IOP Conf. Series: Earth and Environmental Science **969** (2022) 012029 doi:10.1088/1755-1315/969/1/012029

Design of a solar power plant system for micro, small, medium enterprise uses PVSyst 7.1 as a renewable energy alternative source in remote areas

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Abstract. PLN electricity distribution goal for remote areas is not achieved yet so that alternative sources are needed, for instance, solar power plants. The purpose of this study is to design and analyze the solar power plant potential with an off-grid system that is used to supply SME electricity in electrical and economic terms. The daily load data profile used by SME is 1.8 kWh. This study uses PVSyst 7.0 software as design tool simulation system and RETscreen software as an economic analysis tool simulation. The result of this solar power plant system design requires a 700Wp solar module, 24V 160Ah battery, 24V 1000W inverter, and SCC 30A. With the planned system design, the electrical energy generated in the PVSyst simulation in one day is estimated to reach 2 kWh with the use of 50% Deep of Discharge battery capacity considering the length of battery life span. To return the investment cost of this solar power plant system, PLN electricity cost needed is Rp 2,664.

1. Introduction

The electricity demand growth is projected to increase up to nine times from the early demand of 254.6 TWh in 2018 to 1,918 TWh in 2050. During the 2018-2050 period, the demand for electrical energy recorded an increased rate of 6,5% per year and has a relatively similar pattern. The largest electricity demand portion comes from the household sector, the industrial and commercial sectors, transportation sector, and followed by other sectors. The energy needs demand in the commercial sector is still dominated by electricity with a portion of 60 – 70. In 2050, the electricity demand in the commercial sector is estimated to increase seven times to 305 TWh [1]. Energy production that still relies on fossil fuels causes the petroleum supply to decrease.

The commitment and efforts of countries worldwide to reduce greenhouse gas emission continues to boost, therefore, this encourages the Indonesian government to maintain the national energy security and independence. The increase of new and renewable energy roles is also continuously pursued. As written on PP No. 79 of 2014 concerning National Energy Policy, the targets of new and renewable energy mix in 2025 have to be at least 23%, followed by 31% by 2050. Huge renewable energy potential in Indonesia is targeted to achieve the primary energy mix plan [1]. The new and renewable energy utilization in 2018 only achieved 8.8 GW, which is 0.019% of the total renewable energy potential in

Indonesia. Renewable energy that can be utilized for power plants has a total potential equivalent of 442 GW. Moreover, solar energy has the greatest potential among other renewable energy sources of 207.8 GWp. With the average radiation level/day in Indonesia that reaches 4.80 KWp/m2/day, which is considered a relatively high category, solar energy is the best potential opportunity that can be utilized on a small-scale experiment. This solar power plant is also functional and flexible so that it can be easily applied to places with sufficient sun exposure. The use of this renewable energy would take a slight contribution in reducing the effects of global warming.

2. Methodology

2.1. Solar Power Plant

Solar Power Plant utilizes new and renewable energy sources. This plant has solar cells that function to convert solar radiation into electrical energy. Solar cells are made of semiconductor materials and layers of pure silicon. Moreover, solar power plant does not produce pollution or hazardous waste or it can be said that this plant is environmentally friendly. The output power efficiency of solar cells is influenced by several factors, including solar radiation, temperature, shadow leverages, solar panels slope, and solar panels direction [2].

2.2. Technical Analysis

Technical analysis is carried out according to solar power plant capacity, the use and determinate component specifications, solar panel orientation, and energy produced from the plants. The energy produced from solar power plants is influenced by such factors which are sun radiation in research location, solar panel slant and aim, sunray, temperature, and each component technical capabilities that will be used in this research. The energy produced will decrease as time goes by due to solar panels and other parts function degradation. Moreover, the solar power plant is also considered by its performance ratio. Performance ratio may generally be shown in percentage value that shows the total produced energy and loss that occurs when the system is on STC condition. Loss in solar power plants is also affected by solar panel efficiency, solar charge controller, battery, inverter, inverter efficiency, and other components [3].

