International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 20 (2019) pp. 3923-3929

Investigation of Solar Photovoltaic (PV) Performance in Surakarta City for Design of Home Energy System

Wiji Lestari[1], Rudi Susanto[2], Herliyani Hasanah[3], Nuryani Nuryani[4], Budi Purnama[5]

[1,2,3] Faculty of Computer Science, Duta Bangsa University Surakarta, Jl. Bhayangkara 55 Tipes Surakarta 57154, Indonesia.

[4,5]Physics Department of Sebelas Maret University, Jl. Ir. Sutami 36A Kentingan Jebres Surakarta 57126, Indonesia.

E-mail: wiji_lestari@udb.ac.id

Abstract

The solar radiation energy is a major source of energy in the Earth. That is abundant. The use of solar radiation energy is a solution to the limited energy of fossil fuels. This research was carried out in Surakarta, Indonesia. Surakarta and its surroundings are located near the equator so that this area gets solar radiation throughout the year with almost the same duration, about 12 hours. The research method is calculating the electrical energy of PV system due to the sun irradiation. The next step was to calculate the cost of using PLN (Perusahaan Listrik Negara) electricity (conventional Electricity) for 25 years. The final step was to compare the installation cost of the PV system with conventional electricity consumption cost for 25 years. The power tariff 1300 VA, instalation PV system cost is IDR 292,805,852 and total cost of conventional electricity is IDR 865,791,351. The power tariff 900 VA, instalation PV system cost is IDR 192,437,852 and total cost of conventional electricity is IDR 487,408,464. The power tariff 450 VA, instalation PV system cost is IDR 148,157,852 and total cost of conventional electricity is IDR 75,133,758. The development of PV systems for home energy system can be used for alternative solutions for the supply of electricity, especially in Surakarta and surrounding areas.

Key words : Photovoltaic, Solar radiation, Electricity, Home energy system

I. INTRODUCTION

The electrical energy compsumtion in Indonesia increase 7% of annual grow rate and not balanced with adequate fossil fuel reserves after economic recession 1998 [1, 2]. The Electricity needs in Indonesia continue to increase along with Indonesia's economic growth. Based on the prediction of PT PLN (Perusahaan Listrik Negara) that electricity needs reach 217 TWh in 2016 and 457 TWh in 2025. PLN is State Electricity company in Indonesia. During 2016 until 2025 the average electricity demand in Indonesia grow by 8.6% per year while in Java -Bali is 7.8%. To supply these needs PT PLN plans an additional 80.5 GW of power plants. In addition, the government issued a policy contained in Government Regulation No.79 of 2014 to increase the portion of gas-fueled plants and renewable energy replacing coal-fired plants with a portion of renewable energy of 23% in 2025 [3].

The main energy source used to produce electrical energy is derived from fossil fuel [4]. Electrical energy needs increase every year due to both daily growth of population and modernization. Limitations of the main source need alternative energy sources, namely renewable energy [5, 6]. Renewable energy has many kinds such as solar energy, wind energy, micro hydro and so on. Renewable energy will be used in the world, because of their advantages especially solar energy [5]. Solar Energy has the greatest potential to be used as an alternative energy substitute for fossil fuel because of its abundant, safe, clean and reliable availability. The sun is an abundant source of natural energy and available all day in Indonesia [7, 8, 9]. The energy which is coming from the Sun depends on weather factors and the geographical location of the place [10, 11, 12].

The household electricity consumption in Indonesia about 41.21% with percentation of customer of PLN is 92.77% . In addition, household electricity loads are generally very volatile, so Low load factors result in high investment costs to build electricity supply facilities, so PLN's electricity supply price becomes high [3]. The geographical locates of Indonesia in the tropics or low latitudes and close to the equator. Indonesia is exposed to the sun almost all year long, this is a potential renewable energy. The solar radiation energy is estimated to be around 4 kwh/m^2 everyday [1]. Development of a renewable energy system as an alternative energy crisis solution, influenced by various factors such as economic, social, political and so on [13, 14, 15]. The study of the usage renewable energy, especially the use of household scale solar cells is needed. Selection of renewable energy from solar cells because technically solar cell systems can work well. The community is comfortable and satisfied with the use of solar cells [16]. The other reason electrcity consumption cost from PLN increase every years.

