

# Simulation and Experimental Validation of a Grid-Connected Microgrid for Rural Electrification in Sarawak, Malaysia

Halyani Mohd Yassim<sup>1</sup>, Muhammad Lutfi Syed Hussain@Zul<sup>1</sup>, Asif Ahmed<sup>2</sup>

<sup>1</sup>Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia

<sup>2</sup>Green and Sustainable Energy (GSEnergy) Focus Group, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia

Email: halyani@utem.edu.my, lutifi9552@yahoo.com, asifrahimoon@ieee.org

**How to cite this paper:** Yassim, H.M., Hussain@Zul, M.L.S. and Ahmed, A. (2025) Simulation and Experimental Validation of a Grid-Connected Microgrid for Rural Electrification in Sarawak, Malaysia. *Journal of Power and Energy Engineering*, 13, 22-31. <https://doi.org/10.4236/jpee.2025.1312003>

**Received:** November 13, 2025

**Accepted:** December 13, 2025

**Published:** December 16, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution-NonCommercial International License (CC BY-NC 4.0).

<http://creativecommons.org/licenses/by-nc/4.0/>



Open Access

## Abstract

Rural electrification remains a major challenge in South Asian countries, where many rural settlements still lack access to reliable electricity. In line with the 2030 Agenda, decentralized energy systems that incorporate distributed renewable resources have become an option for improving rural energy access. Among these systems, microgrids provide a structured way to supply rural settlements. However, operating a microgrid can be challenging due to variability of renewable resources. This study presents a methodology for simulating and validating a grid-connected microgrid designed to improve rural electrification in Sarawak, Malaysia. The proposed microgrid system comprises a micro-hydro generator, electrical loads, and a connection to the utility grid. The microgrid is modeled in HOMER Pro to evaluate its technical feasibility, while its practical implementation is validated using the Lucas-Nuelle Training System with SCADA monitoring. Simulation results indicate that the micro-hydro generator consistently supplied power of 21.3 kW during normal stream flow conditions, while the grid maintained continuous power during low stream flow conditions. Experimental results further confirmed voltage stability, power balance, and smooth transitions between both sources. The findings demonstrate that the grid-connected microgrid offers a technically reliable solution for rural electrification, supporting Malaysia's progress toward achieving Sustainable Development Goal 7.

## Keywords

Distributed Renewable Generation, Microgrid, Micro Hydropower System, Rural Electrification

## 1. Introduction

The global power sector has shifted toward renewable-based and decentralized energy systems to address environmental concerns and climate change [1]. In 2023, renewable energy sources contributed about 30% of global electricity generation [2]. Renewable energy technologies, particularly solar, wind, and small-scale hydropower, play an important role in developing cleaner and more sustainable power systems. Their effective utilization reduces dependence on fossil fuels and supports long-term economic growth and energy security [3]. Despite these advancements, around 8% of the world's population, mainly in rural areas of Sub-Saharan Africa, South Asia, and Latin America, still lack access to electricity [4]. Expanding access to modern, reliable, and sustainable electricity, particularly for rural communities, is aligned with Sustainable Development Goal 7, which aims to ensure affordable and clean energy for all.

In Sarawak, one of Malaysia's largest states, about 42% of the population lives in rural areas [5]. Many of these rural settlements still rely on standalone diesel generators, which are costly to operate and provide limited operating hours. To accelerate rural electrification, Sarawak Energy Berhad introduced the Rural Electrification Scheme and the Rural Power Supply Scheme to extend the transmission line network to rural areas [6]. With this expanding infrastructure, grid-connected microgrid systems offer a practical solution for enhancing system reliability by integrating local renewable generation with the utility grid support [7].

Previous research on rural electrification has focused on either off-grid hybrid systems or simulation-based feasibility studies. Off-grid hybrid system investigations, such as [8] [9], have shown that renewable energy sources can meet rural energy demand. However, these systems operate independently with no connection to the utility grid. This limits their ability to maintain a continuous power supply during periods of low renewable availability. Simulation-based studies, including [10] [11], have provided valuable design insights. However, their findings remain unvalidated through experimental implementation. This leaves uncertainties regarding their practical operational behavior.

In contrast to previous studies, this work simulates and validates a grid-connected microgrid system designed to enhance rural electrification in Sarawak, Malaysia. The system is evaluated using HOMER Pro and validated using the Lucas-Nuelle Training System, providing a comprehensive assessment of its operational performance.