2.3. Technical Economic Analysis

Technical economic analysis can be generally defined as an economic analysis of one engineering investment. This analysis aims to assess technical investment proposal feasibility by conducting an alternative study that is considered the most profitable [4]. In general, this investment has a long economical lifespan, to be exact, for years. To achieve the feasibility status, this technical economic analysis should gain more profit to cover the total initial investment until the investment period ends [5]. In analyzing technical economic analysis, the following equation is used to assist the calculation.

$$PWB = \sum_{t=0}^{n} Cb_t(FBP)_t \quad (1)$$

$$PWC = \sum_{t=0}^{n} Cc_t(FBP)_t \quad (2)$$

$$\text{NPV} = \text{PWB} - \text{PWC} \quad (3)$$

While PWB is Present Worth Benefit, PWC is Present Worth Cost, and NPV is Net Present Value.

2.4. *Research Location*

The research location is carried out at coffee shop in Tembalang, Semarang city which astronomically located at the coordinate of -7.068052663931588, 110.44012904772178 as given in Figure 1.

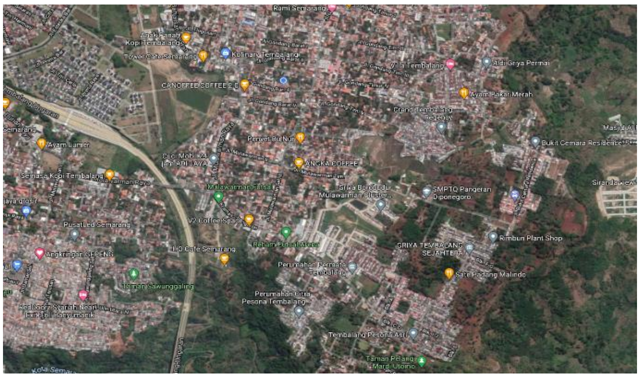

Figure 1. Coffeeshop SME as the object of the research located in Tembalang, Semarang

2.5. *Daily Load Data Profile*

Daily load data is needed to project and estimate the solar power plant system in this research. According to the survey conducted directly in the research location, it can be seen that the daily load data profile is available in Table 1.

Table 1. Daily Load Data Profile at Research Area

No.	Load	Amount	Energy (Watt)	Total Energy (Watt)	Time Used	Total W x H
1	Grinder Latina	1	150	150	2	300
2	Heater Air Idealife	1	350	350	2	700
3	LED	10	4	40	6	240
4	White LED Lamp	1	18	18	3	54
5	Logo Lamp	1	5	5	10	50
6	Router	1	10	10	10	100
7	Socket	10	15	150	2	300
	Total		**552**	**723**		**1744**

According to the Table 1, the daily load data profile in the research area can be represented in hourly parameter graph as illustrated in Figure 2.

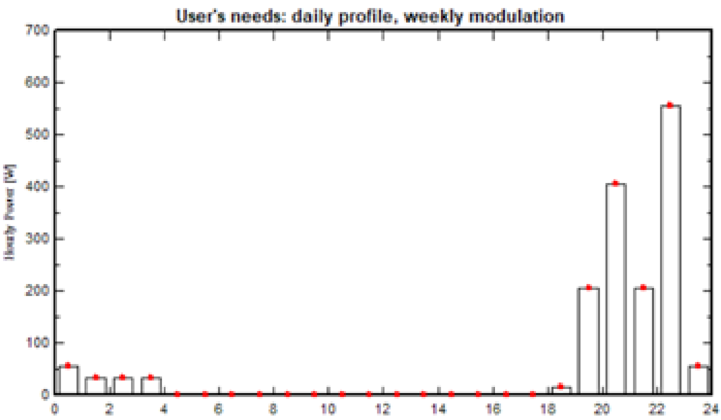

Figure 2. Daily Load Graph at Research Area

2.6. *Sun Radiation Data*

According to meteorological data obtained from NASA Prediction of Worldwide Energy Resources, the average solar energy isolation level in 2018 to 2019 in Kramas, Tembalang is 5 kWh/m2/day. Table 2 describes data obtained from NASA includes irradiation, regional temperature, wind velocity, and moisture data [6].

