International journal of science, engineering, and information technology
Volume 08, Issue 02, July 2024
Journal homepage: https://journal.trunojoyo.ac.id/ijseit

Design of an Off – Grid Solar Power System for the Shashi Baby and Kids Food Industry in Bukittinggi

Dedi Tri Laksono[1], Deni Tri Laksono[2], Monika Faswia Fahmi[3], Nofri Dodi[4]

[1]Politeknik Negeri Padang, Padang, Indonesia
[2]Universitas Trunojoyo, Bangkalan, Indonesia
[3]Universitas Trunojoyo, Bangkalan, Indonesia
[4]Politeknik Negeri Padang, Padang, Indonesia

A B S T R A C T

The transition to renewable energy is increasingly important in addressing global energy demands and environmental issues. Solar energy has emerged as a sustainable option, particularly for small and micro businesses that often face challenges related to energy supply and costs. Shashi Baby and Kids Food, a micro – enterprise producing baby food, can benefit from an off – grid solar power system to support its operational needs, especially lighting during the night. The system design involves analyzing energy requirements, selecting solar panels, batteries, inverters, and simulating the system using PVsyst software to optimize performance. This system is designed to support operations with nine lamps for 12 hours a day, generating sufficient energy and ensuring adequate storage. Simulation results show that the system has a performance ratio (PR) of 75.86% and a solar fraction (SF) of 99.82%, indicating high efficiency and nearly fully meeting energy needs through solar power. Although there is a slight decrease in SF in December, this system design has proven to be efficient and reliable in supporting business operations. Further analysis reveals that the annual energy production reaches 1451 kWh, with specific production of 1210 kWh per kWp, confirming that this system can generate significant energy for the operational needs of the business.

Keywords: Off – grid solar power system, PVSyst Simulation, Solar energy efficiency

Article History
Received 09 May 24 Received in revised form 12 June 24 Accepted 28 July 24

1. INTRODUCTION

The transition to renewable energy sources has become increasingly crucial in addressing global energy demands and environmental concerns. (Hassan et al., 2024).Solar energy, in particular, has emerged as a viable and sustainable option for various applications, including residential, commercial, and industrial uses. For small and micro businesses, which often face challenges related to energy supply and cost, solar power provides a promising solution. This is especially relevant for micro, small, and medium enterprises (MSMEs) operating in off-grid areas where access to reliable electricity is limited or non-existent. [1]

Shashi baby and kids food, a micro enterprise specializing in the production of baby food, is one such business that stands to benefit from the implementation of an off – grid solar power system. The operational requirements of Shashi include consistent lighting for production and quality control processes, which are crucial for maintaining product standards and ensuring safety. Given that the business operates during the evening hours, from 6 p.m. to 6 a.m., a reliable and efficient lighting solution is essential to support its operations during these hours.

Designing an off – grid solar power system involves several key considerations, including the assessment of energy needs, the selection of appropriate solar panels, batteries, and inverters, and the evaluation of system performance. The system must be capable of generating sufficient energy to meet the lighting requirements and ensuring that there is enough stored energy to cover periods without sunlight. Therefore, a comprehensive approach is necessary to ensure that the solar power system is both efficient and cost – effective. [2]

In this study, an initial design for the off – grid solar power system for Shashi is proposed. The design focuses on powering nine lamps with varying capacities, which are used for lighting purposes over a 12 – hour period each day. The design includes the use of nine solar panels, a suitable inverter, and a battery storage system configured to meet the energy needs of the enterprise. Simulation of the system using PVsyst software is then conducted to validate the initial design and optimize the system performance. [3]

* *Corresponding author.* Phone : +0-000-000-0000 ; fax: +0-000-000-0000.
E-mail address: author@institute.xxx .

