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Feasibility Study on the Use of On-Grid Rooftop Solar Power Plants to Reduce Electrical Energy Consumption at LPI. Dayah Ulee Titi Foundation

Teuku Zulfadli[1*], Muliadi[2], Ratna Sary[3], Muhammad Nazar[4]
[1]Department of Energy Generation Engineering Technology, State Polytechnic of Lhokseumawe, Lhokseumawe, 24301, Indonesia
[2]Department of Electrical Engineering, University of Iskandar Muda, Banda Aceh, 23234, Indonesia
[3]Departement of Mechanical Engineering, University of Syiah Kuala, Banda Aceh, 23111, Indonesia
[4]Department of Mechanical Engineering, University of Iskandar Muda, Banda Aceh, 23234, Indonesia
***** Corresponding Author **:** teukuzulfadli@pnl.ac.id

Abstract

Solar power plant is a generator that converts solar energy into electrical energy through solar module media. The utilization of solar energy is very volatile to changes in the weather, causing the production of electrical energy to be disrupted or not optimal. For that, we need a system that can maximise energy from solar modules, namely the on-grid rooftop solar power plants system with State Electricity Company (PLN) network. Currently, on-grid rooftop solar power plants has been widely used, one of which is the Islamic Education Institute (LPI) of the Dayah Ulee Titi Foundation. The on-grid rooftop solar power plants at Dayah Ulee Titi is assisted by the Ministry of Energy and Mineral Resources (ESDM) and has been operating since January 2020. However, based on electricity account data from January 2020 to March 2021, it has not shown a significant decrease in the value of the monthly electricity bill. Its export kWh is still very low. This study aims to determine the cause of the non-maximum power supply and the use of the Rooftop solar power plant in Dayah Ulee Titi. The benefit of this research is to reduce the electricity consumption cost in Dayah Ulee Titi so that it can help reduce its operational costs. As a result, the tilt angle of the solar panels installed on Dayah Ulee Titi is considered very suitable and efficient, which is 32.60. The measurement results using the Automatic Meter Reading (AMR) kWh meter in June 2021 found that the total value of export kWh was 6533.26 kWh, while the total imported kWh value from solar power plant to PLN was 44.13 kWh. From May s.d. To September 2021, the Rooftop solar power plant at Dayah Ulee Titi can produce an average of 1246.3 kWh of electrical energy so that it can reduce electricity consumption (kWh savings) from PLN by an average of 25.2%.

Keywords:
Solar module, Rooftop solar power plants, On-grid, AMR kWh meter, kWh export-import

1 Introduction

Electrical energy sources are one of the most important needs for human survival, especially for household needs, transportation, and industry. According to the World Energy Agency or better known as the International Energy Agency (IEA), world energy demand will increase until 2030 by 45% or an average of 1.6% per year including Indonesia [1][2][3]. Of this percentage, 80% of the world's energy needs come from fossil fuels [4][5]. Furthermore, between 2000 and 2009 energy consumption in Indonesia increased from 709.1 million barrels of oil equivalent (BOE) to 865.4 million BOE or an average increase of 2.2% per year [6][7].

Fossil fuels used as a source of electrical energy in Indonesia generally come from fuel oil, coal, and gas so continuous consumption of these fuels can cause the supply to run low and can also have an impact on environmental pollution, the greenhouse effect, and others. so on [8][9][10]. Therefore, it requires alternative energy sources so as not to depend on energy sources derived from fossil fuels. The alternative energy source in question comes from solar energy which is converted into electrical energy using solar modules [11][12]. Based on data from the Center for Sustainable Systems, the average radiation from the sun reaching the earth is $1.73x10^5$ terawatts, but the world's average demand for electricity is 2.7 terawatts. This shows that in a few hours if sunlight can be used properly and efficiently it can meet the world's energy needs for a whole year. Indonesia also has the potential to develop Solar Power Plants, because the potential for solar energy reaches 207,898 GWp or 4.80 kWp/m^2/day [13][14][15]. The utilization of solar energy is very volatile to changes in the weather, causing the production of electrical energy to be disrupted or not optimal [16][17]. For that, we need a system that can maximise energy from solar modules, namely the on-grid rooftop solar power plants system with the State Electricity Company (PLN) network.