Table 2. Insolation, Temperature, Diffuse Radiation, and Wind Velocity in Semarang City

Month	Data			
	Radiation (kWh/m^2.day)	**Temperature (^oC)**	**Diffuse Radiation (kWh/m^2.day)**	**Wind Velocity (m/s)**
January	4.60	25.2	2.33	2.59
February	5.29	25.2	2.39	1.42
March	4.55	24.9	2.32	2.06
April	5.08	25.7	2.06	1.76
May	5.41	25.2	1.76	2.65
June	5.14	23.9	1.62	2.82
July	5.37	23.5	1.63	3.04
August	5.94	23.9	1.80	3.11
September	6.49	25.3	2.06	2.99
October	6.54	26.7	2.31	2.75
November	6.02	27.0	2.34	2.37
December	5.30	26.3	2.32	1.42

3. Result and Discussion

3.1. *Details of Used Components Detail*

3.1.1. *Battery*

The battery use in the off-grid solar power plant system for SME Coffee shop will be calculated according to the SME daily load data that is already listed in the Table 1. Total load in a day at the research location based on the gathered data is 1744Watt/hour. Therefore, the minimum battery calculation is in accordance with the total daily energy. However, the battery use is not necessarily similar as what is written in the specification. The research will be carried out in one autonomous day and Deep of Discharge of 50% considering the battery life span. In calculating the battery specification requirement, the following equation is used:

Total Energy in a day = 1744 Wh
DoD of battery = 50 %

$$Avg.\ Battery\ Load = \frac{Avg.\ Daily\ Load}{Inverter\ Efficiency \times Nominal\ Battery\ Voltage}.$$

= 1744 / 0.9 x 24
= 80 Ah

$$C_x = Days\ of\ Autonomy \times Avg.\ Battery\ Load \times \frac{1}{End\ of\ Life\ Rating}$$

= 1 x 80 x 1 / 0.5
= 160 Ah

Therefore, the battery specification needed is 24 V / 160 Ah battery or 4 parallel configurations of 12 V/80 Ah batteries.

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3.1.2. Solar Panel

To achieve daily battery charging, solar panels energy is required to fulfill the battery in accordance with the used specification. To calculate the solar panels energy requirement, the equation needed is as follows:

Irradiation effectiveness = 3,25 hours
Total required panel = Total daily load / (Radiation length x inverter efficiency)
= 1744 / (3,25 * 0.9)
= 605 Wp

Therefore, minimum specification of required panel in this design is 586 Wp.

3.1.3. Solar Charge Controller

SCC is needed as the battery charger with MPPT (Maximum Power Point Tracking) technology. With panel specification of 600 Wp, therefore, the current estimation that will be used with a 24 V battery system is as follow:

Nominal current SCC = Total panel energy / Battery voltage system
= 605 / 24
= 25,3 A

Therefore, the minimum current specification for SCC in this design is 25,3 A.

3.1.4. Inverter

Inverter is utilized to change the direct current to alternating current. Therefore, the inverter specification needed can be calculated with the following equation:

Peak load power = 552 Watt
Battery voltage system = 24 V
Maximum inverter DC = Peak Load Power / Battery voltage * Efficiency
= 552 / 24 * 0,85
= 27,8 A
Inverter energy after losses = 552 * 1,25
= 690 W

Therefore, the minimum inverter specification is 24 V, 690 W.

3.2. Simulation

In conducting SME coffee shop solar power plant design simulation with PVSyst software, technical data is needed to influence the simulation results. There are also several factors that will affect the output/results of solar power plant simulation such as solar energy potential, irradiation value, location temperature, wind velocity, solar panels position and orientation, component specifications, and daily load data of the installation object [7]. The simulation process is carried out to see how much electrical energy potential that will be generated from the solar power plant simulation. The simulation will also show the amount of electrical energy produced, the electrical power amount supplied to the load at the research area, and the minimum amount of battery needed in this research. The research object is a coffee shop located in Tembalang, Semarang city.

