International journal of science, engineering, and information technology
Volume 10, Issue 01, December 2025
Journal homepage: https://journal.trunojoyo.ac.id/ijseit

Performance Evaluation of a 250 Wp Solar Photovoltaic Water Pumping System in Tropical Climate: A Case Study in Pangkalan Kerinci, Indonesia

Rien Afrianti[1], Dedi Tri Laksono[2], Deni Tri Laksono[3], Monika Faswia Fahmi[4]

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

A B S T R A C T

Access to clean water in remote tropical regions remains a critical challenge, particularly where grid electricity is unavailable. Solar photovoltaic (PV) water pumping systems offer a sustainable, off-grid solution. This study evaluates the technical performance of a 250 Wp PV-powered deep well water pumping system installed in Pangkalan Kerinci, Indonesia (0.41°N, 101.85°E). The system employs a single Trina Solar TSM-310PD14 module connected to a Sun Pumps SDS-D-128 DC membrane pump via an MPPT controller. Using PVSyst v7.4.6, a one-year simulation was conducted under realistic meteorological and hydraulic conditions, including a static water table at 4 m depth and a daily water demand of 0.30 m³. Results indicate that the system reliably meets annual water needs (109 m³/year) with negligible water deficit (0.163 m³, or 0.15%). The annual specific water yield is 522 m³/kWp/bar, while the system operates at an overall efficiency of 4.3% and a pump efficiency of 16.7%. Energy analysis shows 15.5 kWh/year delivered to the pump, with 42.6 kWh/year of excess solar energy unused due to tank capacity limits. The performance ratio (PR) is approximately 87%, confirming high system reliability in equatorial conditions. This study demonstrates the technical viability of small-scale solar pumping for rural water supply in Indonesia.

Keywords: Photovoltaic water pumping, Solar energy, Pvsyst simulation.

Article History
Received 12 October 25 Received in revised form 14 November 25 Accepted 09 December 25

1. Introduction

Access to reliable clean water remains a persistent challenge in remote and off-grid communities across Indonesia, particularly in regions like Riau Province where infrastructure development lags behind urban centers [1]. While rainfall is abundant in these equatorial zones, the absence of centralized water distribution systems and grid electricity often forces communities to rely on manual or diesel-powered extraction methods, which are either labor-intensive or economically and environmentally unsustainable.

Solar photovoltaic (PV) water pumping systems have emerged as a promising alternative for decentralized water supply [2]. These systems convert solar irradiance directly into electrical energy to drive submersible or surface pumps, eliminating fuel costs and reducing carbon emissions [3]. Unlike conventional grid- or diesel-dependent systems, solar pumps offer autonomous operation, low maintenance, and long service life—making them especially suitable for rural and island communities in archipelagic nations like Indonesia [4].

Despite their advantages, the real-world performance of PV pumping systems is highly sensitive to local climatic conditions, hydraulic requirements, and component sizing. In tropical climates, high ambient temperatures reduce PV module efficiency, while cloud variability affects daily energy availability [5]. Moreover, mismatch between PV output and pump characteristics—especially in direct-coupled or MPPT-controlled systems—can lead to significant energy losses or water deficits if not properly modeled during the design phase.

This study addresses these challenges through a detailed PVSyst-based simulation of a 250 Wp solar pumping system deployed in Pangkalan Kerinci, Indonesia. The system is designed to meet a daily demand of 0.30 m³ from a deep well, using a single crystalline silicon module and a DC membrane pump. By evaluating annual water yield, system efficiency, and energy losses, this work contributes empirical performance data for small-scale solar pumping in equatorial humid climates—a context underrepresented in current literature.

* *Corresponding author.*
E-mail address: rienafriyanti@pnp.ac.id

E-ISSN 2548-4214

2. Methodology

2.1. Site and System Configuration

The study is located in Pangkalan Kerinci, Riau Province, Indonesia (0.41°N, 101.85°E, 13 m above sea level), a region characterized by consistent solar irradiance (~1637 kWh/m²/year) and high humidity typical of equatorial climates. The water demand is set at 0.30 m³/day (109.5 m³/year), reflecting average domestic needs for a small rural household. The well has a static water level at 4 m depth, with the pump installed at 10 m to ensure submergence under dynamic drawdown conditions.

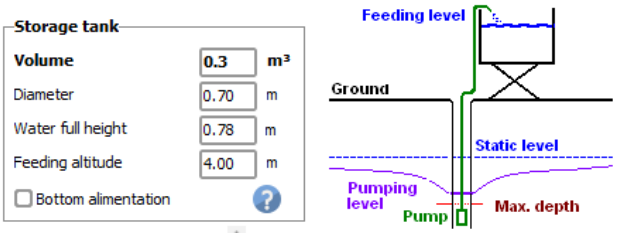


Figure 1. System configuration and storage parameters.