In Indonesia, on-grid rooftop solar power plant has been widely used, one of which is the Islamic Education Institute (LPI) Dayah Ulee Titi Foundation. The Day is one of many PLN customers with social tariffs with electrical energy needs fully focused on data operations such as recitation activities, education, and Islamic religious symbols. To run the dayah operation, the budget is obtained from an annual fee per student of Rp. 200,000/year or approximately 16,500/month. The budget is used for electricity bills, water bills, maintenance of clean water infrastructure, and infrastructure [18]. Therefore, the use of on-grid Rooftops solar power plant in Dayah Ulee Titi is used to save electricity bill costs and even excess solar power plant production can be supplied to the PLN network (kWh export-import) which is purchased in the form of compensation for reducing kWh for the current month. Excess production in the current month can still be compensated within the next six months (offset). This is by the Minister of Energy and Mineral Resources No. 26 of 2021concerning the Use of Rooftop Solar Power Plant Systems by Consumers of PT. PLN [19].

Currently, the rooftop solar power plants at Dayah Ulee Titi has been installed on-grid since December 2019, with assistance from the Ministry of Energy and Mineral Resources (ESDM) and has been operating since January 2020. However, based on electricity bill data from January 2020 to March 2021, it has not shown there is a significant decrease in the value of its monthly electricity bill including the number of its export kWh which is still very low. This study aims to determine the cause of the non-maximum power supply and the use of the rooftop solar power plant in Dayah Ulee Titi. The benefit of this research is to reduce the electricity consumption cost in Dayah Ulee Titi so that it can help reduce its operational costs.

2 Research Method

In this study, an evaluation of the on-grid rooftop solar power plant performance in helping to reduce electrical energy consumption was carried out at the LPI. Dayah Ulee Titi Foundation which is located at coordinates 5030'44" S 95022'07" E with the address Sultan Iskandar Muda International Airport road km. 1.5 Siron Lambarot, Ingin Jaya Sub-District, Aceh Besar Regency. The results of the search for research locations carried

out using the Google Maps browser are obtained as shown in Fig. 1. In the image, it is clear that the position of the solar power plant has been installed on the roof of the dayah.

Fig. 1. The research location of the Ulee Titi Dayah Foundation

Furthermore, to be able to evaluate the performance of the rooftop solar power plant in Dayah Ulee Titi, several tools are needed such as the compass android application, solar tilt angle, shine phone application, and laptop. Furthermore, observations and measurements of the rooftop solar power plant that have been installed are carried out. There are several stages of research carried out, including:

1. Observing the intensity of sunlight hitting the solar panels, measuring the azimuth direction and tilt angle of the installed solar panels.
2. Take measurements of electrical energy consumption using Automatic Meter Reading (AMR) to get the number of Wh of Dayah usage (daily load).
3. Evaluating the use of rooftop solar power plant through the inverter reader application, both mobile and the website: https://server.growatt.com/.

At the Dayah Ulee Titi Foundation, a total of 30 solar modules were installed and divided into 2 (two) groups. Each group consists of 15 solar modules connected in series. Furthermore, there are DC combiner boxes, inverters, distribution panels, and export-import kWh. The complete on-grid rooftop solar power plant system installed at the Dayah Ulee Titi Foundation is shown in Fig. 2.