## 2. Materials and Methods

### 2.1. Overview

This study presents the simulation and experimental validation of a grid-connected microgrid designed for rural electrification in Sri Aman, Sarawak. The methodology consists of:

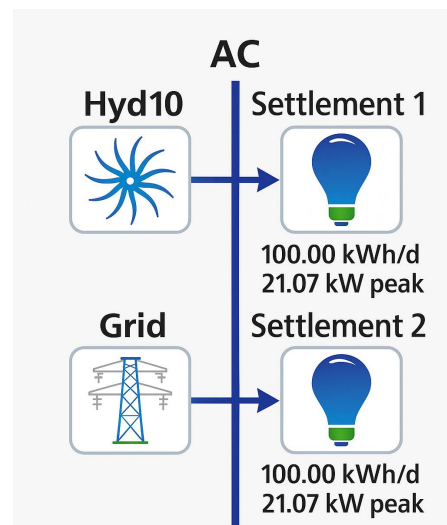
- 1) modeling and evaluating the microgrid performance using HOMER Pro;
- 2) testing its practical implementation using the Lucas-Nuelle Training System

with SCADA.

## 2.2. Microgrid System Model

**Figure 1** shows the proposed microgrid system for the rural settlements in Sri Aman, Sarawak. The system integrates a micro-hydro generator as the primary renewable energy source and the utility grid as a backup when hydro generation becomes insufficient. The microgrid is designed to serve two rural settlements, each with an estimated daily energy use of about 100 kWh and a peak demand of 21.07 kW.

The microgrid components are interconnected through a common AC bus. Under normal stream flow conditions, the micro-hydro generator supplies most of the demand, while the grid provides additional support during the months with low rainfall, when stream flow drops below the turbine's minimum operating requirement (approximately 150 L/s). This microgrid configuration ensures stable voltage and frequency within acceptable operating limits.



**Figure 1.** The proposed microgrid system for rural Sri Aman, Sarawak.

## 2.3. Input Data

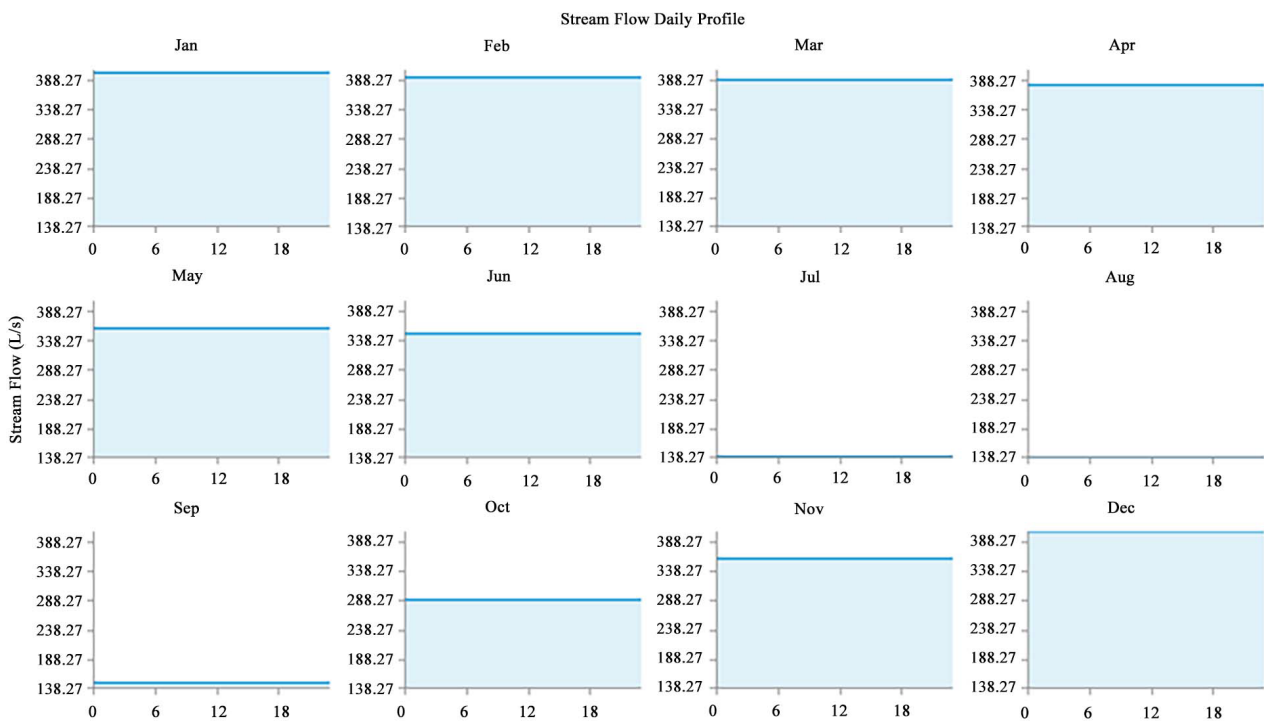
The simulation used two main input data: the stream flow and load profiles. These data represent the hydro resource availability and load demand of the rural area in Sri Aman, Sarawak.

