Solar Power Station for High-Powered Electronics

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Intisari - Banyaknya rumah tangga pengguna PLN dengan daya di bawah 2200 VA di Indonesia menyebabkan pemakaian peralatan elektonik berdaya tinggi (HPE) seperti misalnya kompor listrik, microwave, dan oven, menjadi terbatas. Pada kasus tertentu HPE tidak dapat beroperasi karena daya listrik kurang atau menjadi penyebab miniature circuit breaker (MCB) trip. Pada kenyataannya, penggunaan HPE tersebut dapat meningkatkan kualitas hidup masyarakat. Sumber daya (power station) terpisah dengan PLN (off-grid) dengan penyimpan daya berkapasistas rendah dirasa mampu mengatasi permasalahan tersebut dikarenakan pemakaian HPE harian kebanyakan pada jangka waktu 1-3 jam. Solar home system (SHS) dapat menjadi basis power station off-grid untuk HPE. Akan tetapi, studi SHS yang dilakukan hanya terbatas pada daya rendah dibawah 1000 VA atau daya tinggi diatas 3000 VA. Mengatasi hal tersebut, dalam penelitian ini akan dibuat power station daya tinggi antara 1000 VA - 3000VA berbasis SHS dan dianalisis penggunaan hariannya untuk peralatan HPE kompor listrik, microwave, dan oven. Proses pengisian daya power station dengan empat 100 Wp polikristalin solar panel dapat menghasilkan daya berkisal 1 kWh perharinya. Hasil memasak harian menunjukan dengan 2-3 menu dapat dibuat perharinya dengan HPEs yang di tenagai power station.

Kata kunci: power station, solar home system, off-grid solar panel, kompor listrik

Abstract - The number of PLN power users below 2200 VA for households in Indonesia causes the use of high-powered electronic equipment (HPE) such as electric stoves, microwaves, and ovens, to be limited. In some cases, the HPE can't operate due to lack of power or being the cause of the miniature circuit breaker (MCB) down. In fact, the use of HPE can improve the quality of life of people. Power stations separated by PLN (off-grid) and high-powered are thought to be able to solve the problem due to the daily use of HPE mostly over 1-3 hours. Solar home system (SHS) can be the base power station off-grid for HPE. However, the SHS studies carried out are limited to low power below 1000 VA or high power above 3000 VA. Addressing this, the study will create high power stations between 1000 VA - 3000VA based on SHS and analyze its daily use for electrical HPE equipment such as electric stoves, microwaves, and ovens. The charging of a power station with four 100 Wp Polycrystalline solar panels can charge around 1 kWh on sunny days in Yogyakarta, Indonesia. Daily cooking activity shows the power station can support 2-3 menus daily with the usage of HPEs.

Keywords: power station, solar home system, off-grid solar panels, electric stoves

I. INTRODUCTION

Advancement in technology is also followed by improvement in living standards. Household electronic devices such as electric stoves, air conditioners, etc [1], [2]. mostly need high electrical power consumption for operation. Statistical data of state electricity company (PLN) Indonesia in 2021, the number of customers with electric power category below 2200 VA or category R1 dominates as much as 75.6 million compared to customers above 2200VA or R2 and R3 groups as 1.7 million and 0.3 million [3]. The low power availability (below 2200 VA) became one of the reasons the majority of Indonesian households did not use high-power electronic equipment (HPE) such as electric stoves, microwaves, ovens, etc. The power consumption for electric stoves was around 800-1600 watts while microwave and oven range between 450-3000 watts. The usage of HPE in houses with power less than 2200 VA will often result in a miniature circuit breaker (MCB) down. Although some HPEs are usually used for short periods for 1-3 hours. This short working time may allow for the relocation of HPE power sources from PLN to reserve sources with large power but low storage.

Solar power is widely used as a power supply in households, industries, or farms. PLTS produces direct current (DC) electricity that can be used directly or converted to alternating current (AC). The transition from a PLN system to independent energy with PLTS in households or the solar home system (SHS) needs to be considered because there is a risk of loss given the installation of PLTS requires a large cost. In addition to cost risks, different weather risks in each region and different electricity needs in each home are an obstacle to the rise in SHS popularity. The SHS cost mostly comes from the inverter system and storage. Suppressing these outputs and risks, the SHS can be formed in the form of a power station [4] or a mini SHS with a specific performance [5]–[8]. The existing power stations are too large while mini SHSs are usually only in small power capacities below 1000 watts [9]–[11]. When there is a power station or Mini SHS with a high power between 1000 – 3000 watts but low storage, the HPE problem can be solved. Vocational school faculty has a research roadmap with a focus on the Green-Blue Economy. In the focus of the research, the application of solar panels in buildings has become one of the leading research projects. By implementing this approach, our research aims to address the issue of MCBs tripping and enhance the utilization of HPE without necessitating an increase in PLN power. This will be achieved through the construction of mini SHSs in the form of power stations.