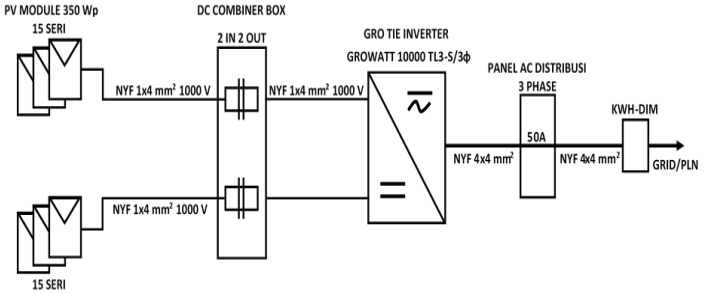

Fig. 2. One line diagram of the rooftop solar power plant in Dayah Ulee Titi

2.1 Solar Module

The specifications of the solar module installed on the roof of the Dayah Ulee Titi building are Monocrystalline type with dimensions (length 1956 mm, width 992 mm, and height of 40 mm). This type of solar module is somewhat better than polycrystalline solar modules because the cells are made of silicon (Si) through the Czochralski process. This module is also characterized by a dark colour and an efficiency of about 17% [20]. The complete specifications are shown in Table 1.

Tabel 1. Solar module specification (SP350-24M)

Parameter	Value
Maximumpower (P_{max})	350 Watt
Voltage when maximum power (V_{mp})	39,2 Volt
Current when maximum power (I_{mp})	9,06 Amp
Open circuit voltage (V_{oc})	48,3 Volt
Short circuit current (I_{sc})	9,6 Amp
Solar module efficiency	Min 20,1%
Power tolerance	+5%

2.2 DC Combiner Box and Inverter

In the solar power plant system, the combiner box is an important piece of equipment that functions to protect the PV mini-grid system from various disturbances that can cause other components to be damaged so it must be water and dust resistant. For protection, it usually has to have IP65, NEMA4 or higher standards. The combiner box also functions to make several strings of solar panels into one output which is then connected to the inverter [21][22]. The DC combiner box is shown in Fig. 3.

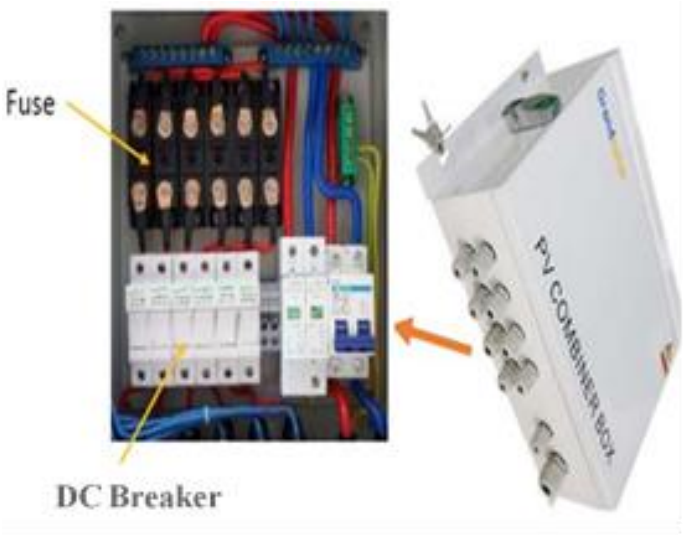

Fig. 3. DC combiner box

Furthermore, the inverter installed at the Dayah Ulee Titi Foundation is type 10000TL3-S with a unit capacity of 10 kWp. The inverter serves to convert direct current (DC) from the output of the solar panel into alternating current (AC) in the load section [23][24]. The complete specifications are shown in Table 2.

Tabel 2. Inverter specification (10000TL3-S)

Component Data	Description
Brand	GROWATT
Type	10000TL3-S
Unit capacity	10 kWp
Amount Max DC voltage	1 units1000 Volt
Nominal Voltage	600 Volt
Maximum Efficiency	98%

2.3 Distribution Panel and kWh Meter Export-Import

The distribution panel is a connecting box that acts as a link between the inverter output, the grid and the load. The distribution panel layout is usually installed indoors and has monitoring tools such as voltage, current, frequency, power, and the amount of solar power plant energy produced [24]. Furthermore, the Dayah Ulee Titi Foundation also uses an export-import kWh meter (kWh meter EXIM) which functions to measure excess electrical power (surplus) transferred to the PLN network, as well as to calculate the amount of PLN electricity consumption when solar power plant cannot produce electrical energy. such as at night, in rainy weather, and when the solar panels are covered with clouds (shading). The kWh meter is provided by PLN after consumers apply for the installation of the rooftop solar power plant. The available EXIM kWh meters are 1 (one) phase and 3 (three) phases in postpaid services [25].

