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Preliminary Analysis of DC Grid with Photovoltaic for Row House Considering Off-Grid and On-Grid Conditions

Fitrah Wicaksono Yunianto Saputra[1], Sujito[1], Hidayatul Falahiyah Ats Tsabitah[1], Mohamad Rodhi Faiz[1], Arif Nur Afandi[1], Saodah Omar[3], Norzanah Rosmin[4], dan Aripriharta[1,2]*
[1]Department of Electrical Engineering and Informatics, State University of Malang, Indonesia
[2]Center of Advanced Material for Renewable Energy, State University of Malang, Indonesia
[3]School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA, Malaysia
[4]Centre Of Electrical Energy System (CEES), Sekolah Kejuruteraan Elektrik, Fakulti Kejuruteraan, Malaysia
e-mail: aripriharta.ft@um.ac.id*

***Abstrak*—Pada penelitian ini, desain sistem jaringan DC mempertimbangkan beberapa hal, yaitu desain jaringan DC, kemiringan dan azimuth PV, penentuan pemasangan kabel instalasi, efisiensi, dan jatuh tegangan. Pada penelitian ini juga disajikan bentuk gelombang tegangan dan arus pada perubahan beban, kondisi on grid, dan off grid. Desain awal ini dibantu dengan aplikasi Matlab/Simulink untuk mensimulasikan dan menganalisa bagaimana kinerja dari DC microgrid. Penerapan DC grid pada sistem microgrid dengan beban rumah tangga memiliki efisiensi rata-rata yang tinggi yaitu mencapai 98,48%. Efisiensi sistem DC grid dipengaruhi oleh jumlah beban yang disuplai, resistansi kabel, dan konverter. Sistem jaringan DC juga akan mengurangi konversi AC ke DC atau sebaliknya sehingga memiliki efisiensi yang tinggi. Berdasarkan hasil penelitian ini, dapat dilihat bahwa jaringan DC dapat menjadi alternatif yang menjanjikan dalam aplikasi perumahan di daerah terpencil. Penelitian ini dapat menjadi bahan pertimbangan untuk pengembangan sistem DC di daerah terpencil di masa depan. Dengan mempertimbangkan potensi sumber daya dan efisiensi jaringan yang tinggi, diharapkan dapat membantu daerah-daerah terpencil untuk mendapatkan listrik.**

Kata kunci: ***Beban Perumahan, Microgrid Dc, On Grid, Off Grid, Sistem PV***

***Abstract*—In this research, the design of DC grid system considers several things, namely DC grid design, PV tilt and azimuth, installation cabling determination, efficiency, and voltage drop. In this study, the voltage and current waveforms are also presented in load changes, on grid, and off grid conditions. This initial design is assisted by Matlab/Simulink application to simulate and analyze how the performance of DC microgrid. The application of DC grid in microgrid systems with residential loads has a high average efficiency of up to 98.48%. The efficiency of the DC grid system is affected by the amount of load supplied, cable resistance, and converters. The DC grid system will also reduce the conversion of AC to DC or vice versa so that it has a high efficiency. Based on our research results, it can be seen that DC grids can be a promising alternative in residential applications in remote areas. This paper can be taken into consideration for the future development of DC systems in remote areas. By considering the potential resources and high efficiency of the network, it is expected to help remote areas to get electricity.**

Keywords: ***Dc Microgrid, On Grid, Off Grid, PV System, Residential Load***

I. INTRODUCTION

Currently, the development of world electrical systems began to reconsider the DC grid system. Some countries that have implemented it are India, Malaysia, and China. The development of loads that lead to DC loads such as computers, LED lights, LED TVs, smartphones, and other loads make a DC grid system become popular [1]. With an increase in DC load, the DC grid can make the system more efficient, reduce conversion loss, and lesser complexity [2]. DC grid 240 Vdc improve efficiency in the transmission of buildings, thus minimizing loss of power [3]. In addition, other research also states that the DC electrical system allows having high efficiency when applied to the industry [4].