The design will be carried out using roof support as shown in Figure 3-5.

Figure 3. Research Object Visualization (Side View)

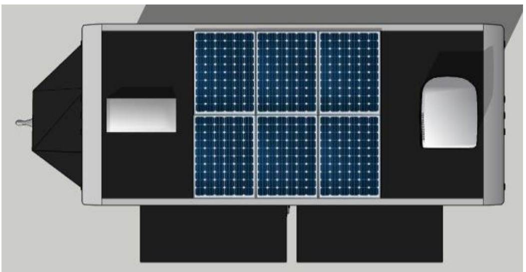

Figure 4. Research Object Visualization (Upper View)

Figure 5. Research Object Visualization (Front View)

This solar power plant design has 4 (four) main components that will be considered in designing an off-grid solar power plant system including solar panel, battery, inverter, and Solar Charge Controllers. According to the calculation result, the alternative components that will be used in this solar power plant design in SME coffee shop can be seen in Table 3.

Table 3. Solar Power Plant Component Configuration

Component	Amount	Specification	Brand	Configuration
Battery	4 pieces	12 V 80 Ah	SMT Power	2 series battery
Solar Panel	2 modules	Monocrystalline 350Wp	JA Solar	2 modules series-parallel
SCC	1 piece	12V / 24V / 36V 30 A	Make Sky Blue	-
Inverter	1 piece	Pure Sine Wave 1000 Watt	STEC Power	-

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3.3. *Detailed Engineering Design on Solar Power Plant System*

Detailed engineering design from the solar power plant design according to the component specifications in Table 3 can be seen in Figure 6.