3 Results and Discussion

3.1 Observation of Sunlight Intensity, Measurement of Azimuth Direction, and Tilt Angle

In this study, observations of the intensity of sunlight that hit the solar panels were carried out using a direct survey method to the field, the results found that the solar panels installed on the roof of Dayah Ulee Titi could receive maximum sunlight throughout the day and throughout the year without being disturbed by the surrounding environmental conditions. In sunny conditions, solar power plant is capable of producing around 8,000 W of power from 30 installed modules with a capacity of 350 Wp. The complete position of the rooftop solar panels in Dayah Ulee Titi is shown in Fig. 4.

Fig. 4. The position of the rooftop solar panels of Dayah Ulee Titi

Fig. 4 shows that the solar panels are at a sufficient height (second floor) and free from the shadows of trees and buildings so that the intensity of sunlight that can be absorbed by the solar panels can be fully by the specifications of the solar module. So, these results make the rooftop solar power plant in Dayah Ulee Titi able to produce electrical energy properly and maximally.

Then the coordinates were measured using the android application (Google Maps) to get the coordinates and azimuth direction of the solar panel using a compass from a smartphone. The coordinates of the solar power plant in Dayah Ulee Titi using google Maps are at 50 north latitude of the earth as shown in Fig.ure 1 and the complete azimuth direction of the solar panel is shown in Fig. 5.

Fig. 5 shows that the results of measuring the azimuth direction of the solar panel using a compass from a smartphone show that the azimuth direction is at 96 E. This means that the rooftop solar panel at Dayah Ulee Titi is in the north earth position facing north so that the solar panel can receive the intensity of sunlight. best and maximum.

Fig. 5. The azimuth position of the roof solar panels of Dayah Ulee Titi

At this stage, the solar panels installed on Dayah Ulee Titi are measured tilt angles using the solar tilt application installed on the smartphone. The measurement results are shown in Fig. 6.

Fig. 6. The angle of inclination of the roof solar panels of Dayah Ulee Titi

The results of the measurement of the tilt angle of the solar panels installed on Dayah Ulee Titi (Fig. 6) were found to be 32.6^0. So, the slope angle is considered very suitable and efficient because it is not too tilted and easy to maintain and dirt and dust can be washed away well by rainwater. The angle of the slope also faces north so that the absorption of sunlight can be maximum for a full day.

3.2 Measurement of Electrical Energy Consumption in Dayah Ulee Titi

At this stage, measurements are carried out using an AMR kWh meter to obtain the amount of energy (kWh) of Dayah usage (daily load). The data was taken for 1 month, starting from the 1st to the 30th of June 2021. The complete results are shown in Table 3. Based on the recapitulation results in Table 3, shows that the total value of export kWh is 6533.26 kWh, while the total imported kWh value from solar power plant to PLN in June 2021

is 44.13 kWh. This value is still very small when compared to the number of kWh used by Dayah Ulee Titi from the PLN system.

Tabel 3. Recapitulation of the number of kWh export-inport in Dayah Ulee Titi using AMR kWh meter

June (*Date*)	kWh Eksport	kWh Import
1	151,31	0,73
2	176,14	0,10
3	175,97	2,23
4	197,47	0,28
5	239,37	0,09
6	246,31	0,41
7	152,79	0,42
8	242,28	0,99
9	220,98	1,87
10	243,94	0,00
11	214,44	0,77
12	257,65	0,11
13	233,92	0,41
14	234,29	1,47
15	224,42	1,40
16	212,57	2,73
17	193,51	3,47
18	193,65	3,41
19	217,61	5,40
20	204,92	2,84
21	215,37	1,70
22	214,63	3,70
23	241,28	0,03
24	196,92	4,23
25	239,61	0,02
26	240,98	1,20
27	233,87	1,26
28	245,72	0,76
29	248,77	0,10
30	222,57	2,00
Total	6533,26	44,13

3.3 Evaluating the use of Rooftop Solar Power Plant in Dayah Ulee Titi

At this stage, the rooftop solar power plant in Dayah Ulee Titi evaluates energy production (kWh) using the Shine Phone application or website. The energy data taken is data in June 2021 in the form of an excel table as shown in Table 4 below.