The purpose of this study is to evaluate the feasibility and effectiveness of the proposed solar power system for Shashi. By conducting simulations and analyzing key performance metrics such as Performance Ratio (PR), Solar Fraction, Global Horizontal Irradiation, and Effective Global Irradiation, the study aims to provide insights into the system's capability to meet the energy demands and identify potential areas for improvement. The results will guide the final implementation of the solar power system, ensuring that it delivers reliable and sustainable energy to support the business operations effectively. [4]

II. MATERIALS AND METHODS

2.1 PVSyst Software

PVSyst is a widely used software for the design and simulation of photovoltaic (PV) systems. The latest version of this software, PVSyst 7.4.6, offers a range of advanced features designed to assist users in analyzing and optimizing solar power systems. By utilizing PVSyst version 7.4.6, users can perform in-depth calculations and gain a better understanding of the performance of the solar power systems they design. [5]

Version 7.4.6 of PVSyst introduces several enhancements and improvements over previous versions. Key features of this version include:

1. Enhanced User Interface

Version 7.4.6 features a more intuitive user interface, allowing users to more easily access and utilize the various features and tools available. This includes improved navigation and helpful features that streamline the system design process.

2. Increased Simulation Accuracy

PVSyst 7.4.6 provides more accurate algorithms for calculating the energy output of photovoltaic systems. These improvements allow for more precise analysis of system performance under various operational and weather conditions.

3. Advanced Performance Analysis Tools

This version introduces more sophisticated performance analysis tools, including detailed assessments of Performance Ratio (PR), Solar Fraction, and other critical parameters. These tools help evaluate the effectiveness of the system and identify areas for improvement.

4. Comprehensive Weather Data and Global Irradiation

PVSyst 7.4.6 offers access to more comprehensive weather data and a more extensive Global Horizontal Irradiation (GHI) database. This enables more accurate calculations of solar radiation potential at specific locations.

5. Integration with Other Design Tools

The software also supports integration with various other design tools, such as CAD and BIM software, facilitating the system design process and further analysis.

In this study, PVSyst version 7.4.6 was used to simulate the off-grid solar power system designed for Shashi. By leveraging the advanced features of this version, the analysis includes calculations of energy needs, performance evaluation, and design optimization to ensure the system efficiently meets energy requirements. The results from these simulations provide valuable insights into system performance and aid in making informed decisions for effective implementation. [6]

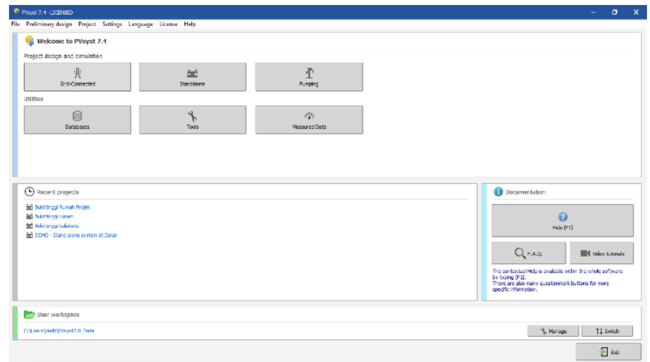


Figure 1. PVsyst initial screen

2.2 Methods

In this study, the methodology is designed to ensure accuracy and relevance in evaluating the off-grid solar power system for Shashi. The methodology consists of several key steps, as shown in Figure 2.

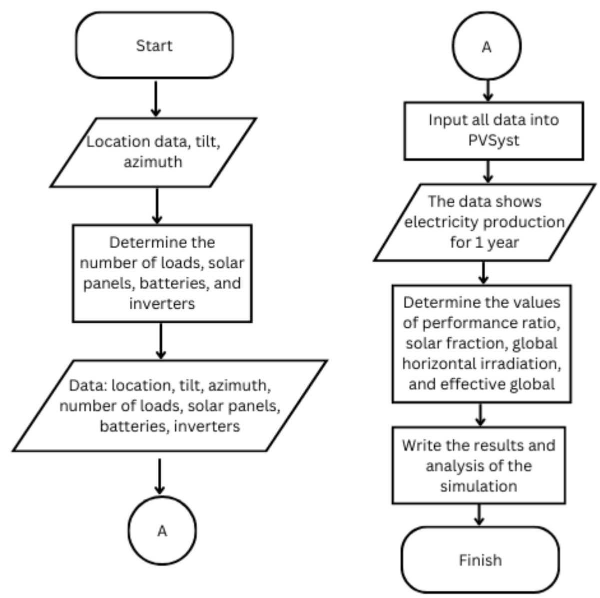


Figure 2. flowchart for off-grid solar power system design

2.3 Location Data

The data collected includes location data. Location data can be obtained by determining the coordinates through Google Maps, as shown in Figure 3

