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Design of an Off-Grid Solar Power System for a Residential-Scale 1300 VA Application

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Abstract

This study presents the design and simulation of an off-grid solar power system optimized for a 1300 VA residential application in Keude Geudong Village, North Aceh, Indonesia. Motivated by the global reliance on non-renewable energy sources, this research aims to offer a sustainable and autonomous energy solution for rural households. The methodology includes detailed energy load auditing, component selection, and system performance simulation using PVSyst software. The system is configured to supply 3.5 kWh of energy per day, utilizing twelve 100 Wp monocrystalline solar panels, a 45 A MPPT charge controller, a 2000 W inverter, and six 52 Ah lithium-ion batteries, ensuring operation for up to three days without additional power input. Simulation results indicate a performance ratio of 58% and a solar fraction of 1:1, confirming the system's capability to operate independently from the national grid. The proposed configuration demonstrates the technical and practical feasibility of residential solar electrification in rural Indonesian settings. This study offers a fully autonomous home solar solution based on actual energy usage data and site-specific solar information, unlike previous research that focused on large-scale or hybrid systems, providing a scalable model for expanding energy access in off-grid areas.

Keywords

Off-grid solar power system, residential application, monocrystalline PV, battery autonomy

Introduction

Electricity is essential for both daily life and industrial operations. However, more than 80% of global energy consumption still relies on non-renewable resources such as fossil fuels, which are finite and contribute significantly to environmental degradation through greenhouse gas emissions (Ahmad et al., 2021; Mirzaei & Rahimpour, 2024; Odeh et al., 2022; Singh, 2024). As fossil fuel reserves continue to decline, a global transition toward sustainable and environmentally friendly renewable energy sources has become increasingly imperative (TN et al., 2024).

Solar energy is one of the most prominent renewable energy sources, owing to its abundance and accessibility—particularly in equatorial regions such as Indonesia, which receives

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an average solar radiation of 4.8 kWh/m² per day (Layarda, 2023; Nugraha et al., 2024; Syahputra et al., 2022; Windarta et al., 2019). Off-grid solar systems, which operate independently from the main grid, are well-suited for both rural and urban applications. These systems provide reliable electricity while reducing dependence on fossil fuels and minimizing carbon emissions (Pratheeba et al., 2023). Recent research on off-grid solar systems has focused on optimizing system configurations, improving efficiency, and reducing costs to ensure a stable energy supply under fluctuating irradiance conditions (Barakat, 2024; He et al., 2023; Liu et al., 2022; Pukšec et al., 2020). Simulation tools such as PVSyst play a crucial role in evaluating the performance and feasibility of these systems across various environmental scenarios (Grover et al., 2020; Islam, 2022; Kumar Vashishtha et al., 2022).

This study presents the design of a 1300 VA off-grid solar power system for a household in North Aceh, utilizing monocrystalline PV panels, a charge controller, an inverter, and battery storage to meet a daily energy demand of 3.5 kWh. Through simulation and analysis, the study supports the feasibility of solar energy adoption in line with Indonesia's sustainability objectives. Globally, the transition to renewable energy is critical for mitigating climate change and reducing dependence on fossil fuels, with solar energy emerging as a widely accessible and viable solution (Ahmad et al., 2021). Regions with high solar irradiance, such as Indonesia, are particularly well-suited for efficient solar power generation (Layarda, 2023; Nugraha et al., 2024; Jiang et al., 2024).

Off-grid solar systems provide a reliable energy solution for areas without access to centralized electricity, utilizing photovoltaic (PV) panels, charge controllers, inverters, and battery storage to ensure continuous power supply (Pratheeba et al., 2023). Recent advancements in high-efficiency monocrystalline PV technology have significantly improved the performance and cost-effectiveness of off-grid systems (Barakat, 2024; He et al., 2023).

Battery storage plays a critical role in balancing supply and demand in off-grid systems, with research focusing on optimizing capacity and lifespan to enhance reliability and reduce costs (Liu et al., 2022; Pukšec et al., 2020). Simulation tools such as PVSyst are widely utilized to evaluate solar system performance under varying environmental conditions, aiding in component selection and system design optimization (Grover et al., 2020; Kumar Vashishtha et al., 2022). In the Indonesian context, studies by (Syahputra et al., 2022) and (Windarta et al., 2019) underscore the technical and economic potential of solar energy, reinforcing its significance in supporting the country's sustainable development goals.