Tabel 4. Daily production kWh of rooftop solar power plant in Juni 2021

Pesantren Ullee Titi Monthly Report *2021-06*	
Energy this Month (kWh)	1351.8
Energy Total (kWh)	21324.8
Income this Month (Rps)	1.987.146,1
Income Total (Rps)	3.134.745,8
CO2 Emission Reduced this Month (kg)	540.7
CO2 Emission Reduced Total (kg)	8529.9

Table 4 shows that the energy (kWh) obtained by Dayah Ulee Titi in June 2021 was 1351.8 kWh with an input (income) of Rp. 1,987,146.1. The table also shows that the use of the Rooftop solar power plant can reduce carbon dioxide emissions by 540.7 kg. The total daily energy produced by the Rooftop solar power plant in Dayah Ulee Titi is shown in Fig. 7.

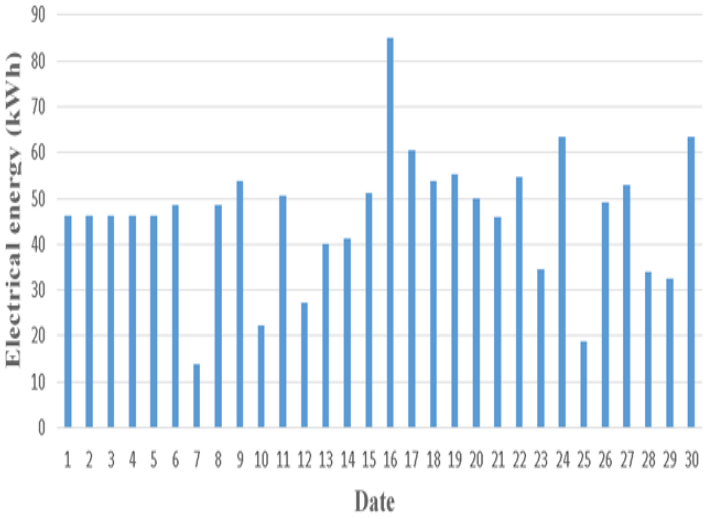

Fig. 7. Total daily kWh of Dayah Ulee Titi

Fig. 7 shows that the Rooftop solar power plant installed at Dayah Ulee Titi can produce average energy in June of 2021, which is 46.07 kWh. The lowest energy is produced on June 7, 2021, which is 14 kWh while the highest energy is 84.90 kWh which is produced on June 16, 2021. So, based on the results in Table 4 and Fig. 7, it can be concluded that rooftop solar power plant can operate with and produces energy (kWh) continuously.

3.4 Comparing the Total kWh of Rooftop Solar Power Plant Production and Export-Import kWh

At this stage, the number of kWh of roof solar power plant production is compared with the number of kWh sent to PLN and kWh of power consumption from PLN supply (kWh export-import). The data on the number of kWh taken is for 5 (five) months, starting from May to September 2021, the details are shown in Table 5.

Tabel 5. Comparison of the number of production kWh and export-inport kWh in Dayah Ulee Titi

Month	kWh of Rooftop Solar Power Plant Production	kWh Import PLN	kWh Import *(%)*	kWh Self Use	Kwh from PLN	kWh Total Power Consumption	Energy Saving *(%)*	Description
Mei	1437,6	763	53,1	674	1943	2617	54,9	Ramadan & Eid Holidays
Jun	1351,8	44	3,3	1307	6533	7840	17,2	Activity
Jul	1294,9	671	51,8	624	3927	4551	28,5	Eid Al-
Agust	1092,5	33	3,0	1060	7330	8390	13,0	Activity
Sept	1054,9	34	3,2	1021	7350	8371	12,6	Activity
Total	6231,7	1546	24,8	4686	27083	31769	19,6	