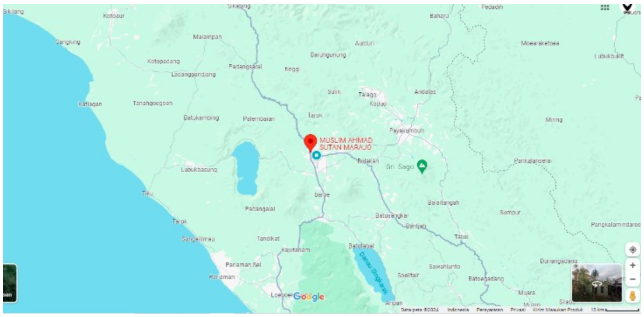


Figure 3. Location data Shashi Baby and Kids food

2.4 Tilt and Azimuth

Tilt and azimuth angles are crucial parameters in designing solar power systems, as they affect the efficiency of solar energy collection. These angles determine the orientation of solar panels to maximize exposure to sunlight. [7]

According to data obtained from Global Solar Atlas, the tilt angle for the location with the given coordinates is 4 degrees. This angle is set to optimize solar energy capture throughout the year. The azimuth angle for the same location is 0 degrees. This means that the solar panels should face north to maximize sunlight exposure. By setting the tilt and azimuth angles to these values, the solar power system can achieve optimal performance and efficiency. Tilt and azimuth will shown in figure 4.

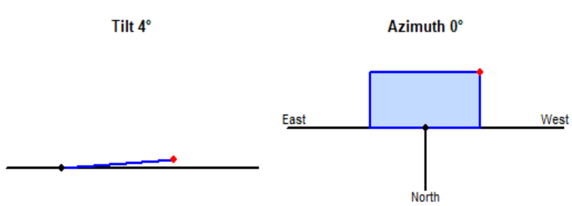


Figure 4. Tilt and azimuth in PVSyst Software

2.5 Determine Loads, Photovoltaic, Batteries and Inverter

The load design uses 3 lamps of 30 watts each and 6 lamps of 40 watts each. Assuming the lamps are estimated to be on for 12 hours, the calculation is as follows:

1. Calculate the total power consumption for each type of lamp:
   - For 30 watt lamps:
     Total Power = 3 lamps x 30 watts = 90 watts
   - For 40 watt lamps:
     Total Power = 6 lamps x 40 watts = 240 watts
2. Calculate the total power consumption for all lamps:
Total Power = 90 watts + 240 watts = 330 watts
3. Calculate the total energy consumption over 12 hours:
Total Energy = 330 watts x 12 hours = 3.960 watt – hours (Wh)

This calculation helps in determining the total energy consumption of the lighting system, which is crucial for sizing the solar power system and energy storage requirements. The Lamp Load Data is Shown in Figure 5

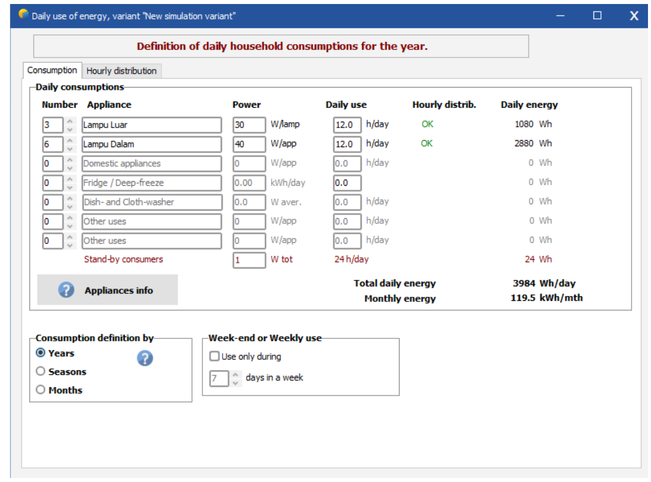


Figure 5. The Lamp load data in PVSyst

To calculate the power of the solar panels, use the following formula:

PV Power (W) = $\frac{Energi\ Requirement\ (Wh)}{Peak\ Sun\ Hour\ (h)}$ [8]

Given:

- Energy requirement = 3,960 Wh
- Peak sun hours = 4 hours

The calculation is as follows:

PV Power (W) = $\frac{3{,}960\ Wh}{4\ h} = 990\ W$

Thus, the required solar panel power is 990 watts

This value indicates the total power capacity that the solar panels must have to meet the energy needs under the given sunlight conditions.