This study builds upon previous research to design a residential off-grid solar power system in North Aceh, contributing to the advancement of renewable energy adoption in Indonesia.

Methodology

This study followed four key phases—data collection, energy demand analysis, system design, and performance simulation—to ensure an accurate and practical off-grid solar power system.

Data Collection: Site-specific solar irradiance and climatic data were obtained from the Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG) and the Photovoltaic Geographical Information System (PVGIS). These datasets were used to estimate the solar energy potential in Keude Geudong Village, North Aceh. In parallel, a comprehensive household electrical load audit was conducted. Information on appliance types, power ratings (in watts), average daily usage duration, and usage frequency was collected through field observations and interviews with residents.

Energy Demand Analysis: Daily energy consumption was calculated by multiplying the power rating of each appliance by its usage duration and quantity. An additional 25% buffer was applied to account for power losses and peak usage variability. The resulting total daily energy demand was estimated at 3.5 kWh. A detailed breakdown of energy consumption by appliance is presented in Table 1 and was used as the primary reference for system sizing.

Table 1. Daily energy consumption

Appliance	Power (W)	Usage (hours/day)	Quantity	Total Energy (Wh/day)
LED Lights	30	14	3	1260
Fan	45	8	1	360
Water Pump	125	4	1	500
Miscellaneous Load	200	-	-	200
Total Energy Demand				2838 Wh

The total daily energy demand was increased to 3.5 kWh after applying a buffer to account for energy losses. System Design and Component Selection: The system components were selected based on the estimated energy demand, available solar irradiance, and the desired level of system autonomy. The photovoltaic (PV) panel area was calculated using equation (1):

$$PV_{Area} = \frac{E_L}{G_{avg} \times TCF \times \eta_{PV} \times \eta_{out}} \, m^2 \quad (1)$$

where: E_L is the daily energy load (kWh/day)
G_{avg} is the average daily solar radiation (kW/m²/day)
TCF is the temperature coefficient factor
η_{PV} is the panel efficiency
η_{out} is the overall output efficiency

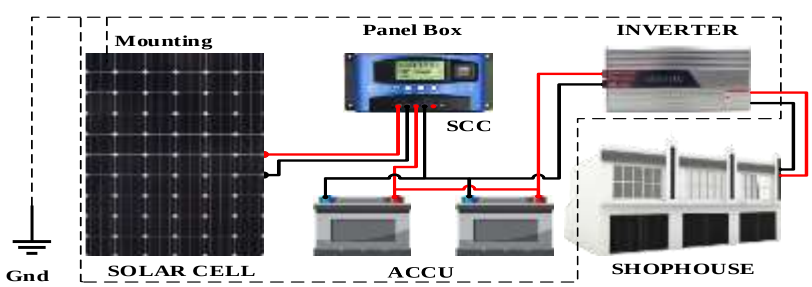

Figure 1. Wiring diagram of the off-grid solar power system

Based on the calculation, a PV panel area of 7.51 m² was determined. To meet the daily energy requirement, twelve 100 Wp monocrystalline solar panels were selected. The system includes a 45 A MPPT charge controller, six 52 Ah lithium-ion batteries providing three days of autonomy, and a 2000 W inverter for converting DC to AC power. The integration of system components is illustrated in Figure 1.

Performance Simulation: The system was evaluated using PVSyst version 7.3.1, incorporating site-specific data to assess its technical feasibility based on key performance metrics, including performance ratio, solar fraction, and annual energy yield.

Results and Discussion

Simulation Results: To assess the technical feasibility of the system, a performance simulation was conducted using PVSyst software version 7.3.1. The simulation incorporated site-specific parameters such as solar irradiance, ambient temperature, and the household energy load profile. The key performance metrics obtained from the simulation are presented in Table 2.

Table 2. Simulation results summary

Metric	Value
Performance Ratio (PR)	58%
Solar Fraction	1:1
Annual Energy Yield	1885 kWh

The simulation showed that the system achieved a performance ratio (PR) of 58%, which is considered acceptable for small-scale off-grid PV systems operating in tropical climates. A solar fraction of 1:1 indicates that the household's entire energy demand can be met independently, without reliance on external grid sources. The annual energy yield of 1885 kWh confirms the system's capacity to consistently meet the estimated daily load of 3.5 kWh, with an additional margin to accommodate seasonal variations and unexpected increases in usage.