The photovoltaic (PV) pumping system is configured as a direct-coupled, battery-less setup using a single crystalline silicon module—Trina Solar TSM-310PD14 (250 Wp nominal power)—connected via an MPPT-DC converter to a Sun Pumps SDS-D-128 diaphragm-type submersible pump. This configuration aligns with best practices for small-scale off-grid applications, where simplicity, reliability, and cost-effectiveness are prioritized over energy storage.

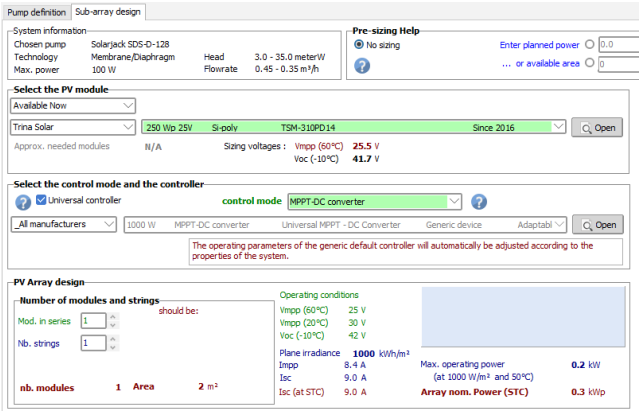


Figure 2. PV system design interface in PVsyst

2.2. Simulation Framework and Parameters

System performance was simulated using PVSyst v7.4.6, a widely validated tool for PV system modeling that incorporates meteorological, electrical, and hydraulic submodels [6]. The simulation used synthetic weather data from Meteonorm 8.1 (1996–2015) with 100% satellite coverage, ensuring representativeness of local climate variability[7]. Key modeling assumptions include:

- Fixed-tilt mounting at 10° tilt and 180° azimuth (true south), optimal for low-latitude sites,
- DC wiring resistance of 53 mΩ (1.5% loss at STC),
- Albedo coefficient of 0.20,
- IAM (Incidence Angle Modifier) modeled using ASHRAE bo = 0.05,

Pump control via MPPT algorithm with 97% peak converter efficiency. The storage tank volume (0.3 m³) matches daily demand, and the hydraulic circuit includes 16 m of PE25 piping (29 mm internal diameter). All energy and water balances were computed on an hourly basis over a full calendar year to capture seasonal effects.

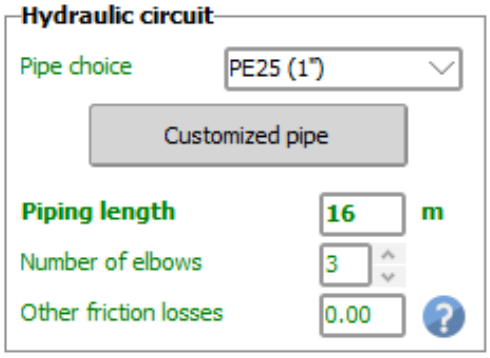


Figure 3. Hydraulic circuit spesification

3. Results and Discussion

3.1. Water and Energy Performance

The simulated system delivers 109.34 m³/year of water, satisfying 99.85% of the annual demand of 109.5 m³ (0.30 m³/day). The minor shortfall of 0.163 m³ (0.15%) occurs only in March, primarily due to temporary tank saturation limiting pump operation despite available solar energy. Monthly water output remains stable between 8.4–9.3 m³, demonstrating high reliability across seasons—a critical attribute for domestic water supply in remote tropical areas.

Annual electrical energy delivered to the pump (E_PmpOp) is 15.5 kWh, yielding a specific energy consumption of 0.14 kWh/m³. This value aligns closely with benchmarks for small-scale DC solar pumping systems (0.1–0.2 kWh/m³) reported in similar equatorial contexts. Notably, 42.6 kWh/year of PV-generated energy remains unused due to the storage tank reaching full capacity—a design trade-off between cost and performance in battery-less configurations.

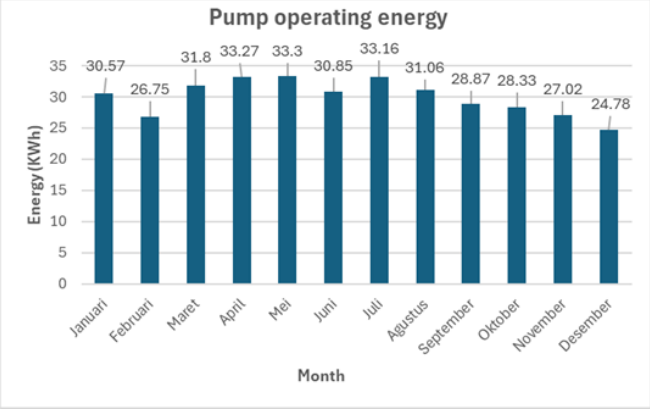


Figure 4. Monthly pump operating energy

3.2. Efficiency and Loss Analysis

The system achieves an overall system efficiency of 4.3%, defined as the ratio of hydraulic energy output to incident solar irradiation on the collector plane. The pump efficiency (hydraulic output / electrical input) reaches 16.7%, consistent with manufacturer specifications for low-flow diaphragm pumps under 8.5 m average head conditions.