Today we are also beginning to switch to using renewable energy. Photovoltaic is a renewable energy that is often used in electrical systems. [5] has also managed to increase efficiency in photovoltaics, so that photovoltaics can transfer maximum power to the load. The development of renewable energy such as photovoltaics also caused a lot of research to discuss how the performance of DC electrical systems is fed by photovoltaics. One country that has great potential for developing photovoltaics is Indonesia. Most parts of Indonesia get sufficient solar radiation intensity with average daily radiation of around 4 kWh / m2 [6]. Quoted from [7] Indonesia will target strengthening national energy security through the achievement of renewable energy. Indonesia aims to increase the renewable energy mix by 5% in 2015 to 23% in 2025. This is the background of the Declaration of the Million Solar Roof National Movement Towards Gigawatt Photovoltaics in Indonesia[8]. From the national movement, further research is needed on how PV can be integrated properly and efficiently to be able to supply homes in Indonesia, especially in remote areas.

Pollution due to fossil fuels move the world to look at various green energies. The massive movement supported by the government and industry in various countries has caused the popularity of solar panels to increase rapidly. Several countries in Asia such as India and China have built large-scale solar power plants. Indonesia has and is currently building renewable energy power plants including solar power at several strategic points. Indonesia is one of the countries that have great potential in developing and utilizing solar panels.

Based on data from the Ministry of Energy and Mineral Resources, Indonesia still has 1.8 million homes without electricity. That is because some areas are very difficult to reach for electricity. But actually, these remote areas have great potential in terms of renewable energy. In our previous research [9], the measurement of solar energy potential has been measured in one of the most remote areas in Indonesia, Poncokusumo. From these studies, it is known that the average solar radiation in the area reaches 1021.54 W/m2, and very potential for PV development. Solar energy can be a solution to the problem of limited electrical energy in remote areas such as Poncokusumo. We contribute to knowledge as follows.

1. We developed a Matlab framework for testing the technical performances of dc microgrids for row houses.
2. We provided investment cost and analysis.

This paper will discuss how the preliminary design development of DC microgrids for remote areas in Indonesia. Through Matlab simulation, it can be seen how the performance of the DC microgrid is applied to a residential load in on-grid and off-grid conditions. Section II will discuss related works regarding DC microgrids and their development in Indonesia. The method of this paper will be explained in section III. Results and Discussion of DC microgrid performance will be presented in section IV. And in section V will be presented the conclusions.

II. METHODOLOGY

In this study, the design of a DC grid system considers several things, that is the design of a DC grid, tilt and azimuth PV, Determination of installation wiring, efficiency, and voltage drop. This study also presented how the voltage and current waveform in load changes, on grid, and off grid conditions. This preliminary design was assisted with the Matlab / Simulink application to simulate and analyze how the DC microgrid is performing.

A. DC Grid with Residential Load

In this paper, a DC grid system will be designed at the household load as shown in Fig 4. The household load will be supplied by two sources that are from the PV array and the main grid. [15] has discussed how to manage energy with several renewable energy sources. By combining several generating sources, the following equation will be obtained.

$$PRE + PMG = P_{Load} \quad (1)$$

Where PRE is the renewable energy output power and PMG is the output power from the main grid. With a microgrid, the main grid or PLN will not fully supply all loads so it will greatly save conventional energy resources.

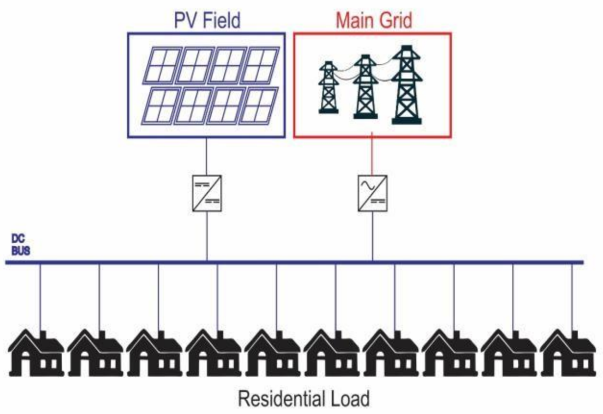

Fig. 1. DC microgrid

The output voltage of the PV array needs to be increased so that losses on the cable are reduced. To increase the DC voltage, a DC-DC converter is used. DC- DC converter will increase and stabilize the PV output voltage to 220 VDC. On a DC grid, the main grid needs to be converted to a DC voltage first using a rectifier. The integrated PV and main grid on a DC bus will supply several homes.

DC power systems can be more reliable when considering how the load is used [16]. In our previous research, we surveyed consumption behaviour in 10 families in Indonesia. The survey results produce a load profile as in Fig 5. With the load profile data, it can be investigated how the influence of load changes with efficiency, voltage drop, current, and voltage waveform.