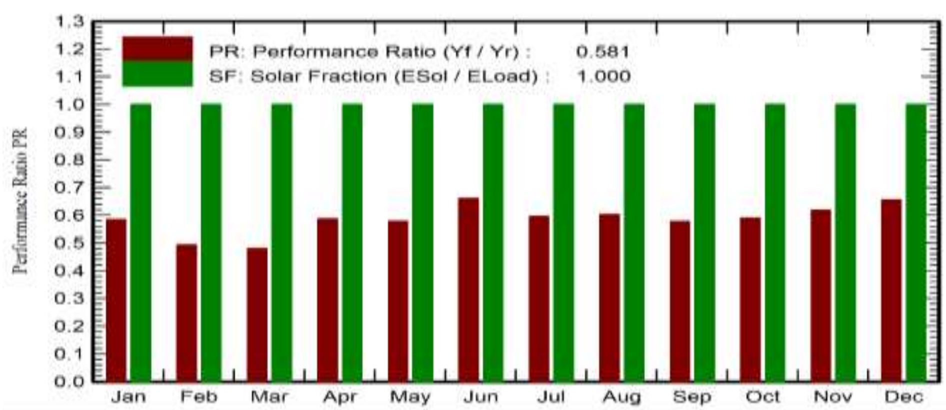

Figure 2. Energy output and system losses of the 1300 VA off-grid solar system simulated in PVSyst

The system comprises twelve 100 Wp PV panels, a 45 A MPPT charge controller, six 52 Ah batteries, and a 2000 W inverter, all selected to optimize performance under varying irradiance conditions. Simulation results (Figure 2) indicate that energy losses are primarily attributed to temperature effects and inefficiencies during battery charging. MPPT technology enhances energy harvesting, while lithium-ion batteries provide greater efficiency and longer lifespans compared to lead-acid batteries, ensuring stable system performance.

The novelty of this study lies in its focus on a 1300 VA residential-scale off-grid system, a topic that is rarely addressed in existing literature. This research emphasizes the technical feasibility of a fully autonomous solution for single-household applications, incorporating real load profiling and localized irradiance data to enhance design accuracy and contextual relevance. In contrast to previous studies that concentrate on larger-scale or hybrid systems, this study offers a compact, scalable, and practical model for rural electrification in Indonesia.

The analysis demonstrates that the system effectively meets the household's energy needs while maintaining operational efficiency. A performance ratio of 58% aligns with off-grid standards and confirms the reliability of the selected components. A solar fraction of 1:1 indicates that the system is fully capable of operating independently from the grid. As shown in Table 2, the annual energy yield of 1885 kWh sufficiently covers the household's energy requirements, providing a margin for unexpected increases in demand. The graphical representation in Figure 2 further supports the system's reliability and efficiency. Compared to similar studies conducted in regions with comparable solar potential, this system exhibits competitive performance. Notably, the use of MPPT technology in the charge controller significantly minimizes energy losses, while lithium-ion batteries ensure durability and efficient energy storage. However, factors such as seasonal variations and potential shading require further consideration. Regular system monitoring and maintenance are recommended to ensure optimal performance.

This study demonstrates the successful design and simulation of a 1300 VA off-grid solar power system in North Aceh, developed to meet a daily energy demand of 3.5 kWh. The system, consisting of twelve 100 Wp photovoltaic panels, a 45 A MPPT charge controller, six 52 Ah lithium-ion batteries, and a 2000 W inverter, achieved a performance ratio of 58% and full energy autonomy. These results confirm its technical feasibility and potential scalability as a sustainable energy solution for rural areas lacking access to the electricity grid.

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References

Ahmad, T., Zhang, D., Huang, C., Zhang, H., Dai, N., Song, Y., & Chen, H. (2021). Artificial intelligence in sustainable energy industry: Status Quo, challenges and opportunities. Journal of Cleaner Production, 289, 125834. https://doi.org/10.1016/J.jclepro.2021.125834

Barakat, S. H. (2024). Optimal Sizing and Techno-Economic Analysis of an Off-Grid PV/Battery System for Fruit Farm Electrification. Journal of Engineering Science and Sustainable Industrial Technology, 2(1), 26–32. https://doi.org/10.21608/jessit.2023.218793.1000

Grover, A., Khosla, A., & Joshi, D. (2020). Design and simulation of 20MW photovoltaic power plant using PVSyst. Indonesian Journal of Electrical Engineering and Computer Science, 19(1), 58–65. https://doi.org/10.11591/ijeecs.v19.i1.pp58-65

