LCC, CR and kWh values, then the energy cost (LCoE) for planning this PLTS system is calculated by the equation below:

$$\begin{aligned} LCoE &= \frac{LCC\ x\ CRF}{Produksi\ kWh\ Tahunan} \\ &= \frac{Rp\ 35.750.286\ x\ 0,0747}{1.762,95\ kWh} \\ &= Rp.\ 1.514 - /kWh \end{aligned}$$

4.14. Investment feasibility analysis

Is said to be feasible to be determined from the Net Present Value (NPV), Profitability Index (PI), and Discounted Payback Period (DPP). The calculation uses energy costs, which are IDR 1,514/kWh. With energy costs and a large kWh of annual production of 1,763 kWh, the annual cash inflow is IDR 90,090,000. Meanwhile, the annual expenditure is IDR 315,552 which is determined based on the annual PLTS maintenance and operational costs. Table 4.4 shows the results of calculating net cash flow, discount factor (i) of 4.25%, and the present value of net cash flow. The discount factor (DF) is calculated by the following equation:

$$D = \frac{1}{(1+i)^n}$$

For example, the calculation of the discount factor with n is the 1st year:

$$D = \frac{1}{(1+0{,}0425)^1}$$

$$= 0{,}9592$$

The following is a table for calculating NCF, DF, and PV NCF with i = 4,25%

Table 6. Calculation of NCF, DF, and PVNCF with i = 4,25%.

Tahun	Biaya	Arus Kas Masuk	Arus Kas Keluar	Arus Kas Bersih (Net Cash Flow)	Discount Factor (DF) 4,25%	Present Value NCF (NCF x DF)	Kumulatif PV NCF
1		90090000	315.552	89.774.448	0,9592	86114578	86.114.578
2		90090000	315.552	89.774.448	0,9201	82603912	168.718.490
3		90090000	315.552	89.774.448	0,8826	79236367	247.954.857
4		90090000	315.552	89.774.448	0,8466	76006107	323.960.964
5		90090000	315.552	89.774.448	0,8121	72907537	396.868.500
6		90090000	315.552	89.774.448	0,779	69935287	466.803.787
7		90090000	315.552	89.774.448	0,7473	67084208	533.887.996
8		90090000	315.552	89.774.448	0,7168	64349360	598.237.356
9		90090000	315.552	89.774.448	0,6876	61726005	659.963.361
10	Rp. 31.555.222	90090000	315.552	89.774.448	0,6595	59209597	719.172.958
11		90090000	315.552	89.774.448	0,6326	56795777	775.968.735
12		90090000	315.552	89.774.448	0,6069	54480361	830.449.096
13		90090000	315.552	89.774.448	0,5821	52259339	882.708.436
14		90090000	315.552	89.774.448	0,5584	50128863	932.837.299
15		90090000	315.552	89.774.448	0,5356	48085240	980.922.539
16		90090000	315.552	89.774.448	0,5138	46124931	1.027.047.469
17		90090000	315.552	89.774.448	0,4928	44244538	1.071.292.007
18		90090000	315.552	89.774.448	0,4727	42440804	1.113.732.811
19		90090000	315.552	89.774.448	0,4535	40710603	1.154.443.413
20		90090000	315.552	89.774.448	0,435	39050938	1.193.494.352

1. *Net Present Value* (NPV)

The Net Present Value technique in the calculation is:

$$NPV = \sum_{t=1}^{n} \frac{NCFt}{(1+i)^t} IA$$

Table 4.4 indicates that the total present value of net cash flows (PV NCF) is the result of multiplying the net cash flows (NCF) with the discount factor (DF) which is equal to NPV = $\sum_{t=1}^{n} \frac{NCFt}{(1+i)^t} IA$ namely Rp. 86,114,578. And thus the initial investment cost (IA) of Rp. 31,555,222 then the resulting NPV is:

NPV = amount of cash income − investment amount

$= Rp.86.114.578 - Rp.31.555.222$

$= Rp.54.559.356$

Calculation of a positive NPV Rp. 144,333,804, (NPV> 0), indicating that the planned PLTS investment at SDN 023905 Binjai is feasible to realize.

2. *Profitability Index* (PI)

The Profitability Index method is calculated using the calculation system below:

$$PI = \sum_{t=1}^{n} \frac{NCFt\ (1+i)-t}{IA}$$

The total present value of the net cash flow is Rp. 54,559,356 and the initial investment value (IA) is IDR 31,555,222 so the PI value:

$$PI = \frac{Rp.54.559.356}{Rp.31.555.222}$$

$$= 1{,}7290$$

After obtaining a PI of 1.7290 (> 1), it indicates that the PLTS investment is feasible.

3. *Discounted Payback Period* (DPP)

Discounted Payback Period (DPP) is obtained by calculating how many years the current cumulative net cash flow value (Cumulative PV NCF) can be seen in table 4.6 in year 1, the cumulative PV NCF exceeds the value of the initial investment cost which is more than Rp. 54,559,356, namely from Rp. 86,114,578 – Rp. 31,555,222. So in the 1st year, the present value of net cash flow (PV NCF 1st year) is IDR 86,114,578 and can cover the initial investment costs of IDR 31,555,222, so the time needed is around 1 year 1 month.

5. CONLUSION

Based on this PLTS plan, it is obtained that the daily load consumption at SDN 023905 Binjai is 5.676 kWh/5h (time of sunshine), which is 1,135.2 and the PLTS will supply a capacity of 1.2 kWp. In planning for the construction of this PLTS, it can be seen from the average daily electric load in elementary schools, which is 5,676 kWh. So, it can be a reference to find out the required PLTS capacity. Therefore, the PLTS planned to be built requires 4 solar panels with a capacity of 300Wp for each module and arranged in series with the power output generated by the PLTS, namely 9.60A and 159.2V and 1 inverter with a capacity of 1.2kW to 3kW and components -other supporting components. The PLTS installation plan will be placed on a roof with a slope of 5o and facing south. Based on the results of economic calculations, this PLTS plan requires an investment cost of IDR 31,555,222. This plan is profitable if it is developed as well and initial cost recovery occurs in the 1st year and 1st month of the 20-year project life. In general, this project is also promising because the cost per kWh is higher (Rp. 1,514.-) than BPP PLN. (Rp. 1,247,-)

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