**1) Stream flow data:** Monthly rainfall data for Sri Aman are obtained from [12], which provides historical precipitation statistics for Sarawak. These rainfall patterns are used to construct the stream flow profile applied in Homer Pro. As shown in **Figure 2**, the stream flow increases significantly during the months of heavy rainfall (October-June), providing sufficient water for continuous hydro generation. During the months of low rainfall (July-September), water availability decreases. This leads to a reduction in hydro output. In this case, grid support becomes necessary to maintain an uninterrupted power supply.

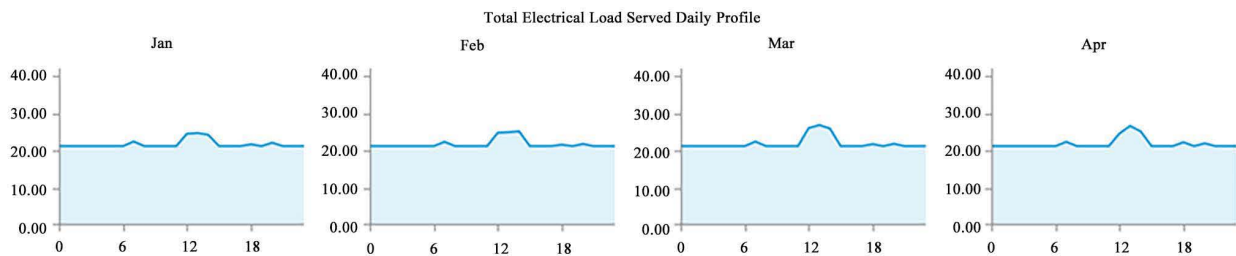
**2) Load data:** The daily load profile is based on estimated appliance usage in a typical longhouse settlement in Sri Aman (refer to **Table 1**). Each settlement of 40 households has a total daily energy demand of 95.6 kWh/day, which was rounded to 100 kWh/day for modeling in HOMER Pro. The corresponding daily load profile used in the simulation is presented in **Figure 3**.

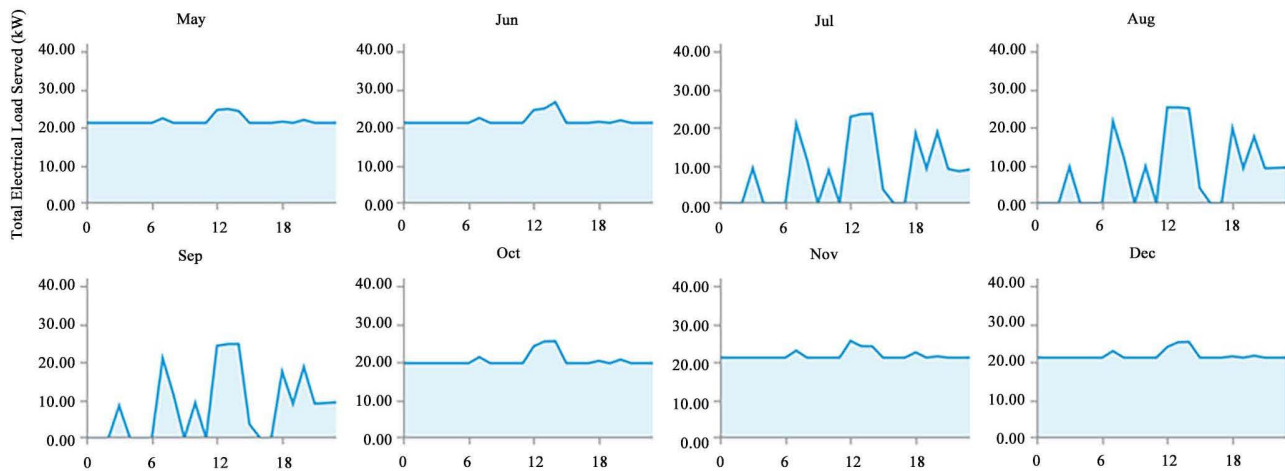
**Table 1.** Average household electrical appliance usage in rural areas.