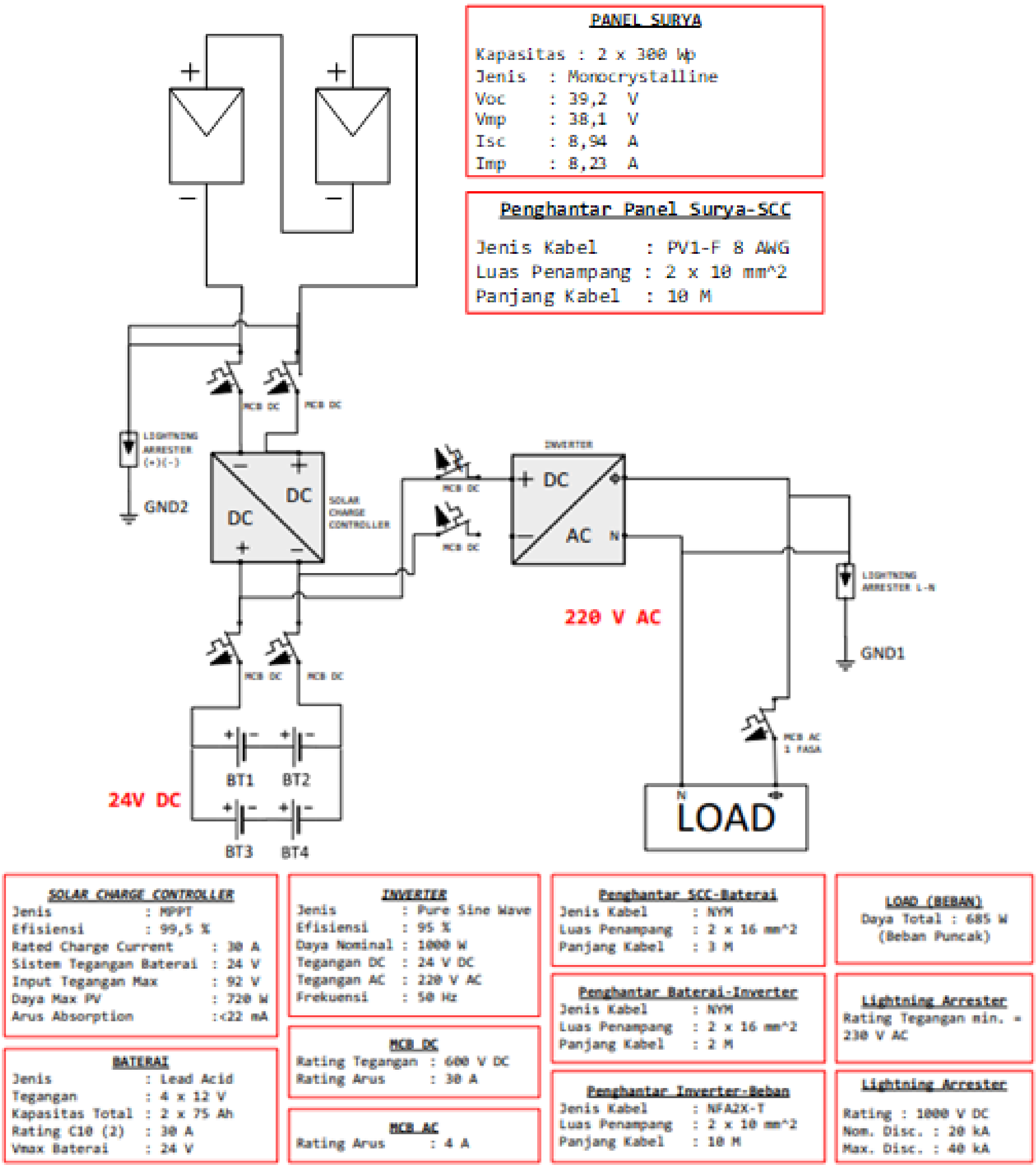

Figure 6. Detailed Engineering Solar on Power Plant System

3.4. Result

After inputting all data and performing calculations, the next step is stimulating the component configuration systems that have been defined previously using PVSyst 7.1 software. Figure 7 shows the simulation results.

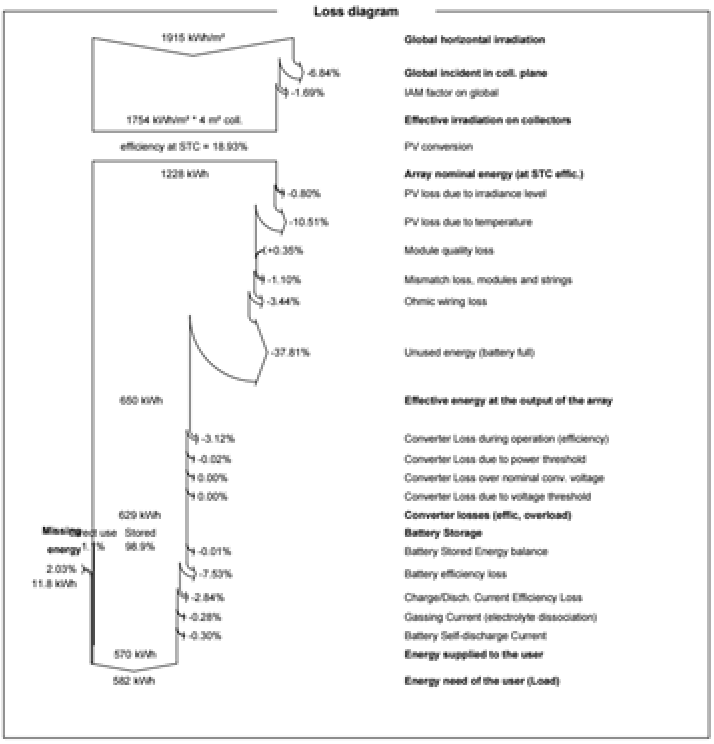

Figure 7. Simulation Results

3.5. Discussion

3.5.1. Technical Analysis

After conducting the simulation with the PVSyst 7.0 software, the result on the SME coffeeshop is summarized as in Table 4.