The research on the usage of renewable energy including solar cells has been carried out in Indonesia. As in research [17] which states that solar cells are suitable for use in areas / islands that are still isolated from the PLN network. In addition, optimization of renewable energy for energy independent villages with the criteria of being able to meet a minimum of 60% of the total energy needs. The results of the study indicate that the cost of electricity from the system is US $ 0.013 / KWh which of cost the cheaper than electricity cost from PLN. The different results that there are no chance of economic savings for photovoltaic systems connected to

the PLN electricity grid for household with installed power of 1300 VA and 2200 VA [17, 18, 19, 20]. Calculation of the use of solar energy using economical is quite feasible [22, 23, 24].

This study examines the performance of Solar Cells experimentally in the City of Solo as a calculation material in determining investment costs to build a household-scale Solar Cell system. Electrical energy demand data and the average cost of electrical energy per month were obtained from data of household electricity consumption of PLN [24]. From this paper we will get the value of economic feasibility from the application of solar cells on a household scale.

II. RESEARCH METHOD

This research studied the performance of PV (Photovoltaic) which has dimensions of 485 mm x 360 mm x 25 mm Model type: 156P-20 with a maximum power of 20 W. The research was carried out by measuring PV current and voltage based on irradiation in the Surakarta city. On the other hand, household electricity needs were reviewed through data of electricity consumtion of PLN customers in Surakarta and surrounding areas. Based on the results of the study, a renewable energy system was designed using PV which is expected to have the opportunity to provide customers economic savings. The study was carried out by comparing the cost of PV electricity system procurement, operational and maintenance up to 25 years life time with electricity costs for the 450 VA, 900VA and 1300VA classes from PLN.

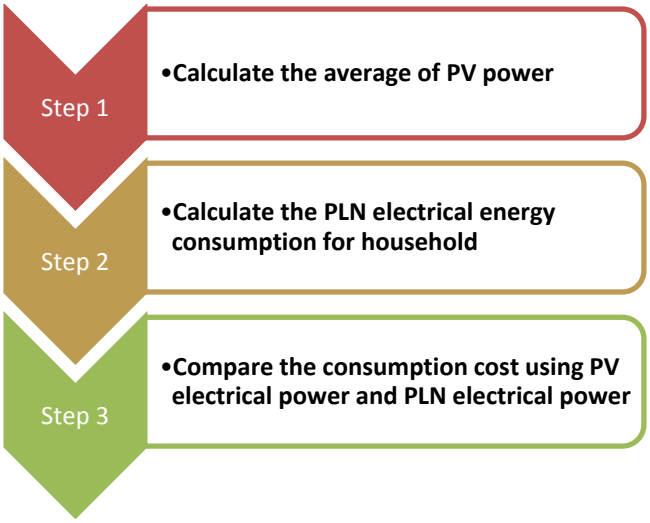

Figure 1: Step of Research Methods

This research was conducted in Surakarta which has weather conditions in accordance with http://globalweather.amu.edu presented in Table 1. These data include max temperature, min temperature, Precipitation, Wind, Relative Humidity and Solar [24]. From these data it is known that weather factors are also related to variations in solar radiation intensity.