II. METHODOLOGY

In this study, a separate solar power station was built for HPE. This solar power was tested on electric stoves, microwaves, and ovens. The results obtained were then analyzed by the performance.

A. Mathematical Model

The power station requirement was determined by calculation. In one household with the main cooking activity in the morning and noon, the usage of the electric stove was assumed around 1 hour, the microwave around 10 minutes, and the oven 20 minutes. The energy usage for one day E_{day} was determined using (1) [12].

$$E_{day} = \sum_{i=0}^{n} \frac{p_i \times u_i \times n_i}{1000} \ (kWh)$$
$$= \frac{(1200 \times 1 \times 1) + \left(1200 \times \frac{1}{6} \times 1\right) + \left(500 \times \frac{1}{3} \times 1\right)}{1000} \quad (1)$$
$$= 1.567 \ kWh \quad (1)$$

where i is the index for each type of HPE, u_i = number of hours of use of device type i per day, p_i = power rating of device type i, n_i = number of device type i. Total power PV needed P_{pv} consider efficiency and derating factors can be calculated using (2) [8], [12].

$$P_{pv} = \frac{E_{day}}{S_d \times d} (kW) = \frac{1.567}{5.13 \times 0.8} = 0.381 \ (kW) \quad (2)$$

where S_d = the average duration of solar radiation, d = the derating factor is influenced by efficiency effects such as soiling the panels, lost wires, shadows, snow cover, aging, and so on. In this study we use S_d = 5.13 $kWh/m^2/day$ as the data taken at Yogyakarta, Indonesia, and the value d = 80 % based on available weather information in [13]. The number of solar panels required n_p was calculated using (3) [12].

$$n_p = \frac{P_{pv}}{P_o} = \frac{0.381}{0.1} = 3.81 \quad (3)$$

where P_o is the power output capacity of each panel (100 Wp). Battery LifePo4 was used as power storage in this research. The number of batteries needed in this power station was calculated using (4) [12].

$$N_{bat} = \frac{E_{day} \times n_d}{V_{bat} \times I_h \times DOD} = \frac{1{,}567 \times 1}{24 \times 100 \times 0.9} = \frac{1{,}567}{2{,}160} = 0.725 \quad (4)$$

where n_d is the number of days required for power reserves, V_{bat} is the voltage rating, I_h is the ampere-hour rating and DOD is the depth of discharge of the battery system. The 1-day power reserves were chosen to maintain power station cost.

Four polycrystalline solar panels 100 Wp were used as a voltage provider stored in a lifepo4 24 V 100 Ah lithium battery storage. The electricity was converted from DC to AC with a Techfine hybrid inverter 2 kVA MPPT 24V Low frequency 24 V 2000 watt and secured with MCB. The 2 kVA hybrid inverter was chosen as the maximum load of around 1200 watts. The low-frequency type was used to accommodate high power spikes and frequent on off of the devices.

Three kinds of HPE consist of an Oxone OX-655D electric stove with a power consumption of 1200 watts, a Maspion MOT-500 oven with 500 watts, and a Samsung ME83M-B3 microwave with 1200 watts were used as a load alternately. The power station network is illustrated in Figure 1.

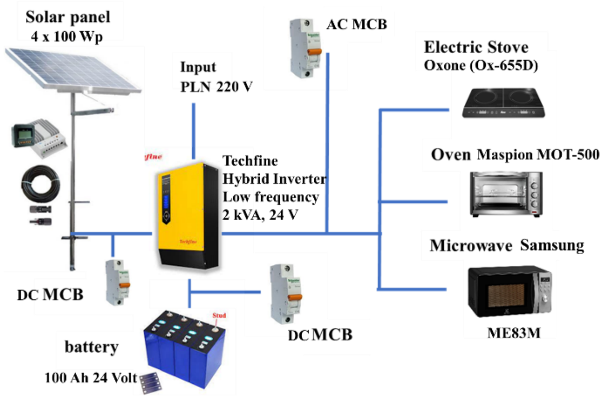

Figure 1. The power station network diagram

The HPE was used to cook different types of food to check the daily consumption of the power station. Four 50 Wp and 550 Wp solar panels were also used as comparisons for more suitable solar panel sources.