Next, Determine the Number of Solar Panels, To calculate the number of solar panels required, use the following formula:

$Number\ of\ panels\ \frac{PV\ Power\ (W)}{Panel\ Capacity\ (Wp)}$ [8]

Given:

- PV Power = 990 W
- Panel capacity = 100 Wp (Watt – peak)

The calculation is as follows:

$$Number\ of\ panels\ \frac{900\ W}{100\ Wp} = 9.9$$

Therefore, the required number of solar panels is 10 panels (rounded up). This calculation helps determine the number of solar panels needed to generate the required power.

Next, determine the Inverter Power, to calculate the required inverter power, use the following formula:

Inverter Power (W) = Total Power (W) x Safety Factor

Given:

- Total power = 330 W
- Safety factor = 1

The calculation is as follows:

Inverter Power (W) = 330 W x 1 = 330 W

Therefore, the required inverter power is 330 watts. This ensures that the inverter can handle the total power demand of the system with an appropriate safety margin.

III. RESULT AND DISCUSSION

3.1 Performance Ratio and solar Fraction

Based on the simulation data from PVsyst, the performance ratio (PR) obtained is 75.86%. This indicates that the solar power system operates at 75.86% of its theoretical maximum efficiency under the given conditions. A performance ratio above 70% is generally considered good, meaning that system losses due to factors such as temperature, shading, and inefficiencies are within acceptable limits. This result suggests that the system design has been well-optimized for the location and should perform reliably in real-world applications. The performance ratio is shown in Figure 6.

Additionally, the solar fraction was calculated at 99.82%, indicating that the system can meet 99.82% of the energy demand through solar power alone. This high solar fraction shows that the system is highly self-sufficient and can provide nearly all the required energy without relying on external sources. This near-complete reliance on solar energy highlights the effectiveness of the system design, particularly in maximizing the use of available solar resources. The solar fraction is shown in Figure 6.

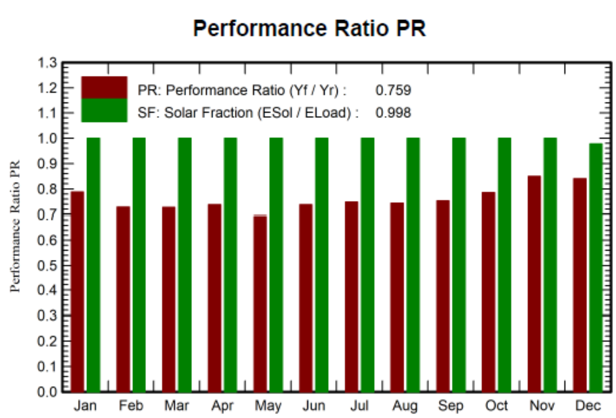


Figure 6. PF and SF ratio

If analyzed on a monthly basis over the course of a year, the solar fraction (SF) averages around 1. This indicates that the solar power system is able to fully meet energy demands through solar energy almost throughout the entire year. In other words, the system is highly efficient in utilizing solar resources and almost entirely does not require additional energy sources to meet the energy needs. The high SF value confirms that the system design is very effective in maximizing the use of solar energy and demonstrates the system's reliability and adequacy in providing the required energy.

However, in December, the SF shows a slight decrease to 0.978. This reduction indicates that during December, there is a minor shortfall in meeting energy needs solely from solar power, and a small portion of the energy demand may need to be met from external sources. This decrease in SF during this month could be attributed to seasonal factors such as lower solar irradiance during the rainy season. Nevertheless, the SF value approaching 1 indicates that the impact of this decrease is very minimal and not significant. This condition shows that the system remains highly dependent on solar energy and that the system design is still very efficient in meeting the majority of energy needs throughout the year. The solar fraction graph, illustrating monthly variations, can be seen in Figure 7.