Table 1: Weather Data on Surakarta City

Max Temperature (^{0}C)	Min Temperature (^{0}C)	Precipitation (mm)	Wind (m/s)	Relative Humidity (fraction)	Solar irradiation (x 10^6 watt/m^2)
27.96	22.89	14.15	1.48	0.91	13.78
29.35	21.87	37.39	1.08	0.91	20.84
27.62	22.53	20.70	0.75	0.92	11.66
29.48	21.06	13.65	1.03	0.91	23.71
29.26	22.13	10.90	0.98	0.91	18.78
26.83	21.30	2.48	1.58	0.91	15.68
28.03	20.88	0.78	3.22	0.88	24.98
27.27	21.07	1.26	3.11	0.86	20.32
28.24	20.98	2.82	3.23	0.85	25.07
27.50	20.44	1.42	2.59	0.87	23.78
28.46	20.43	10.92	1.23	0.89	22.52
28.94	21.90	13.54	1.56	0.90	23.48
28.43	21.96	33.23	1.52	0.91	22.53
27.55	22.75	62.37	1.11	0.93	19.16
26.50	22.37	56.76	1.12	0.95	9.69
26.70	21.84	31.23	0.86	0.94	11.45
28.22	20.92	19.13	0.72	0.93	21.27
28.38	21.39	13.10	0.96	0.91	19.78
27.78	21.63	8.75	1.18	0.91	21.66

The PV that was studied in this study was Solar Photovoltaic Module Model: P20W SUNLITE brand with specifications as in table 2. Measurements were made on the coordinates of 7 ° 34'41.2 "S 110 ° 48'32.6" E in the city of Surakarta. The measurement results are shown in Table 3. From the measurement results in table 3, it can be seen that PV is capable of producing a power of 4.170 watts.

Table 2: PV specifications

Maximum Power (Pmax)	20 W
Maximum Power Voltage (Vmp)	18.5 V
Maximum Power Current (Imp)	1.08 A
Open Circuit Voltage (Voc)	22.14 V
Short Circuit Current (Isc)	1.16 A
Maximum System Voltage	1000 VDC
Dimention	485x360x25 mm
Efficiency	15 %

III. RESULT AND DISCUSSION

The result of the measurement of electric current, the voltage generated by PV due to exposure to the sun at a certain time period as in the table 3. The table shows the magnitude of the solar Solar irradiation from 9 am to 3.30 pm and the current and voltage generated in each time range. Average power for

5 hours measurement is 4.170 watt. This value is equal to 0.02085 Kwh.

Table 3: Results of measurements of light intensity, Electrical Current (I), Voltage (V) and power (P)

Time (western Indonesia time)	Solar Irradiation (watt/m^2)	I (Ampere)	V (Volt)	P (Watt)
9.00	77.7834	0.16	19.6	3.136
9.30	101.673	0.16	19.8	3.168
10.00	258.8593	0.21	20.2	4.242
10.30	258.8593	0.21	19.8	4.158
11.00	258.8593	0.22	20.4	4.488
11.30	258.8593	0.23	20.4	4.692
12.00	258.8593	0.24	20.8	4.992
12.30	258.8593	0.23	20.8	4.784
13.00	258.8593	0.23	20.4	4.692
13.30	258.8593	0.22	20.4	4.488
14.00	243.0593	0.22	20.4	4.488
14.30	117.3624	0.22	20.0	4.400
15.00	80.9434	0.18	19.7	3.546
15.30	55.6792	0.16	19.4	3.104
Average of power (P)				4.170