III. RESULTS AND DISCUSSION

A. Charging of Power Station

The power station was built off-grid and moveable as an independent source, as shown in Figure 2. Solar panels were not permanently installed as the power station is moveable and easy to remove or change to increase its portability.

Figure 2. Portable power station with removable solar panels

The charging process of the solar power station was conducted from 10.00 until 15.00 with four 100 Wp polycrystalline solar panels in series. According to the obtained result in Table 1, solar power stations can charge for around 1 kWh on a sunny day each day. This result was lower compared to the targeted 1-day power charging (1,567 Wh). This condition may cause of derating factor d was less than 80%. Later, the charging process can be supported with PLN when the charging with solar panel was lower than the discharging by HPE. As a consideration of other alternatives, we also compared 50 Wp and 550 Wp monocrystalline as power sources. The obtained power is shown in Table 2. The result shows more than half the power produced by 100 Wp Poly could be obtained with 50 Wp Mono and 550 Wp produced power almost near to the targeted power (1,567 Wh) with higher current than 100 Wp and 50 Wp.

B. Discharging Power Station by Cooking Activity

Daily cooking was conducted to estimate the power consumption of the power station. All HPE was working at around 220 V voltage and 50 Hz frequency. The working current for the electric stove was 4.6 A, the microwave was 6.1 A, and the Oven was 2.2 A. The power consumption for daily cooking activity is shown in Table 3 The result of the cooking activity shows for 2-3 menus each day the power consumption was under 2000 Wh. The power consumption is also possible to be reduced by better management. This result confirms with this specification that, the power station can work properly to support HPE for household usage. Table 3 Daily cooking activity with HPE powered by the power station.

Table 1. Power gain of power station with four 100 Wp solar panels as source

Time	PV Input					
	Day 1		Day 2		Day 3	
	Power (Wh)	Current (Ah)	Power (Wh)	Current (Ah)	Power (Wh)	Current (Ah)
10.00 – 11.00	181.9	3.1	190.0	3.2	190.9	3.4
11.00 – 12.00	275.7	4.3	358.5	5.7	107.0	1.9
12.00 – 13.00	291.0	4.6	252.5	4.0	237.1	3.9
13.00 – 14.00	184.9	3.1	231.2	3.8	156.8	2.5
14.00 – 15.00	98.0	2.2	86.5	1.6	74.0	1.4
Total	1,031.5	17.3	1,118.7	18.3	765.8	13.1

Table 2. Comparison between different solar panels for solar power station electricity source

Time	PV Input					
	Four 50 Wp Mono in series		Four 100 Wp Poly in series		A 550 Wp Mono	
	Power (Wh)	Current (Ah)	Power (Wh)	Current (Ah)	Power (Wh)	Current (Ah)
10.00 – 11.00	101.6	1.8	190.0	3.2	176.8	5.2
11.00 – 12.00	179.6	2.6	358.5	5.7	385.5	13.8
12.00 – 13.00	169.3	2.4	252.5	4.0	396.3	13.8
13.00 – 14.00	166.3	2.4	231.2	3.8	337.4	11.6
14.00 – 15.00	52.7	0.8	86.5	1.6	151.1	5.0
Total	669.5	10.0	1,118.7	18.3	1447.1	49.4

Table 3. Daily cooking activity to estimate power consumption per day

Time	Menu	Load	Time	Power Consumption (Wh)
Day1/ Morning	Opor Ayam (500 gr Chicken)	Stove 1200 W	28 min.	546
	Heating Water (500 mL)	Stove 1200 W	8 min.	158
	Choco chips cookies (200gr)	Stove 1200 W Microwave 1200 W	Stove 2 min. Microwave 6 min.	166
Day 1/ Noon	Heating Opor	Stove 1200 W	12 min.	256
Total				1,126
Day 2/ Morning	Mac n Cheese (500 gr)	Stove 1200 W Oven 500 W	Stove 20 min. 30 sec. Oven 23 min.	657
	Heating Opor	Microwave 1200 W	5 min. 30 Sec.	83
Day2/Noon	Chicken Soup 2 L	Stove 1200 W	26 min	524
Total				1,264

Time	Menu	Load	Time	Power Consumption (Wh)
Day 3/ Morning	Boil papaya's leaf (400 gr)	Stove 1200 W	45 min	1,207
	Fried mackerel (660 gr)	Stove 1200 W	14 min 57 sec	232
	Chili sauce	Stove 1200 W	2 min 40 sec	52
Day 3/ Noon	Fried Tempe	Stove 1200 W	17 min 51 sec	336
Total				1,885

IV. CONCLUSION

The majority of households in Indonesia are PLN customers with category R1 having under 2200 VA power electricity. The low availability of electric power hinders HPE usage in households. Separate solar power sources with low power storage may solve the problem because some HPE has a short time usage. A portable power station with a 2 kVA hybrid low-frequency inverter and 24 V 100 Ah battery storage has successfully been made. The charging of a power station with four 100 Wp Polycrystalline solar panels can charge around 1 kWh on sunny days in Yogyakarta, Indonesia. Daily cooking activity shows the power station can support 2-3 menus daily with the usage of HPE.