Appliances	Units	Power (W)	Average usage (hours/day)	Energy per unit (kWh/day)	Total energy per house (kWh/day)
Fluorescent bulb	3	22	5	0.11	0.33
Refrigerator	1	120	8	0.96	0.96
Television	1	70	5	0.35	0.35
Fan	1	50	6	0.30	0.30
Water pump	1	150	3	0.45	0.45
<b>Total</b>	<b>7</b>	<b>412</b>	<b>-</b>	<b>2.17</b>	<b>2.39</b>



**Figure 2.** Daily stream flow profile for every month.





**Figure 3.** Daily load profile for every month.

## 2.4. Simulation Setup

HOMER Pro is used to simulate and evaluate the operational performance of the proposed grid-connected microgrid system. The simulation examines power balance, power dispatch, and system reliability under varying stream flow conditions representative of rural Sri Aman, Sarawak. A load-following dispatch strategy is applied, in which the micro-hydro generator supplies the base load while the utility grid provides support during periods of low stream flow. This approach promotes efficient use of renewable energy and a continuous power supply to the connected settlements. With a 20 m head, a design flow of 100 L/s, and an efficiency of 85%, the nominal turbine capacity is 16.7 kW. During high-flow periods, HOMER Pro allows up to 150% of the design flow, resulting in peak outputs of up to 21.3 kW.

The main simulation parameters are as follows:

- 1) Hydro turbine nominal capacity: 16.7 kW.
- 2) Design flow rate: 100 L/s (minimum or maximum flow ratio: 50% or 150%).
- 3) Available head: 20 m (pipe head losses: 15%).
- 4) Grid connection: 415 V, 50 Hz.
- 5) Hydro turbine efficiency: 85 %.
- 6) Simulation time step: 1 hour.

In addition to technical parameters, HOMER Pro requires economic parameters for a complete system model. A project lifetime of 25 years and a discount rate of 8% are applied to reflect typical financing conditions for rural electrification projects in Malaysia. Although economic assessment is not the primary focus of this study, these input parameters help ensure a realistic representation of the long-term system performance.

## 2.5. Experimental Setup

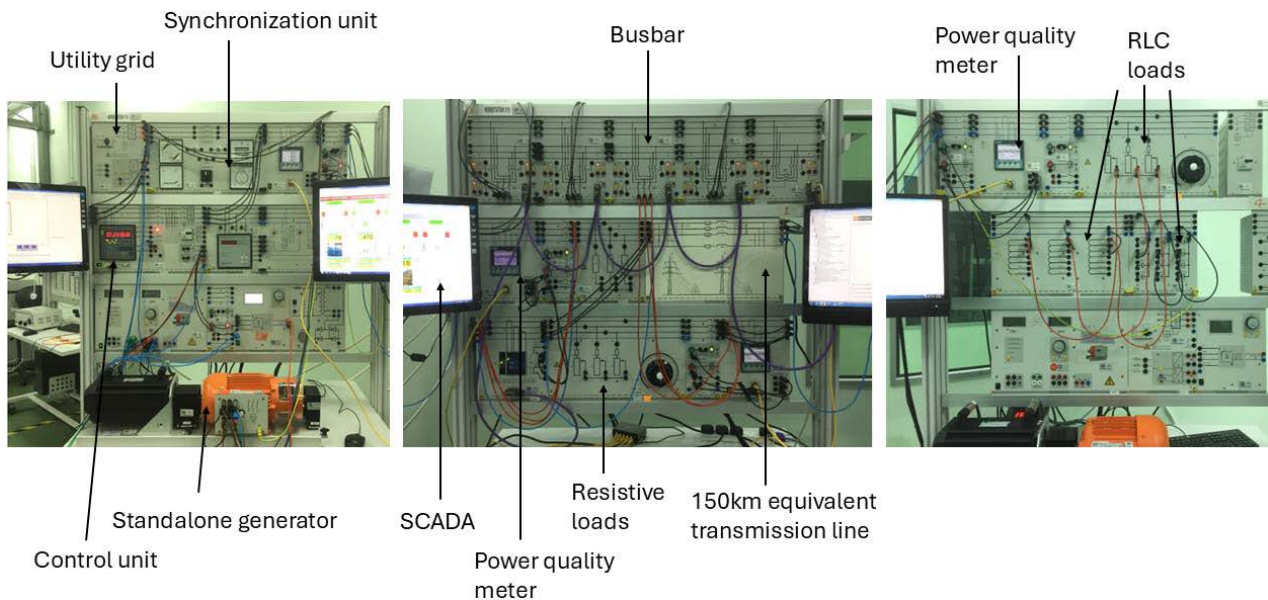
To validate the simulation model, an experimental setup is implemented using the Lucas-Nuelle Training System integrated with SCADA monitoring. The setup