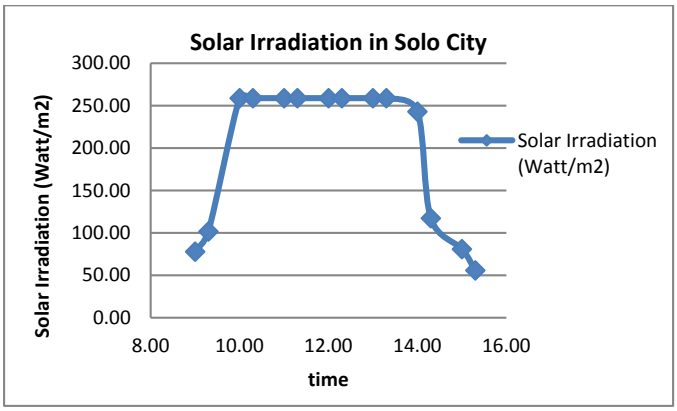

Figure 2: Solar Irradiation in Solo City

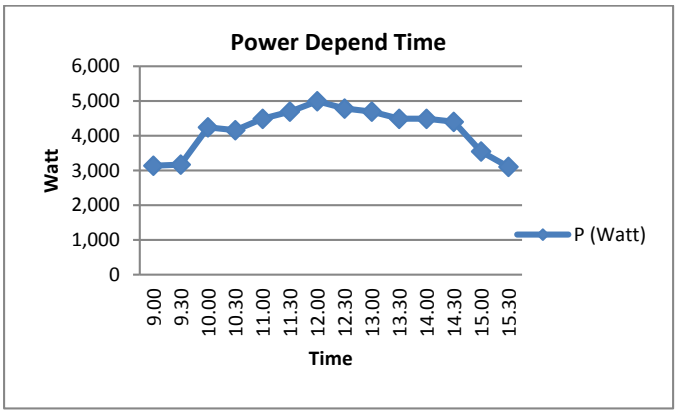

Figure 3: Power PV Depend Time

Based on fig. 1 above it can be seen that the intensity of solar radiation first rises then is constant at 10 pm to 2 am, then drops again. In fig. 2, It also shows that the measurement of the power produced by PV due to the sun's exposure first rises, then is constant and drops again. From the data above related to the radiation range in Indonesia which is located near the equator so that the sun's exposure is around 12 hours a year. The solar radiation intensity between 10 am - 2 pm is quite high.

The PV measurement results are then used as a reference in designing the PV system that will be applied to household needs. Electricity for household needs in the soloraya area is presented in Table 4. The data was obtained from conventional electricity or PLN's electricity bill payment receipt in August 2018 in the Surakarta and surrounding area.

Table 4: Household Electricity Usage per Month

No	Power Tariff	Use of Electricity (Kwh)/Month	Electricity Payment Bill (IDR)
1	1300VA	363	583,559
2	1300VA	199	321,268
3	1300VA	167	267,089
4	900 VA	72	106,105
5	900 VA	214	318,368
6	900 VA	86	126,736
7	900 VA	190	282,999
8	900 VA	124	182,736
9	900 VA	100	147,368
10	900 VA	103	154,789
11	900 VA	101	148,842
12	900 VA	154	226,947
13	900 VA	273	405,315
14	900 VA	144	212,210
15	900 VA	141	207,789
16	900 VA	204	303,631
17	900 VA	78	114,947
18	900 VA	73	107,579
19	900 VA	101	148,842
20	900 VA	167	246,105
21	450 VA	88	37,801
22	450 VA	203	99,849
23	450 VA	119	54,527
24	450VA	80	33,485
25	450VA	39	14,453
26	450VA	3	5,948
27	450VA	104	46,434
28	450VA	45	16,808
29	450VA	148	70,174
30	450VA	69	27,550
Average		**131.73**	**167,342**

From the data in Table 4 it can be seen that the number of PLN customers with 900VA installed power is 17 customers at the most among others. Based on Table 4 can be grouped according to installed power and can be calculated on average daily electricity consumption which is presented in Table 5. The average of these needs is used as a basis for calculating the PV system for analysis to be built. The average of electricity is 131.73 kwh/month and average electricity payment bill is IDR 167,342.00.