B. Tilt and Azimuth

In designing electrical systems with PV systems, it is necessary to consider how the installation of the PV. one that needs to be considered is the slope angle of the PV. In [17] said that different tilt angles give different values of solar radiation in the inclined plane, so the design of the PV system is necessary to determine the optimal tilt angle to provide the highest solar radiation value in the incline.

Besides considering the tilt angle of the PV, it is also necessary to consider the azimuth angle of the PV installation. The azimuth angle is usually known as the direction of sunlight. The azimuth angle of the PV needs to be set to face the equator so that the PV gets the maximum radiation value. To get radiation data in the Poncokusumo area, a PV Syst simulator is used. pv syst simulator also gives information on how the radiation values are obtained with different tilt and azimuth angles

C. *Determination of Installation Cable*

As we know, the cable has a resistance value so there are power losses in the system. The amount of loss in the conductive cable depends on several parameters including the value of cable resistance, load power, and the amount of voltage used. Selection of the right conductive cable can reduce losses on the cable. According to the rules in the Indonesia General Electrical Installation Requirements, the type of cabling rules can be seen based on the maximum current in the house. Each type of conductor cable has its own conductivity Table 1 shows some of the types of conductor cables and their conductivity according to the [18]. selection of conductive cables used is recommended 125% greater than the maximum current limit. From fig. 5 it is known that the peak load on the system reaches 3000 watts with a voltage of 220 VDC. This causes the current flowing to reach 13.63A so the type of cable used is 1.5 mm2 or above.

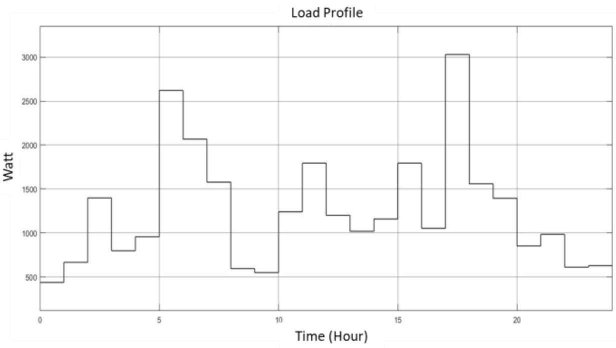

Fig. 2. Load Profile on DC Grid

Table 1 Conductor Data

Cable Cross-Sectional Area mm^2	Conductivity
0.5	2.5 A
0.75	7 A
1	11 A
1.5	15 A
2.5	20 A
4	25 A
6	33 A
10	45 A
16	61 A
25	83 A
35	103 A

Each conductor cable has its resistance value. Resistance to the cable is affected by cable length, cross-sectional area and metal-type resistance[19]. If using a copper-type cable, the metal resistance is 1.72e-8 mΩ. the resistance value in the cable can be determined through eq (2).

$$R = \rho\, L/A \quad (2)$$

D. *Efficiency and Voltage Drop*

[19] has researched losses that occur in the conductor cable in the AC and DC systems. In that study, the power losses in the conductor cable were calculated through eq (6). The power loss that occurs can be illustrated in Fig 3. Parameters for finding losses in the conductor cable include cable resistance, power at load, and the voltage rating used in the system.

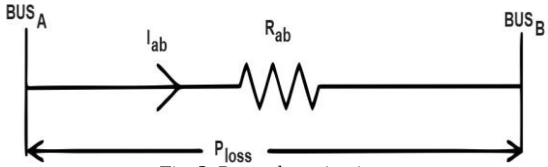

Fig. 3. Power loss circuit

$$P_b = V_b\, I_{ab}\, P^2/V^2 \quad (3)$$

$$I_{ab} = P_b/V_b \quad (4)$$

$$\Delta V = V_a - V_b$$
$$= I_{ab} - R_{ab}$$
$$= P_b/V_b\, R_{ab} \quad (5)$$

$$\Delta P = P_a - P_b$$
$$= (V_a\, I_{ab}) - (V_b\, I_{ab})$$
$$= I_{ab}\,(V_a - V_b)$$
$$= (P_b/V_b)^2\, R_{ab} \quad (6)$$

Besides power losses, the resistance and reactance of the cable also cause a voltage drop. In [20] resistance is calculated on the condition 80˚C with a reactance value of 0.1Ω/km. The reactance value only exists in AC, which is why DC grids can be more efficient. The magnitude of the voltage drop can be determined through eq (5). The criterion for good voltage quality is to have a value of around 10% of the reference voltage [21].