replicates the grid-connected microgrid configuration modeled in HOMER Pro, allowing controlled testing under both hydro-dominant and grid-support operating modes. The experimental setup consists of a 1 kW standalone generator, which emulates a micro-hydro generator. This scaled-down generator is used to validate the control logic and power sharing behavior rather than to reproduce the full power performance of the actual microgrid system. A synchronization unit, a control unit for automatic synchronization, and a utility grid supply are connected via a 150 km equivalent transmission line. Power quality meters are installed at measurement points to record voltage, current, active/reactive power, power factor, and frequency. Two settlement loads represented by resistive and RLC (resistive, inductive, and capacitive) loads are connected to the common AC bus to simulate typical rural load demand. The SCADA interface continuously records real-time electrical parameters, including voltage, current, and power. The complete experimental setup is shown in **Figure 4**.

Two test conditions are performed:

- 1) Hydro-dominant operation.
- 2) Grid-support operation.

Data are captured via SCADA at one-second intervals for analysis in Chapter 3.



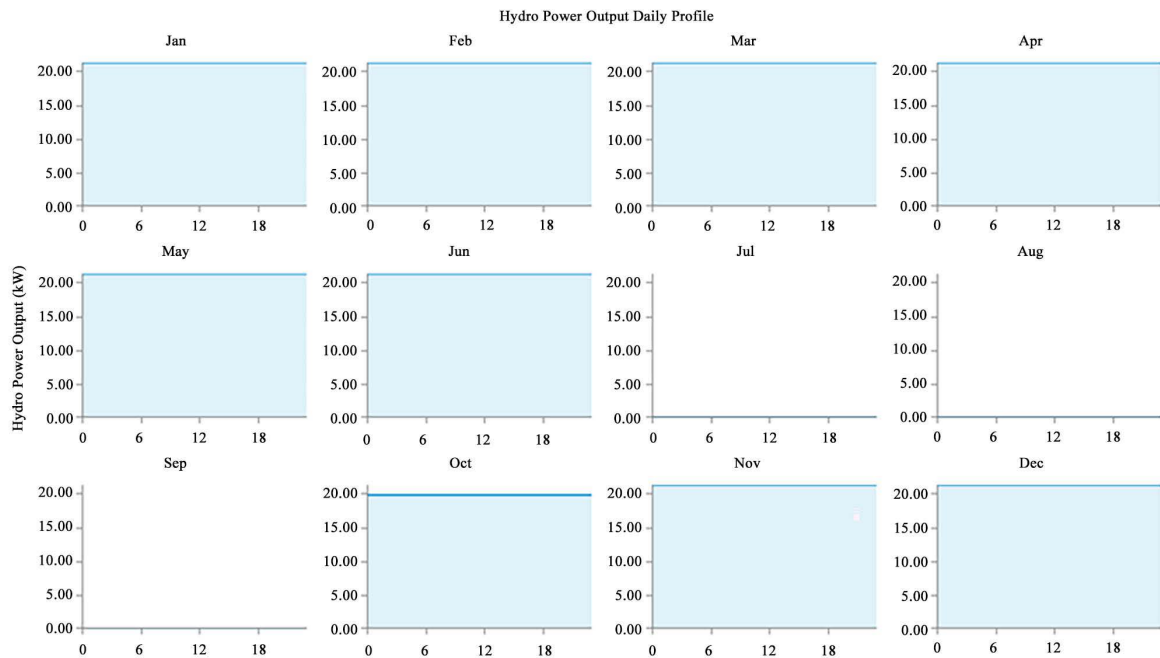
**Figure 4.** Experimental setup using Lucas-Nuelle Training System.