Table 5: Total Electricity Consumption Daily for Each Type of Power Tariff

Power Tariff	The Amount of Costs (Kwh/Month)	Daily Consumption Rate (Kwh)
1300 VA	243.00	8.10
900 VA	136.76	4.56
450 VA	89.80	2.99

Based on the values from table 3 and table 5 we can determine the number of solar panels needed for household electricity consumption. The calculation results of the n the following:

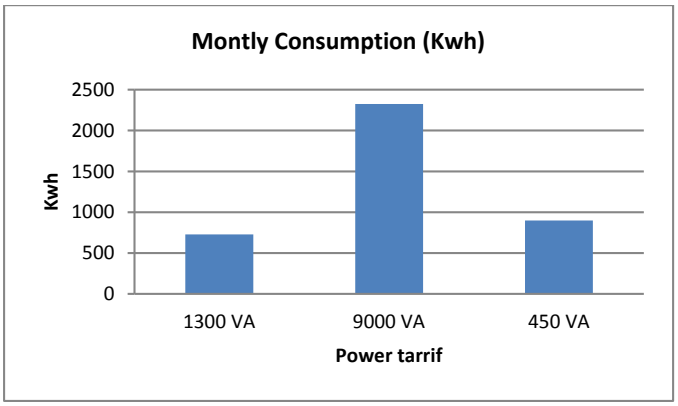

Figure 4 : Monthly Consumption of Electricity

The next step was how many and are of PV are needed based on monthly consumption of conventional electricity or PLN electricity for household scale. The results of these calculations are shown in table 6.

Table 6 : Needs of Solar Panels for Households

Power Tariff	Number of Solar Panels	Area of Solar Panels (m^2)
1300 VA	389	68
900 VA	219	38
450 VA	144	25

Number of solar panels in table 6 calculate from value of Daily Consumption Rate in table 5 divide by average power that is 0.02085 Kwh according to table 3. The solar panels were arranged by seri and parallel show in figure 5. According figure 5, PV 1 until PV 20 were arranged seri that is called group 1. The group 1 to group 7 were arranged parallel. From the solar panels arrangement produce electrical current of 1.08 A and voltage of 370 volt base on Kirchoff Law by formula with series arrangement using formula 1 and 2, parallel arrangement using formula 3 and 4.

$$I_{T\_Seri} = I_{PV1} = I_{PV2} = I_{PV3} = \ldots\ldots = I_{PV20} \ldots\ldots\ldots\ldots \quad (1)$$

$$V_{T\_Seri} = V_{PV1} + V_{PV2} + V_{PV3} + \ldots\ldots + V_{PV20} \ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$I_T = I_{Group\,1} + I_{Group\,2} + I_{Group\,3} + \ldots\ldots + I_{Group\,7} \ldots\ldots\ldots \quad (3)$$

$$V_T = V_{Group\,1} = V_{Group\,2} = V_{Group\,3} = \ldots\ldots = V_{Group\,7} \ldots\ldots \quad (4)$$