The Performance Ratio (PR) calculated as PR,

$$PR = EArrMPP/EArrNom \quad (1)$$

$$= 359.8/409.7 = 0.87$$

It is approximately 87%, indicating minimal deviation from ideal module performance after accounting for real-world losses. The dominant energy losses include:

- Thermal losses
  11.55% (due to high module operating temperatures in humid tropics),
- Converter losses
  18.85% (from MPPT operation below nominal power),
- Unused energy
  73.36% of operating energy (due to tank limitation, not system fault).

While the unused energy fraction appears high, it reflects conservative storage sizing rather than inefficiency. In practice, this energy could be redirected to auxiliary loads (e.g., lighting or phone charging) without compromising water delivery—suggesting opportunities for multifunctional rural solar systems.

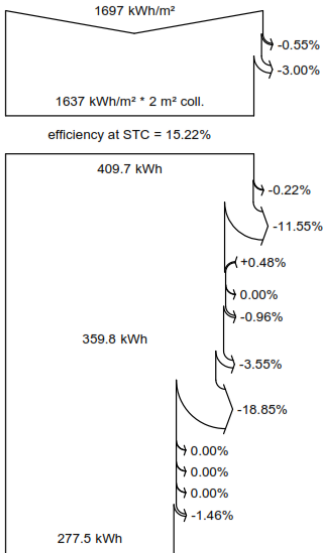


Figure 5. Loss diagram of PV pumping system

4. Conclusion

This study demonstrates that a 250 Wp solar PV pumping system can reliably supply 0.3 m³/day of water from a deep well in equatorial Indonesia. With a performance ratio of 87% and near-complete fulfillment of water demand, the system proves technically viable for off-grid domestic use. Future work should explore battery-less pump control strategies to utilize excess energy and increase water yield during high-irradiance periods. The findings support policy efforts to scale decentralized solar water solutions across Indonesia's archipelago.

Acknowledgements

The author gratefully acknowledges colleagues at Politeknik Negeri Padang for their technical discussions and constructive feedback during the simulation phase. This work also benefited from academic collaboration with Universitas Trunojoyo Madura, particularly in aligning the study with journal standards and renewable energy research frameworks.

REFERENCES

[1] Suryadi, "Akses Air Layak dan Aman di Riau Belum Terpenuhi, Mengapa?," https://mongabay.co.id/2024/04/09/akses-air-layak-dan-aman-di-riau-belum-terpenuhi-mengapa/.

[2] R. J. Chilundo, U. S. Mahanjane, and D. Neves, "Design and Performance of Photovoltaic Water Pumping Systems:

Comprehensive Review towards a Renewable Strategy for Mozambique," *Journal of Power and Energy Engineering*, vol. 06, no. 07, pp. 32–63, 2018, doi: 10.4236/jpee.2018.67003.

[3] M. M. Ahmed, H. M. Bawayan, M. A. Enany, M. M. Elymany, and A. A. Shaier, "Modern advancements of energy storage systems integrated with hybrid renewable energy sources for water pumping application," *Engineering Science and Technology, an International Journal*, vol. 62, p. 101967, Feb. 2025, doi: 10.1016/j.jestch.2025.101967.

[4] C. N. Nwagu, C. O. Ujah, D. V. V. Kallon, and V. S. Aigbodion, "Integrating solar and wind energy into the electricity grid for improved power accessibility," *Unconventional Resources*, vol. 5, p. 100129, Jan. 2025, doi: 10.1016/j.uncres.2024.100129.

[5] T. Dewi, P. Risma, and Y. Oktarina, "A Review of Factors Affecting the Efficiency and Output of a PV System Applied in Tropical Climate," *IOP Conf Ser Earth Environ Sci*, vol. 258, p. 012039, May 2019, doi: 10.1088/1755-1315/258/1/012039.

[6] D. T. Laksono, L. A. C. P. Pratama, A. Ubaidillah, M. F. Fahmi, and D. T. Laksono, "Simulasi dan Perancangan PLTS Offgrid 3 kW Menggunakan Software PVsyst," *Jurnal Teknik Elektro Uniba (JTE UNIBA)*, vol. 9, no. 2, pp. 581–588, Apr. 2025, doi: 10.36277/jteuniba.v9i2.1264.

[7] P. Barua and N. K. Das, "Seasonal Performance Evaluation of A 6 MW Photovoltaic System: A Comparative Study Using PVsyst and MATLAB Simulink Model," in *2025 International Conference on Electrical, Computer and Communication Engineering (ECCE)*, IEEE, Feb. 2025, pp. 1–6. doi: 10.1109/ECCE64574.2025.11013510.