### 3. Results and Discussion

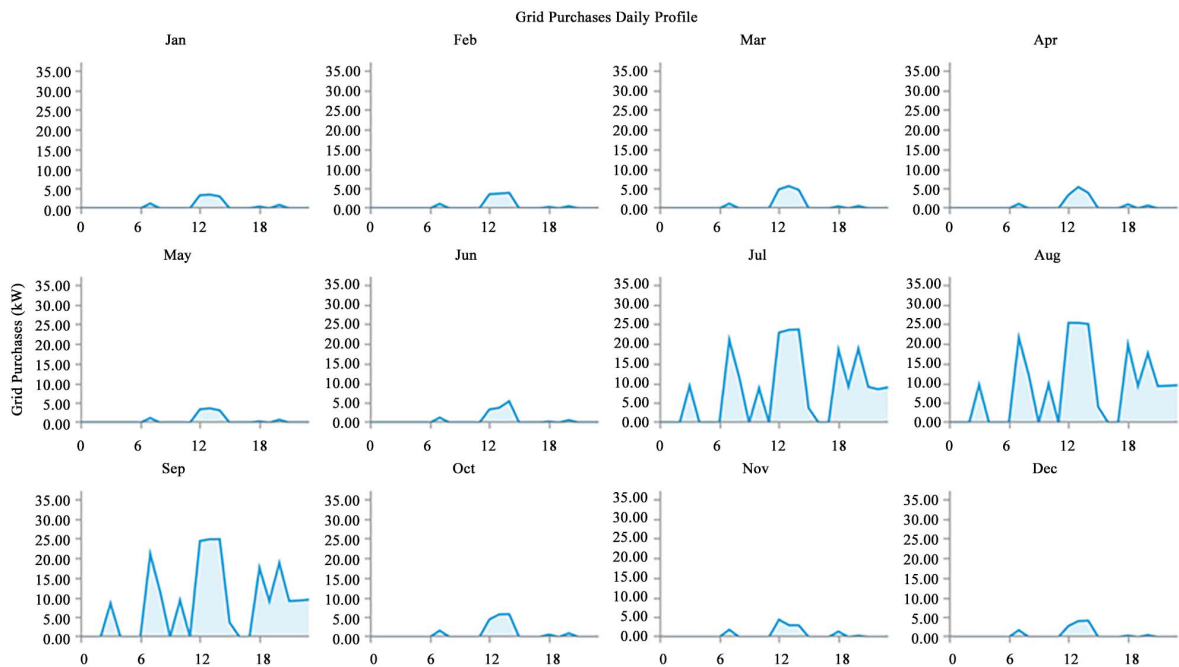
#### 3.1. Simulation Results Using HOMER Pro

**Figure 5** shows that during months with sufficient rainfall (January-June and October-December), the hydro generator supplied a steady output of 21.3 kW, meeting most of the load. The utility grid supplied the remaining portion of the demand. During the months of low rainfall (July-September), stream flow fall below the turbine's minimum operating requirements (approximately 150 L/s). This

causes the hydro generator output to drop to zero. As shown in **Figure 6**, the system automatically shifted to the utility grid, which supplied up to 25 kW during peak hours to maintain power balance and ensure an uninterrupted power supply to the two settlements. Overall, the simulation confirms that the grid effectively supports the micro-hydro system during low rainfall periods, ensuring reliable power delivery throughout the year.