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REFERENCES

[1] Y. Yudiartono, J. Windarta, and A. Adiarso, "Sustainable Long-Term Energy Supply and Demand: The Gradual Transition to a New and Renewable Energy System in Indonesia by 2050," *Int. J. Renew. Energy Dev.*, vol. 12, no. 2, pp. 419–429, 2023, doi: 10.14710/ijred.2023.50361.

[2] J. Martínez-Gómez, D. Ibarra, S. Villacis, P. Cuji, and P. R. Cruz, "Analysis of LPG, electric and induction cookers during cooking typical Ecuadorian dishes into the national efficient cooking program," *Food Policy*, vol. 59, pp. 88–102, 2016, doi: 10.1016/j.foodpol.2015.12.010.

[3] PT.PLN (persero), "Statistics PLN 2022," *Stat. PLN*, no. 03001–230526, p. 98, 2023, [Online]. Available: https://web.pln.co.id/statics/uploads/2022/08/Statistik-PLN-2021-29-7-22-Final.pdf.

[4] J. Barton *et al.*, "A Portable Power Station for Humanitarian Contexts," *2021 IEEE Int. Humanit. Technol. Conf. IHTC 2021*, 2021, doi: 10.1109/IHTC53077.2021.9698942.

[5] S. Siddiqua, S. Firuz, B. M. Nur, R. J. Shaon, S. J. Chowdhury, and A. Azad, "Development of double burner smart electric stove powered by solar photovoltaic energy," *GHTC 2016 - IEEE Glob. Humanit. Technol. Conf. Technol. Benefit Humanit. Conf. Proc.*, pp. 451–458, 2016, doi: 10.1109/GHTC.2016.7857319.

[6] M. Rezwan Khan and I. Alam, "A solar pv-based inverter-less grid-integrated cooking solution for low-cost clean cooking," *Energies*, vol. 13, no. 20, 2020, doi: 10.3390/en13205507.

[7] A. Lamkaddem *et al.*, "System for powering autonomous solar cookers by batteries," *Sci. African*, vol. 17, p. e01349, 2022, doi: 10.1016/j.sciaf.2022.e01349.

[8] A. Altouni, S. Gorjian, and A. Banakar, "Development and performance evaluation of a photovoltaic-powered induction cooker (PV-IC): An approach for promoting clean production in rural areas," *Clean. Eng. Technol.*, vol. 6, p. 100373, 2022, doi: 10.1016/j.clet.2021.100373.

[9] M. Soltani, A. Hajizadeh Aghdam, and Z. Aghaziarati, "Design, fabrication and performance assessment of a novel portable solar-based poly-generation system," *Renew. Energy*, vol. 202, no. October 2022, pp. 699–712, 2023, doi: 10.1016/j.renene.2022.10.119.

[10] N. El Moussaoui *et al.*, "Autonomous Power System Powered by Solar Batteries: A Case of Box Oven Heating," *Int. J. Renew. Energy Res.*, vol. 12, no. 3, pp. 1269–1278, 2022, doi: 10.20508/ijrer.v12i3.13139.g8512.

[11] G. Zubi, F. Spertino, M. Carvalho, R. S. Adhikari, and T. Khatib, "Development and assessment of a solar home system to cover cooking and lighting needs in developing regions as a better alternative for existing practices," *Sol. Energy*, vol. 155, pp. 7–17, 2017, doi: 10.1016/j.solener.2017.05.077.

[12] A. Jasuan, Z. Nawawi, and H. Samaulah, "Comparative Analysis of Applications Off-Grid PV System and On-Grid PV System for Households in Indonesia," *Proc. 2018 Int. Conf. Electr. Eng. Comput. Sci. ICECOS 2018*, pp. 253–258, 2019, doi: 10.1109/ICECOS.2018.8605263.

[13] M. Rumbayan, A. Abudureyimu, and K. Nagasaka, "Mapping of solar energy potential in Indonesia using artificial neural network and geographical information system," *Renew. Sustain. Energy Rev.*, vol. 16, no. 3, pp. 1437–1449, 2012, doi: 10.1016/j.rser.2011.11.024.