III. RESULTS AND DISCUSSION

A. *Simulation Tilt and Azimuth PV*

From the simulation results in Table 2, it is known that the tilt angle of the PV affects the solar radiation captured by the PV. From this table, it is known that the use of PV in Poncokusumo, is recommended to have a tilt angle of 15˚. Actually, in equatorial regions like Indonesia, the arrival of sunlight is almost perpendicular, so the optimal angle of PV is 0˚. But installing PV with a tilt angle of 0˚ is not recommended. This is because a flat surface will cause standing water or dust buildup on the PV surface.

Table 2 Simulation Results of Irradiation

Angel	Global Radiation Incident	Loss with Respect to Optimum
5	1420	-1.2%
10	1433	-0.3%
15	1437	0.0%
20	1433	-0.3%
25	1421	-1.1%
30	1402	-2.4%
35	1376	-4.3%
40	1341	-6.7%
45	1300	-9.5%

Poncokusumo is one of the areas below the equator. In establishing PV systems in areas below the equator, it is highly recommended that PV face north, whereas for the area north of the equator it is recommended to build a PV system facing south. It aims to get maximum solar radiation by calculating the sun's azimuth. Table 3 is the result of the azimuth angle simulation at Poncokusumo on the tilt of PV 15˚. From these results, it is known that PV gets maximum radiation when facing north between 0˚ - 10˚.

Table 3 The result of the azimuth angle simulation

Angel	Global Radiation Incident	Loss with Respect to Optimum
10	1436	0.0%
20	1434	-0.2%
30	1430	-0.5%
40	1426	-0.8%
50	1420	-1.2%
60	1413	-1.7%
70	1405	-2.2%
80	1397	-2.8%
90	1388	-3.4%
100	1378	-4.1%
110	1368	-4.8%
120	1357	-5.5%
130	1348	-6.2%
140	1340	-6.8%
150	1333	-7.2%
160	1328	-7.6%
170	1325	-7.8%
180	1324	-7.9%
190	1324	-7.8%
200	1327	-7.6%
210	1332	-7.3%
220	1338	-6.9%
230	1347	-6.3%
240	1356	-5.7%
250	1366	-5.0%
260	1376	-4.3%
270	1385	-3.6%
280	1395	-2.9%
290	1403	-2.3%
300	1411	-1.8%
310	1418	-1.3%
320	1424	-0.9%
330	1429	-0.5%
340	1433	-0.3%
350	1436	-0.1%
360	1437	0.0%

B. *Efficiency and Voltage Drop Calculation*

In this paper efficiency and voltage drop are calculated through eq (6) and eq (5). The type of conductive cable used is copper 4 mm2 with a resistance reaching 0.84Ω. Fig 7 is the efficiency of a DC grid system. This efficiency data is taken for 24 hours with the power consumption pattern as in Fig 5. From Fig 7 we know that efficiency is inversely proportional to the power used. The higher the power at the load, the efficiency of the system will decrease. This can be solved by choosing the right cable. From the calculation results, it is known that the DC grid efficiency is relatively high. In this case, the efficiency of the DC grid reaches 98.48%.

In addition, voltage drops need to be considered in electrical systems. In this paper, we have calculated how the voltage drop condition in the system is shown in table 4. From the table, it is known that the percentage of voltage drop in the system designed is approximately 10%. This proves that the system design has a good voltage quality.

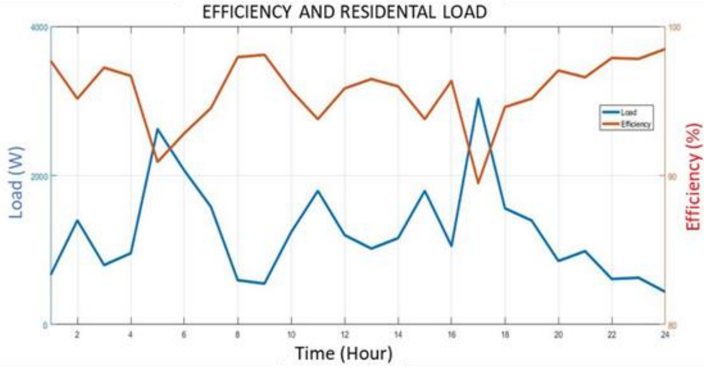

Fig. 4. Efficiency and residential load profile

Table 4 Voltage drop

Time	Voltage Drop	
	in V	in %
1:00	5.086	2.31
2:00	10.676	4.85
3:00	6.094	2.77
4:00	7.308	3.32
5:00	20.015	9.10
6:00	15.784	7.17
7:00	12.050	5.48
8:00	4.544	2.07