	SolFrac
	ratio
January	1.000
February	1.000
March	1.000
April	1.000
May	1.000
June	1.000
July	1.000
August	1.000
September	1.000
October	1.000
November	1.000
December	0.978
Year	0.998

Figure 7. Solar fraction each month of the year

3.2 Global Horizontal Irradiation and Effective Global

PVsyst simulation is used to analyze the potential energy generated by a solar power system. Two important parameters analyzed are Global Horizontal Irradiation (GHI) and Effective Global (EG), which represent the amount of solar radiation received on a horizontal surface and the effective radiation after accounting for various factors. [9]

From the GHI data, it is evident that the month with the highest radiation is May with 145.0 kWh/m², while the month with the lowest radiation is November with 119.7 kWh/m². This indicates that May has the highest potential for generating electricity from the PV system, while November has the lowest potential. In the EG data, a similar pattern is observed, with May having the highest value of 143.8 kWh/m², and November having the lowest value of 113.1 kWh/m². The difference between GHI and EG is usually due to factors such as the angle of incidence of sunlight, shading, and system efficiency. Based on the PVsyst simulation, May shows the highest potential for energy generation from the solar power system, while November has the lowest potential. Overall, the fluctuations in solar radiation throughout the year indicate that energy production from the PV system will vary, but can be optimized through proper system adjustments and planning. GHI and EG are shown in Figure 8

	GlobHor	GlobEff
	kWh/m²	kWh/m²
January	133.7	126.1
February	129.6	123.6
March	141.8	137.3
April	133.9	131.2
May	145.0	143.8
June	131.2	130.9
July	134.4	133.4
August	136.7	134.2
September	132.2	128.2
October	132.7	127.3
November	119.7	113.1
December	123.0	115.4
Year	1594.1	1544.6

Figure 8. GHI and EG each month

3.3 Solar Power System Performance Analysis

System Production

This solar power system generates a total energy production of 1451 kWh per year. This figure reflects the amount of electricity produced by the system over a full year of operation.

Specific Production

The specific production of this system is recorded at 1210 kWh per year. Specific production represents the amount of energy generated by the system per unit of installed capacity over one year.

Performance Ratio (PR)

The Performance Ratio (PR) of this system is 0.759. PR measures the efficiency of the photovoltaic (PV) system in converting solar energy into electricity. With a value of 0.759, it indicates that the system is operating quite efficiently, although there are some factors that reduce its ideal performance.

Normalized Production

The normalized production of this system is 3.31 kWh/kWp per day. This means that for every kilowatt peak (kWp) of installed capacity, the system produces an average of 3.31 kWh of electricity per day.

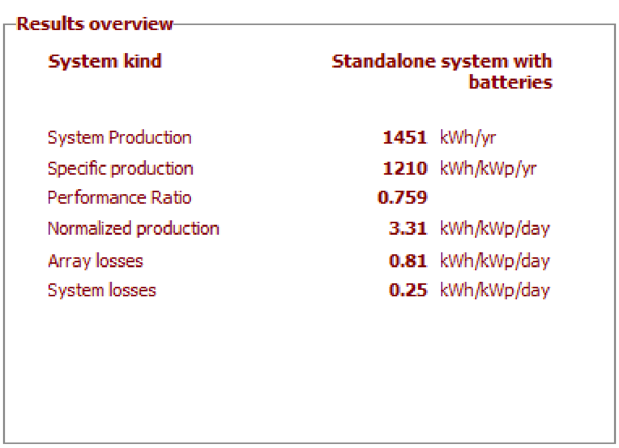
Array Losses

The PV array losses are recorded at 0.81 kWh/kWp per day. These losses may be caused by various factors such as shading, high temperatures, or mismatches within the PV modules.

System Losses

The overall system losses are recorded at 0.25 kWh/kWp per day. These losses include those from the inverter, cables, and other components within the system that reduce the amount of energy the system can generate.

Based on this data, it can be concluded that the solar power system is operating with good performance, producing significant energy annually. While there are some array and system losses, these values are still within reasonable limits for a PV system, indicating that the system's efficiency and production are at an adequate level. Result overview is shown in Figure 9.


Results overview

System kind	Standalone system with batteries	
System Production	1451	kWh/yr
Specific production	1210	kWh/kWp/yr
Performance Ratio	0.759	
Normalized production	3.31	kWh/kWp/day
Array losses	0.81	kWh/kWp/day
System losses	0.25	kWh/kWp/day

Figure 9. Result overview from PVSyst

V. CONCLUSION

The simulation results from PVsyst provide an in-depth understanding of the solar power system's performance and efficiency. With a performance ratio (PR) of 75.86%, the system operates at a high level of efficiency, suggesting that losses due to temperature, shading, and other inefficiencies are within acceptable limits. This value, exceeding the 70% benchmark, indicates that the system design has been well-optimized for the location, ensuring reliable performance in real-world applications.