**Figure 5.** Daily hydro generator output for every month.



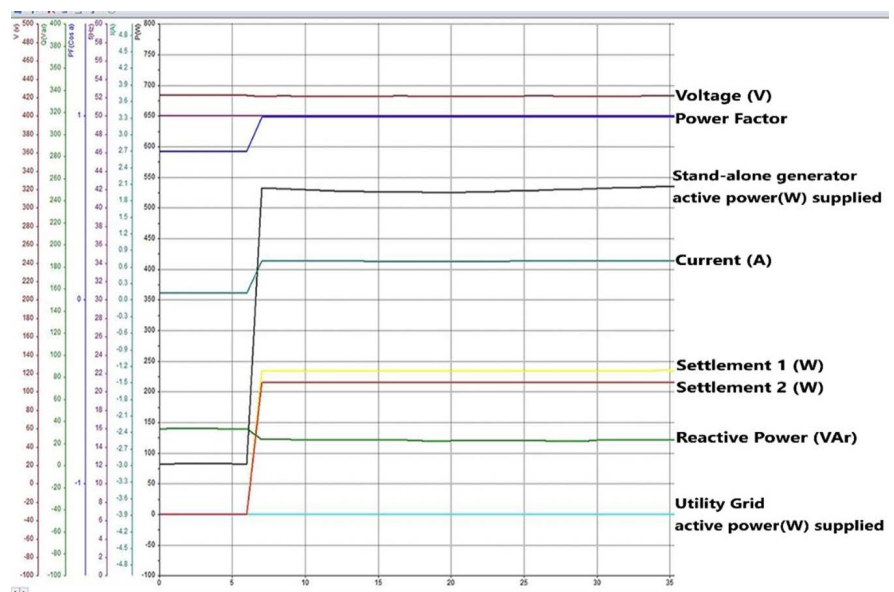
**Figure 6.** Daily grid supply for every month.

### 3.2. Experimental Validation Using Lucas Nuelle Training System

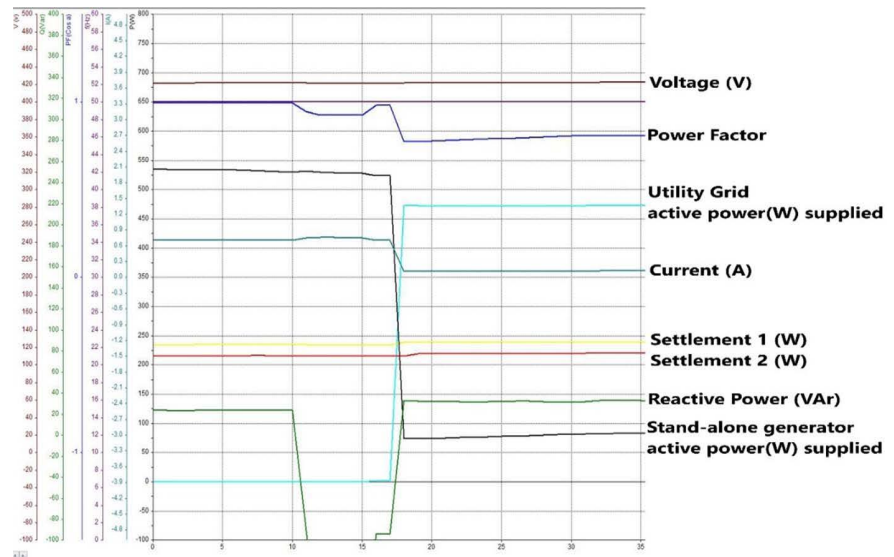
The Lucas-Nuelle Training System is used to replicate the microgrid operation under both hydro-dominant (normal stream flow) and grid-support (low stream flow) conditions. As shown in **Figure 7**, under normal stream flow conditions, the standalone generator supplied both settlement loads (235 W and 216 W), scaled from the simulation data to the microgrid model in HOMER Pro. The generator current increased proportionally with the load, while the utility grid delivered no active power. Throughout the test, the system voltage remained stable, and the power factor was close to 1.0, indicating efficient power delivery with minimal reactive power involvement.

Under low stream flow conditions, illustrated in **Figure 8**, the generator output decreased while the utility grid increased its active power contribution to maintain a constant supply to the settlement loads. During this automatic power redistribution, the generator current dropped while the grid current rose, demonstrating effective power-sharing coordination between the two sources. The transition between hydro and grid supply occurred smoothly, with voltage remaining stable, and the power factor decreasing slightly to 0.85 - 0.90. This reduction in power factor indicates an increase in reactive power demand, which in real-world deployment would require appropriate reactive compensation, such as capacitor banks, to maintain voltage stability and minimize distribution losses. This behavior is consistent with grid-support operation in microgrid environments.

These experimental results validate the control strategy of the Lucas-Nuelle Training System and confirm the load-following behavior observed in the HOMER Pro. Overall, the grid functions as a reliable backup source during periods of insufficient hydro generation, ensuring continuous service and operational stability for rural electrification.