Table 4. PVSyst simulation results of solar power plant

Energy	**Total Energy**	Unit
Solar Panels Insulation	1747	(kWh/m^2)
Array STC Electrical Energy	1228	(kWh)
Array Output Electrical Energy	650	(kWh)
Saved Energy in Batteries	629	(kWh)
Supplied Energy to Load	570	(kWh)

According to the data obtained in Table 4, the amount of electrical energy produced in the solar power plant design system is 1228kWh/year. The solar module efficiency is influenced by the solar panel type used in the research. This research uses monocrystalline solar panel type which has greater efficiency than the polycrystalline type. This occurs due to the main material for making monocrystalline solar panels which is silicon that has greater concentration. However, monocrystalline type has a smaller surface area than polycrystalline type.

The electrical energy output of the array for one year in the system experiences losses of 186 kWh or 17.7% and unused energy of 403 kWh or 32.8% in the STC condition. Therefore, the stored and supplied energy to the load is 567-570 kWh. The panels used have losses in the range of 18-20%.

The electrical energy that can be supplied to the user is 570 kWh. If compared with the user's necessity of 582 kWh, the supplied total energy has a necessity rate of 98%. The missing energy can be substituted with the saved energy in the battery because of battery DoD which has 50% capacity.

3.5.2. Economic Analysis

The feasibility of solar power plant investment in the research location is determined based on the Net Present Value (NPV) using RetScreen software. The simulation result is also affected by total investment expense, operational costs, electrical energy saving costs, discount rates, and inflation values. The total investment cost is obtained from surveys to offline stores in Semarang city and online stores in various e-commerce sites in Indonesia. Moreover, the discount rate and inflation value are obtained from the official website of Bank Indonesia [8].

The investment costs for each component in the solar power plant design at research site can be seen in Table 5.

Table 5. Solar Power Plant System Initial Investment Cost.

Component	**Amount**	**Unit**	**Price**	**Total Price**
JA Solar Monocrystalline 350Wp Solar Panel	2	Modules	Rp 3,000,000	Rp 6,000,000
Solar Charge Controller Make Sky Blue	1	Piece	Rp 1,500,000	Rp 1,500,000
SMT Power 12V 80Ah Battery	4	Pieces	Rp 1,550,000	Rp 6,200,000
STEC PSW 1000W Inverter	1	Piece	Rp 1,800,000	Rp 1,800,000
Solar Panel Support	1	set	Rp 768,000	Rp 768,000
Cable	1	set	Rp 1,000,000	Rp 1,000,000
Protection	1	set	Rp 2,000,000	Rp 2,000,000
Service and others	1	set	Rp 1,500,000	Rp 1,500,000
	Total			**Rp 20,500,000**

Annual operational and maintenance costs for solar power plant systems are generally calculated as 1-2% of the total initial investment costs for solar power plant plus battery replacement costs during the project period [9]. Therefore, the annual operational costs for this research can be seen in Table 6.

Table 6. Solar Power Plant System Operational Cost.

Component	***Amount***	***Unit***	***Price***	**Total Price**
Solar Panel O&M	1	Year	Rp 64,000	Rp 60,000
SCC O&M	1	Year	Rp 15,000	Rp 15,000
Battery O&M	1	Year	Rp 62,000	Rp 62,000
Inverter O&M	1	Year	Rp 18,000	Rp 18,000
Solar Panel Support O&M	1	Year	Rp 5,000	Rp 5,000
Cable O&M	1	Year	Rp 10,000	Rp 10,000
Protection O&M	1	Year	Rp 20,000	Rp 20,000
Battery Replacement	1	Year	Rp 775,000	Rp 775,000
	Total			**Rp 965,000**

According to Table 5 above, it is shown that there is an initial investment cost needed is of Rp20,500,000 with an annual O&M cost of Rp965,000.