The solar fraction (SF) of 99.82% further reinforces the system's effectiveness, demonstrating its capability to meet nearly all energy demands through solar power alone. This high degree of self-sufficiency highlights the system's reliability and its potential to reduce dependency on external energy sources. Even with a slight decrease in SF to 0.978 in December, likely due to seasonal variations, the system remains highly efficient and effective in utilizing solar energy throughout the year.

When analyzing Global Horizontal Irradiation (GHI) and Effective Global (EG), the data reveals that May offers the highest potential for energy generation, while November presents the lowest. This variation emphasizes the importance of optimizing system performance through careful planning and adjustments to account for seasonal changes.

Overall, the solar power system's annual production of 1451 kWh and specific production of 1210 kWh per kWp demonstrate its capability to generate substantial energy. The normalized production of 3.31 kWh/kWp per day, coupled with manageable array and system losses, underscores the system's solid performance and efficiency. In conclusion, the PV system exhibits strong performance, high efficiency, and minimal losses, making it a reliable and effective solution for meeting energy needs through solar power. The system's design and operation align well with the expected outcomes, and it holds promise for consistent energy generation in real-world applications.

REFERENCES

[1] Q. Hassan *et al.*, "The renewable energy role in the global energy Transformations," *Renewable Energy Focus*, vol. 48, p. 100545, 2024, doi: https://doi.org/10.1016/j.ref.2024.100545.

[2] A. Alkhalidi and N. Dulaimi, "Design of an Off-Grid Solar PV System for a Rural Shelter," 2018. doi: 10.13140/RG.2.2.24352.07689.

[3] R. Kumar, C. Rajoria, A. Sharma, and S. Suhag, "Design and simulation of standalone solar PV system using PVsyst Software: A case study," *Mater Today Proc*, vol. 46, Oct. 2020, doi: 10.1016/j.matpr.2020.08.785.

[4] E. Zell *et al.*, "Assessment of solar radiation resources in Saudi Arabia," *Solar Energy*, vol. 119, pp. 422–438, 2015, doi: https://doi.org/10.1016/j.solener.2015.06.031.

[5] H. Channi, *Analysis and design of solar PV system using Pvsyst software*, vol. 48. 2021. doi: 10.1016/j.matpr.2021.09.029.

[6] A. Shrivastava, R. Sharma, M. Saxena, V. Shanmugasundaram, M. Rinawa, and A. Sharma, "Solar energy capacity assessment and performance evaluation of a standalone PV system using PVSYST," *Mater Today Proc*, Jul. 2021, doi: 10.1016/j.matpr.2021.07.258.

[7] W. Le Roux, "Optimum tilt and azimuth angles for fixed solar collectors in South Africa using measured data," *Renew Energy*, vol. 96, pp. 603–612, Oct. 2016, doi: 10.1016/j.renene.2016.05.003.

[8] E. Suherman and E. Y. Astuty, "Designing a solar power plant model as an energy mix at Darma Persada University," *J Phys Conf Ser*, vol. 1469, no. 1, p. 012103, 2020, doi: 10.1088/1742-6596/1469/1/012103.

[9] R. Urraca, T. Huld, A. Lindfors, A. Riihelä, F. J. Ascacibar, and A. Sanz García, "Quantifying the amplified bias of PV system simulations due to uncertainties in solar radiation estimates," *Solar Energy*, vol. 176, pp. 663–677, Nov. 2018, doi: 10.1016/j.solener.2018.10.065.

[10] R. M. Yusron, T. Prasetyo, and M. Pramudia, "Investigation of Involute Profile Error on Spur Gear Processed using Wire EDM," IOP Conf Ser Mater Sci Eng, vol. 1125, no. 1, p. 012119, May 2021, doi: 10.1088/1757-899x/1125/1/012119.

[11] R. M. Yusron and R. M. Bisono, "Optimization of Machining Parameters for Surface-roughness and Precision in EDM Using Response Surface Method," in Journal of Physics: Conference Series, Institute of Physics Publishing, Jul. 2020. doi: 10.1088/1742-6596/1569/3/032043.