Table 5 shows that solar power plant can produce electrical energy well and has been proven in the last five months from May to. in September 2021 the average production reached 1246.3 kWh. Furthermore, from May s.d. To September 2021, Dayah Ulee Titi can reduce electricity consumption (kWh savings) from PLN by an average of 25.2%. Big savings in Dayah occurred in May and July 2021, which reached 54.9% and 28.5%, this was caused by the maximum (full) solar power plant production, but the use of electricity in Dayah during the day was not optimal because are on holiday fasting Ramadan and Eid al-Fitr and Eid al-Adha. When activities in Dayah take place normally, the percentage of kWh savings is only around 12.6% to 17.2%. So, it can be concluded that the lower the electricity consumption during the day, the more kWh can be exported to the PLN system, and vice versa.

4 Conclusion

After doing research, it can be concluded that the angle of inclination of the solar panels installed on Dayah Ulee Titi is considered very suitable and efficient, which is 32.60. The measurement results using the AMR kWh meter in June 2021 found that the total value of export kWh was 6533.26 kWh, while the total imported kWh value from solar power plant to PLN was 44.13 kWh. From May to September 2021, the rooftop solar power plant at Dayah Ulee Titi can produce electrical energy well with an average production reaching 1246.3 kWh so that it can reduce electrical energy consumption (kWh savings) from PLN by an average of 25.2%.

References

[1] A. Cherepovitsyn, E. Rutenko, and V. Solovyova, "Sustainable development of oil and gas resources: A system of environmental, socio-economic, and innovation indicators," J. Mar. Sci. Eng., vol. 9, no. 11, 2021.

[2] J. L. Holechek, H. M. E. Geli, M. N. Sawalhah, and R. Valdez, "A Global Assessment: Can Renewable Energy Replace Fossil Fuels by 2050?," Sustain., vol. 14, no. 8, pp. 1–22, 2022.

[3] M. Amudy, A. Musfadry, and Hamdani, "Pemanfaatan energi terbarukan: Satu kajian pemanfaatan energi surya untuk pembangkit listrik di Universitas Samudra," J. POLIMESIN, vol. 19, no. 2, pp. 188–193, 2021.

[4] A. Hassan, S. Z. Ilyas, A. Jalil, and Z. Ullah, "Monetization of the environmental damage caused by fossil fuels," Environ. Sci. Pollut. Res., vol. 28, no. 17, pp. 21204–21211, 2021.

[5] W. Wang, L. W. Fan, and P. Zhou, "Evolution of global fossil fuel trade dependencies," Energy, vol. 238, p. 121924, 2022.

[6] M. Bhattacharya, J. Inekwe, and E. Yan, "Dynamics of energy poverty: Evidence from nonparametric estimates across the ASEAN+6 region," Energy Econ., vol. 103, no. September, p. 105549, 2021.

[7] R. Sary, A. Syuhada, and T. Zulfadli, "Analisis Potensi Energi Angin Tahunan sebagai Pembangkit Listrik Tenaga Hybrid di Banda Aceh dan Sekitarnya," J. POLIMESIN, vol. 20, no. 1, pp. 36–41, 2022.

[8] R. Cozzolino, D. Chiappini, and L. Tribioli, "Off-grid PV/URFC power plant fueled with biogas from food waste: An energetic and economic analysis," Energy, vol. 219, p. 119537, 2021.

[9] Muliadi and T. M. Asyadi, "Penentuan Parameter Weibull Untuk Mendapatkan Densitas Daya Angin Di Kawasan Blang Bintang Aceh Besar," Jambura J. Electr. Electron. Eng., vol. 3, no. 2, pp. 51–55, 2021.