He, Y., Guo, S., Dong, P., Zhang, Y., Huang, J., & Zhou, J. (2023). A state-of-the-art review and bibliometric analysis on the sizing optimization of off-grid hybrid renewable energy systems. Renewable and Sustainable Energy Reviews, 183, 113476. https://doi.org/10.1016/J.rser.2023.113476

Islam, Md. S. (2022). Feasibility Analysis and Simulation of the Solar Photovoltaic Rooftop System Using PVsyst Software. International Journal of Education and Management Engineering, 12(6), 21–32. https://doi.org/10.5815/ijeme.2022.06.03

Jiang, B.-H., Gao, Z.-J., Lung, C.-Y., Shi, Z.-E., Du, H.-Y., Su, Y.-W., . . . Wong, K.-T. (2024). Enhancing the efficiency of indoor perovskite solar cells through surface defect passivation with coplanar heteroacene cored a–d–a-type molecules. Advanced Functional Materials, 34(19), 2312819. https://doi.org/10.1002/adfm.202312819

Kumar Vashishtha, V., Yadav, A., Kumar, A., & Kumar Shukla, V. (2022). An overview of software tools for the photovoltaic industry. Materials Today: Proceedings, 64, 1450–1454. https://doi.org/10.1016/j.matpr.2022.04.737

Layarda, B. (2023). Solar Power Plant Planning for Household Scale by The Aid Pvsyst Program. Telecommunications, Computers, and Electricals Engineering Journal (telectrical), 1(3), 306–318. https://doi.org/10.26418/telectrical.V1I3.74504

Liu, K., Yamada, H., Iwatsuki, K., & Otsuji, T. (2022). Study on optimum configuration of off-grid systems from the viewpoint of renewable energy ratio and investment cost. 2022 IEEE International Power and Renewable Energy Conference, Iprecon 2022. https://doi.org/10.1109/IPRECON55716.2022.10059490

Mirzaei, F., & Rahimpour, M. R. (2024). Global Energy Resources Analysis. Encyclopedia of Renewable Energy, Sustainability and the Environment, 1–8. https://doi.org/10.1016/B978-0-323-93940-9.00259-0

Nugraha, A., Armadan, R., & Taryo. (2024). Optimizing Solar Power Generation for Residential Loads in Remote Regions of Indonesia. Malaysian Journal of Science and Advanced Technology, 354–359. https://doi.org/10.56532/mjsat.V4I3.355

Odeh, A. A., Al Taie, W. A. M., & Al-Douri, Y. (2022). Renewable Energy Analysis and Resources. Renewable Energy, 1–20. https://doi.org/10.1063/9780735424272_001

Pratheeba, C., Muthuvinayagam, M., Siva Ramkumar, M., Rohith Bhat, C., Maniraj, P., & Kumar, N. S. (2023). A Review of an off Grid Solar DC System for Rural Houses. Proceedings of the 7th International Conference on Intelligent Computing and Control Systems, ICICCS 2023, 1837–1843. https://doi.org/10.1109/ICICCS56967.2023.10142541

Pukšec, T., Markovska, N., Foley, A., & Duić, N. (2020). Addressing the transition to sustainable energy systems: Special issue dedicated to the 2018 conferences on Sustainable Development of Energy, Water and Environment Systems (sdewes). Renewable and Sustainable Energy Reviews, 119, 109520. https://doi.org/10.1016/J.RSER.2019.109520

Singh, V. (2024). Energy Resources. Textbook of Environment and Ecology, 185–206. https://doi.org/10.1007/978-981-99-8846-4_12

Syahputra, R., Mundakir, D., Ardiyanto, Y., Purwanto, K., & Jamal, A. (2022). Design of a Household-scale Solar Power Plant Using PVSYST Software. AIP Conference Proceedings, 2499. https://doi.org/10.1063/5.0105975

TN, K., R, P., P, S., Kiran G, S., & Selvin, J. (2024). Exploring The Path of Sustainable Development Using Renewable Energy. Futuristic Trends in Renewable & Sustainable Energy Volume 3 Book 1, 260–306. https://doi.org/10.58532/V3BDRS1P2CH4

Windarta, J., Denis, Nugroho, A., & Bagaskoro, B. (2019). Design and Analysis of Technical Economics of Off-grid Systems Solar Power Plant Using Homer at Cemara Island, Brebes Regency. E3S Web of Conferences, 125, 11002. https://doi.org/10.1051/E3SCONF/201912511002