9:00	4.192	1.91
10:00	9.469	4.30
11:00	13.700	6.23
12:00	9.164	4.17

C. *Current and Voltage on DC Grid*

In this paper, the voltage and current conditions on the DC grid are presented. Fig 4 is a 24-hour DC grid voltage and current condition. From the simulation results using Matlab / Simulink, when the load increases the current on the bus also increases, but there aren't voltage drops in the DC grid as previously calculated. Increased load on the DC grid causes the ripple voltage to increase. This is because the DC-DC converter can control and stabilize the output voltage to keep it at 220V DC. This load stability affects the amount of the duty cycle as described in eq (7). Changes in the value of the duty cycle also affect the amount of voltage ripple. The relationship between voltage ripple and the duty cycle is shown through eq (8). To reduce the amount of voltage ripple, a capacitor can be used as a voltage filter. In Fig 8 it appears that the voltage ripple on the DC bus is relatively small so the configuration in this simulation is ready to be implemented.

$$V_o = V_i\, 1/(1-D) \quad (7)$$
$$\Delta V_o = (V_o\, D)/RCf \quad (8)$$

Fig 4 also presents the current on a DC bus for 24 hours. At certain hours when the load increases, a ripple of current occurs on the DC bus. This is because at this hour the AC load on the house is active, so the inverter must work. The effect of switching the inverter causes the voltage and current of the DC grid as shown in Fig 5.