[10] F. Husni, Syukri, Muliadi, and T. M. Asyadi, "Perencanaan Sistem Pembangkit Listrik Tenaga Surya (PLTS) Di Gedung Pasca Sarjana Universitas Iskandar Muda," vol. 2, no. 1, pp. 19–24, 2022.

[11] R. Syahputra and I. Soesanti, "Renewable energy systems based on micro-hydro and solar photovoltaic for rural areas: A case study in Yogyakarta, Indonesia," Energy Reports, vol. 7, pp. 472–490, 2021.

[12] T. Zulfadli and A. Mulkan, "Studi kelayakan energi matahari-angin (hybrid) sebagai sumber daya pompa air untuk sistem pengairan di kawasan Aceh Besar," J. Polimesin, vol. 17, no. 2, pp. 61–66, 2019.

[13] D. F. Silalahi, A. Blakers, M. Stocks, B. Lu, C. Cheng, and L. Hayes, "Indonesia's vast solar energy potential," Energies, vol. 14, no. 17, 2021.

[14] N. Reyseliani and W. W. Purwanto, "Pathway towards 100% renewable energy in Indonesia power system by 2050," Renew. Energy, vol. 176, pp. 305–321, 2021.

[15] M. Tauffauzan, C. Junihartomo, S. Thamrin, and M. S. Boedoyo, "Potential Analysis and Regulations of Solar Power Plant Development in Indonesia," vol. 7, no. 4, pp. 518–522, 2022.

[16] Muliadi and I. D. Sara, "A Novel Technique for Finding Maximum Power Point of Solar Panel with Multiple Peaks Output," in International Conference on Electrical Engineering and Informatics (ICELTICs), 2020, pp. 15–19.

[17] I. Frimannslund, T. Thiis, A. Aalberg, and B. Thorud, "Polar solar power plants – Investigating the potential and the design challenges," Sol. Energy, vol. 224, no. May, pp. 35–42, 2021.

[18] M. A. Muhammad Nazar, Teuku Zulfadli, "Kajian Unjuk Kerja Plts Atap On Grid Di Dayah Ulee Titi Sebagai Upaya Penghematan Biaya Operasional Dayah," J. Ilm. Tek. Unida, vol. 2, no. 2, pp. 61–68, 2021.

[19] Kementerian ESDM, Pembangkit Listrik Tenaga Surya Atap yang Terhubung Pada Jaringan Tenaga Listrik Pemegang Izin Usaha Penyediaan Tenaga Listrik Untuk Kepentingan Umum. 2021.

[20] A. Murat Ates and H. Singh, "Rooftop solar Photovoltaic (PV) plant – One year measured performance and simulations," J. King Saud Univ. - Sci., vol. 33, no. 3, p. 101361, 2021.

[21] C. Ming Lai and R. H. Chen, "Novel heat dissipation design incorporating heat pipes for DC combiner boxes of a PV system," Sol. Energy, vol. 85, no. 9, pp. 2053–2060, 2011.

[22] S. K. Yadav and U. Bajpai, "Performance evaluation of a rooftop solar photovoltaic power plant in Northern India," Energy Sustain. Dev., vol. 43, pp. 130–138, 2018.

[23] Rafli, J. Ilham, and S. Salim, "Perencanaan dan Studi Kelayakan PLTS Rooftop Pada Gedung Fakultas Teknik UNG," Jambura J. Electr. Electron. Eng., vol. 4, no. 1, pp. 8–15, 2022.

[24] S. Muslim, K. Khotimah, and A. N. Azhiimah, "Analisis Kritis Terhadap Perencanaan Pembangkit Listrik Tenaga Surya (PLTS) Tipe Photovoltaic (PV) Sebagai Energi Alternatif Masa Depan," Rang Tek. J., vol. 3, no. 1, 2020.

[25] F. S. Lukman, A. Hasibuan, A. Setiawan, and M. Daud, "Performance of 25 KWP rooftop solar PV at misbahul ulum building, Lhokseumawe City," 2020 4th Int. Conf. Electr. Telecommun. Comput. Eng. ELTICOM 2020 - Proc., pp. 81–86, 2020.