**Figure 7.** SCADA logger during hydro-dominant operation.



**Figure 8.** SCADA logger during grid-support operation.

## 4. Conclusion

This study presents the simulation and experimental validation of a grid-connected microgrid system for rural electrification in Sri Aman, Sarawak. The results show that the proposed system can operate under varying resource conditions, with the micro-hydro generator supplying the base load power and the utility grid maintaining continuous power during periods of low stream flow. Experimental testing further validates the load-following behavior observed in the simulation, confirming stable voltage, effective power dispatch, and smooth transitions between hydro and grid operation. Overall, the study provides a validated approach for implementing grid-connected microgrids in rural Malaysia, supporting national energy sustainability initiatives and contributing toward the achievement of Sustainable Development Goal 7. Future work will extend this analysis to include additional renewable energy technologies, such as solar PV and battery storage, to support the development of larger and more resilient rural microgrid systems.

## Acknowledgements

Authors would like to thank Centre of Research and Innovation Management (CRIM), Universiti Teknikal Malaysia Melaka for the continuous support of this research project.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

- [1] Yassim, H.M., Abdullah, M.N., Gan, C.K. and Ahmed, A. (2024) A Review of Hierarchical Energy Management System in Networked Microgrids for Optimal Inter-Mi-

- crogrid Power Exchange. *Electric Power Systems Research*, **231**, Article ID: 110329. <https://doi.org/10.1016/j.epsr.2024.110329>
- [2] IEA, “Renewables—Energy System”. <https://www.iea.org/energy-system/renewables>
- [3] Wang, S. and Tian, G. (2025) Does Renewable Energy Consumption Reduce the Energy Security Risk? *Energy*, **320**, Article ID: 135182. <https://doi.org/10.1016/j.energy.2025.135182>
- [4] World Bank Group (2025) Energy Access Has Improved, Yet International Financial Support Still Needed to Boost Progress and Address Disparities. <https://www.worldbank.org/en/news/press-release/2025/06/25/energy-access-has-improved-yet-international-financial-support-still-needed-to-boost-progress-and-address-disparities>
- [5] Khengwee, T., *et al.* (2017) A Review of Sarawak Off-Grid Renewable Energy Potential and Challenges. *Journal of Telecommunication, Electronic and Computer Engineering*, **9**, 29-33.
- [6] Rural Electrification—Sarawak Energy. <https://www.sarawakenergy.com/what-we-do/rural-electrification>
- [7] Shahbazitabar, M., Abdi, H., Nourianfar, H., Anvari-Moghaddam, A., Mohammadi-Ivatloo, B. and Hatziargyriou, N. (2021) An Introduction to Microgrids, Concepts, Definition, and Classifications. In: Anvari-Moghaddam, A., *et al.*, Eds., *Power Systems*, Springer International Publishing, 3-16. [https://doi.org/10.1007/978-3-030-59750-4\\_1](https://doi.org/10.1007/978-3-030-59750-4_1)
- [8] Chong, S.E., Gan, C.K., Chin, A.S.Y., Ajan, C.W., Bealt, J., Shaw, D., *et al.* (2020). Electricity Consumption of Remote Villages in Sarawak Powered by Off-Grid Solar System. 2020 *International Conference on Smart Grids and Energy Systems (SGES)*, Perth, 23-26 November 2020, 633-638. <https://doi.org/10.1109/sges51519.2020.00118>
- [9] Oladigbolu, J.O., Ramli, M.A.M. and Al-Turki, Y.A. (2020) Feasibility Study and Comparative Analysis of Hybrid Renewable Power System for Off-Grid Rural Electrification in a Typical Remote Village Located in Nigeria. *IEEE Access*, **8**, 171643-171663. <https://doi.org/10.1109/access.2020.3024676>
- [10] Esan, A.B., Oghorada, O. and Agbetuyi, A.F. (2020) Conceptual Model Framework for Demand Response Ancillary Services Deployed by Inter-Connected Microgrids in West Africa—A Nigerian Case Study. *Renewable Energy Focus*, **34**, 47-56. <https://doi.org/10.1016/j.ref.2020.06.002>
- [11] Phurailatpam, C., Rajpurohit, B.S. and Wang, L. (2018) Planning and Optimization of Autonomous DC Microgrids for Rural and Urban Applications in India. *Renewable and Sustainable Energy Reviews*, **82**, 194-204. <https://doi.org/10.1016/j.rser.2017.09.022>
- [12] Climate: Sarawak in Malaysia. <https://www.worlddata.info/asia/malaysia/climate-sarawak.php>