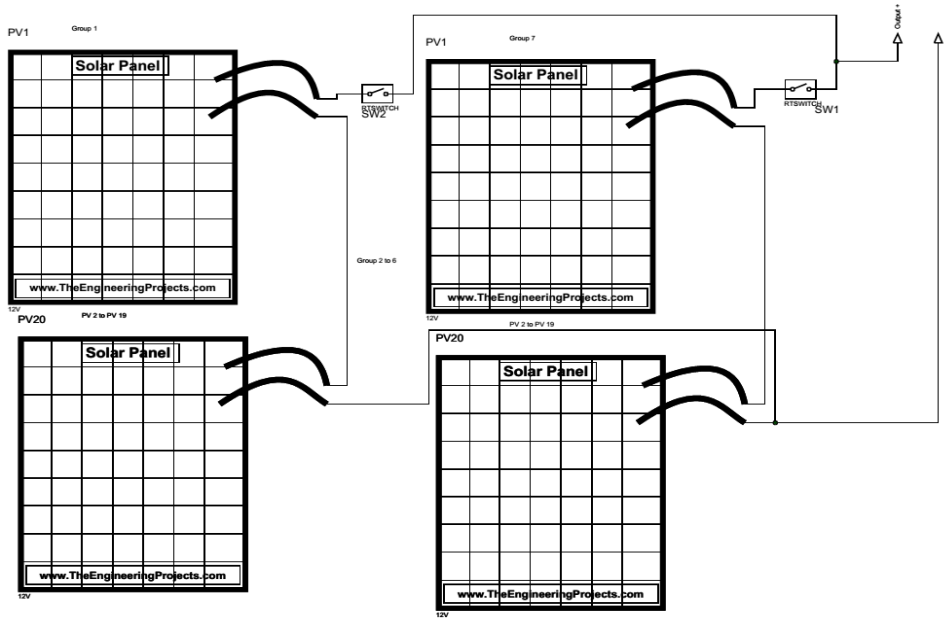

Figure 5: Design of Solar Panels Arrangement

According to the data from the calculation above, the total cost of using electricity from PLN and the PV system will be calculated. Calculation of conventional electricity costs for 25 years, this relates to the life of equipment and equipment maintenance. Over a period of 25 years by taking into account various factors we will compare the total cost between PV systems and PLN electricity.

Table 7 : PLN electricity consumption costs for 25 years for Power tariff

Power tariff (VA)	**PLN electricity consumption costs for 25 years (IDR)**
450 VA	75,133,758
900 VA	487,408,464
1300 VA	865,791,351

From table 7, the list of conventional electricity costs for 25 years for 450 VA 900 VA and 1300 VA power tariffs. Calculation of the total cost of installing a PV system, shown in table 8 below.

Table 8 : The total Costs of PV System Instalation

Cost Component (IDR)	**Power (VA)**			
Investment costs	2200 VA	1300 VA	900 VA	450 VA
Solar module (@ IDR 492,000.00)	98,400,000	18,960,000	107,256,000	70,356,000
Inverter (5000 Watt 12V DC)	16,653,000	16,653,000	16,653,000	16,653,000
The other costs (assuming 20% of the cost of the main component)	23,010,600	40,722,600	24,781,800	17,401,800
Total investment costs	138,063,600	244,335,600	148,690,800	104,410,800
Component Replacement Fee				
Inverter (lifespan 10 years)	10,376,182	10,376,182	10,376,182	10,376,182
Total Cost of PV System	**148,439,782**	**254,711,782**	**159,066,982**	**114,786,982**

According to the data in Tables 7 and 8, it can be compared to the installation cost of a PV system and the total cost of conventional electricity for 25 years. For 3 power tariffs, 2 power tariffs 900 VA and 1300 VA indicate that the cost of installing PV systems is cheaper than conventional electricity costs for 25 years. For a 450 VA power tariff, the installation cost of a PV system is still more expensive than conventional electricity costs. This is because there is a subsidy from the government for the 450 VA power tariff. Installation of PV system installations relates to economic, social and political factors.

IV. CONCLUSION

The results of comparing the PV system installation total costs and conventional electricity total cost indicate that the PV system installation costs are cheaper than conventional electricity costs for 25 years. For the power tariff 2200 VA, total cost instalation PV system is IDR 148,439,782.00 and total cost of conventional electricity is IDR 472,444,169.68. The power tariff 1300 VA, instalation PV system cost is IDR 254,711,782.00 and total cost of conventional electricity is IDR 865,791,351.68. The power tariff 900 VA, instalation PV system cost is IDR 159,066,982.00 and total cost of conventional electricity is IDR 487,408,464.65. The power tariff 450 VA, instalation PV system cost is IDR 114,786,982.00 and total cost of conventional electricity is IDR 75,133,758.04. The result of the comparison of the four power tariffs, there is only a 450 VA power tariff that costs PV installations more expensive than conventional electricity costs for 25 years. So the development of PV systems can be used for alternative solutions for the supply of electricity, especially in Surakarta and surrounding areas.

Acknowledgment

We would like to thanks Direktorat Riset dan Pengabdian Masyarakat (DRPM), Direktorat Jendral Pengauatan Riset dan Pengembangan, Kementerian Riset, Teknologi dan Pendidikan Tinggi (RISTEKDIKTI) has funded this research.

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