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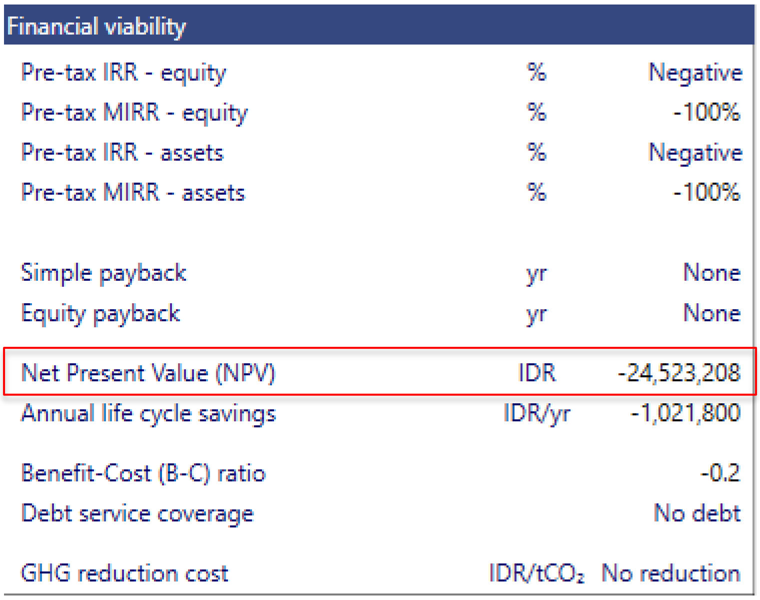
Electrical energy saving is a linear savings calculation from the beginning to the end of solar power plant project. Electrical energy savings is the value obtained from the amount of energy supplied to the load in order to meet daily electrical energy necessities based on PVSyst software. The power produced is 570 kWh per year and the price of 1 kWh electricity is Rp1,444.7. Therefore, the annual electricity savings are Rp 823,479.

The simulation on RetScreen software is carried out by inputting the initial investment costs, operational costs, and savings on the menu. Afterward, proceed to the financial menu by inputting the inflation rate value. The inflation rate value in June 2021 is 1.33% and the data is obtained from the official website of Bank Indonesia [10].

Based on the simulation result, NPV value for the solar power plant system is as described in Figure 8.



Financial viability		
Pre-tax IRR - equity	%	Negative
Pre-tax MIRR - equity	%	-100%
Pre-tax IRR - assets	%	Negative
Pre-tax MIRR - assets	%	-100%
Simple payback	yr	None
Equity payback	yr	None
Net Present Value (NPV)	IDR	-24,523,208
Annual life cycle savings	IDR/yr	-1,021,800
Benefit-Cost (B-C) ratio		-0.2
Debt service coverage		No debt
GHG reduction cost	IDR/tCO$_2$	No reduction

Figure 8. RetScreen simulation result.

According to Figure 2, it can be seen that this solar power plant has NPV value of -Rp24,523,208. This result signs a negative value or less than 1, therefore, this investment is not feasible to be implemented.

The unfeasibility is caused by several factors, mainly caused by the cash outflows are bigger than the inflows. The cash inflows are obtained based on the electrical energy savings value obtained from the amount of energy supplied to the load and then multiplied by the current electricity rate. The electricity rate that applies during the project is Rp1,444.7 which is not affordable to meet the minimum NPV values. Table 7 are the results of calculations with electricity rate variations in solar power plant system.

Table 7. Solar Power Plant NPV Value with electricity rate variations

Price Variation	**NPV**
Rp 1,467	-Rp 24,523,208
Rp 2,000	-Rp 11,943,068
Rp 2,500	-Rp 2,945,496
Rp 2,663	-Rp 12,287
Rp 2,664	Rp 5,708

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According to Table 7, it can be seen that NPV value reaches positive or more than 0, especially when the electricity rate is Rp2.664. Therefore, it can be concluded that solar power plant investment will be considered as feasible if the current electricity price is worth a minimum of Rp2,664.

4. Conclusion

Solar power plant system designed in this study is an off-grid system. The main components selected based on the calculation results are including 2 modul monocrystalline 350Wp solar panels from JA Solar brand, 4 pieces SMT Power 12V 80Ah batteries, one Make Sky Blue solar charge controller, and one STEC Power 1000W inverter.

The results of this design produce usable electricity of 570 kWh per year so that the NPV value is -Rp24,523,208. This indicates that this investment is not feasible because the NPV value is still negative or less than 0. However, solar power plant investment will be considered feasible if the current electricity price is worth a minimum of Rp2,664.

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