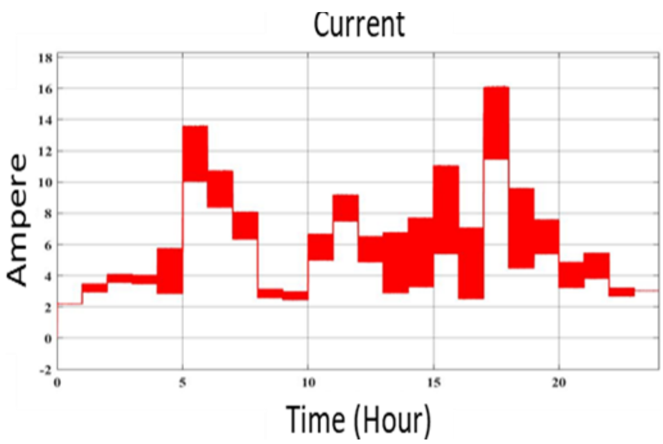

Fig. 5. Current waveform in DC bus

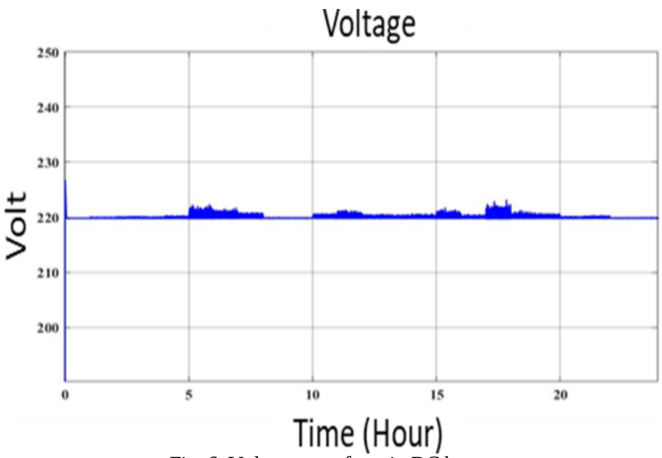

Fig. 6. Voltage waveform in DC bus

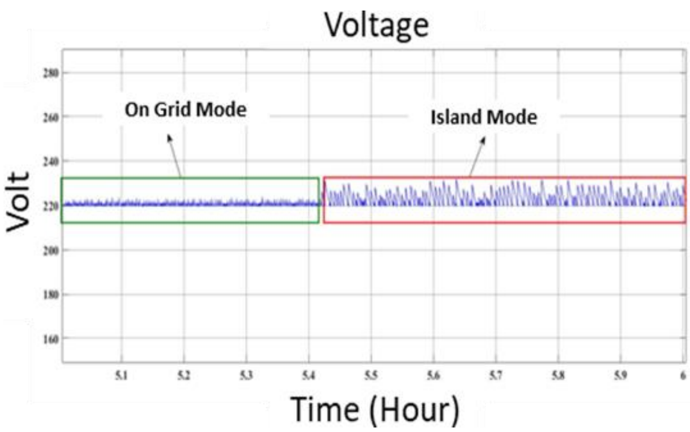

Fig. 7. Voltage Ripple in On-Grid and Island Mode

This paper also simulates voltage conditions when the main grid fails and the system must switch to island mode. Fig 6 shows the change from on-grid mode to island mode. This change causes a ripple on the DC grid to increase. This is explained in eq (1), all loads are supplied by PV so that there is no power-sharing like when on-grid mode. When all loads are supplied by PV, the load on the DC-DC converter will increase so the DC-DC converter must stabilize the voltage on the DC bus by changing the duty cycle value. This causes the ripple voltage to increase during island mode.

D. *Economic Analysis*

In Poncokusumo the load requirement is 30.16 kWh/day, installed DC microgrid of 5.5 kW. The amount of investment can be seen in Table 5. The maintenance costs (Table 6) were set at 2% of the initial investment because Indonesia only experienced two seasons. Maintenance and operational costs of 827.520,00 IDR/year. The analysis is then followed by the calculation of the Net Present Value (NPV) based on the cost of electricity production by the PV system with an inflation rate of around 4%, and a 25-year operational period [22]. NPV value is 3.873.761,48 IDR, it can be said that this project investment is feasible to run. Based on the yearly cost in table VI, Break-Even Point (BEP) value was reached in years 1,4.

Table 5 Component Price Data of DC Microgrid

No	Components	Quantit y	Prince (IDR)	
			Unit	Total
1	PV	22	1,790,000.00	39,380,000.00
2	DC-DC Converter	1	1,343,000.00	1,343,000.00
3	AC-DC Converter	1	653,000.00	653,000.00
	Investment0			41,376,000.00

Table 6 Yearly Cost

Cost	IDR
Annuities	2,068,750.00
Maintenance	827,520.00
Yearly cost	2,896,270.00

IV. CONCLUSION

The initial design of DC grids in Indonesia has been discussed in this paper. For PV installation in the Poncokusumo area to get optimal energy from the sun, it is recommended to use a tilt angle of 15° and face north. Microgrid systems at residential loads using DC grids have also been simulated and calculated in this paper. In the calculation results that have been done, the DC grid has a relatively small voltage drop. However, after being simulated on Matlab / Simulink, the voltage drop does not occur when the load increases. This is because the DC- DC converter stabilizes the voltage on the DC bus. Therefore, when an increase in load on the DC grid causes the ripple voltage to become large.

The application of DC grids on microgrid systems with residential loads has a high average efficiency of up to 98.48%. Efficiency in DC grid systems is affected by the amount of load supplied, cable resistance, and the converter. The DC grid system will also reduce AC to DC conversion or vice versa so that it has high efficiency. Based on our results, it can be noted that DC grids can be a promising alternative in residential applications in remote areas. This paper can be considered for the development of DC systems in remote areas in the future. By considering the potential of resources and the high efficiency of the network, it is hoped that it will help remote areas to get electricity

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REFERENCES

[1] J. J. Justo, F. Mwasilu, J. Lee, and J. W. Jung, “AC-microgrids versus DC-microgrids with distributed energy resources: A review,” Renew. Sustain. Energy Rev., vol. 24, pp. 387–405, 2013.

[2] M. Alam, K. Kumar, J. Srivastava, and V. Dutta, “A Study on DC Microgrids Voltages based on Photovoltaic and Fuel Cell Power Generators,” 7th Int. IEEE Conf. Renew. Energy Res. Appl. ICRERA 2018, vol. 5, pp. 643–648, 2018.

[3] S. Rauf, A. Wahab, M. Rizwan, S. Rasool, and N. Khan, “Application of dc-grid for Efficient use of solar PV System in Smart Grid,” Procedia Comput. Sci., vol. 83, no. Seit, pp. 902–906, 2016.

[4] D. A. Schaab, S. Weckmann, T. Kuhlmann, and A. Sauer, “Simulative Analysis of a Flexible, Robust and Sustainable Energy Supply through Industrial Smart-DC-Grid with Distributed Grid Management,” Procedia CIRP, vol. 69, no. May, pp. 366–370, 2018.

[5] K. H. Wibowo, Aripriharta, I. Fadlika, G. J. Horng, S. Wibawanto, and F. W. Y. Saputra, “A New MPPT based on Queen Honey Bee Migration (QHBM) in Stand-alone Photovoltaic,” 2019 IEEE Int. nf. Autom. Control Intell. Syst., no. June, pp. 123–128, 2019.

[6] N. A. Handayani and D. Ariyanti, “Potency of solar energy applications in Indonesia,” Int. J. Renew. Energy Dev., vol. 1, no. 2, pp. 33–38, 2012.

[7] jjaeger, “Renewable energy for Indonesia,” Alliance Rural Electrif., vol. 2017, pp. 1–8, 2016.

[8] E. Board, “Solar power for houses,” pp. 1–8, 2019.

[9] F. Yunianto, “Efficiency Comparison between DC and AC Grid Toward Green Energy In Indonesia,” 2019 IEEE Int. Conf. Autom. Control Intell. Syst., 2019.

[10] İ. Çetinbaş, B. Tamyürek, and M. Demirtaş, “Design, analysis and optimization of a hybrid microgrid system using HOMER software: Eskişehir osmangazi university example,” International Journal of Renewable Energy Development, vol. 8, no. 1. pp. 65–79, 2019.

[11] F. Dastgeer and H. E. Gelani, “A Comparative analysis of system efficiency for AC and DC residential power distribution paradigms,” Energy Build., vol. 138, pp. 648–654, 2017.

[12] D. L. Gerber, V. Vossos, W. Feng, C. Marnay, B. Nordman, and R. Brown, “A simulation-based efficiency comparison of AC and DC power distribution networks in commercial buildings,” Appl. Energy, vol. 210, pp. 1167–1187, 2018.

[13] A. Sannino, G. Postiglione, and M. H. J. Bollen, “Feasibility of a DC network for commercial facilities,” IEEE Trans. Ind. Appl., vol. 39, no. 5, pp. 1499–1507, 2003.

[14] S. Sidopekso and M. Taufik, “The DC House Project for Sustainable Rural Electrification,” Proc. IEEE 2014 Glob. Humanit. Technol. Conf., no. November 2012, pp. 2–6, 2014.

[15] C. L. Li, C. H. Lin, and L. R. Chang-Chien, “Energy management strategy for renewable backup supply,” 2017 IEEE 2nd Int. Conf. Direct Curr. Microgrids, ICDCM 2017, pp. 577–581, 2017.

[16] R. S. Balog, W. W. Weaver, and P. T. Krein, “The load as an energy asset in a distributed DC smartgrid architecture,” IEEE Trans. Smart Grid, vol. 3, no. 1, pp. 253–260, 2012.

[17] O. Dominic Ekanem, “Determination of Yearly Fixed Optimal Tilt Angle for Flat-Plate Photovoltaic Modules Based on Perez Transposition Model,” Am. J. Softw. Eng. Appl., vol. 6, no. 3, p. 80, 2017.

[18] Badan Standardisasi Nasional, “Persyaratan Umum Instalasi Listrik 2000,” DirJen Ketenagalistrikan, vol. 2000, no. Puil, pp. 1–133, 2000.

[19] G. M. Paul A. Tipler, Physics For Scientists and Engineers. W. H. Freeman and Company, 2008.

[20] Y. J. Lee et al., “A new hybrid distribution system interconnected with PV array,” Conf. Proc. - 2012 IEEE 7th Int. Power Electron. Motion Control Conf. - ECCE Asia, IPEMC 2012, vol. 3, pp. 2037–2041, 2012.

[21] M. Mouheba, A. Hamidatb, and L. Loukarfic, “Impact of PV compensation in improving the voltage drop in electrical networks LV,” Energy Procedia, vol. 18, pp.

751–761, 2012.
[22] H. Umar, M.Amudy, and A. Rizal, "Feasibility study of installation photovoltaic system at a Universitas in Indonesia: a case study", Journal of Physics, vol.5, 2019.