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UNIVERSITI TEKNOLOGI MARA

ISETC2025

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THE POWER OF SCIENTIFIC INNOVATION

INTELLIGENT SOLUTIONS FOR A SUSTAINABLE WORLD

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PREFACE

Welcome to the 2nd International Science, Engineering and Technology Colloquium 2025 (ISETC 2025)!

It is with great pleasure that we present this year's colloquium, a distinguished gathering of scholars, researchers, and professionals dedicated to the advancement of applied sciences. Held virtually on 9th July 2025, ISETC 2025 serves as a platform to highlight cutting-edge research, foster meaningful networking, encourage collaborations, and explore innovative solutions to global challenges.

This year's theme, "The Power of Scientific Innovation: Intelligent Solutions for a Sustainable World" highlights our shared goal to solve global challenges through applied science. It celebrates innovation as a key to building a more sustainable and resilient future. We're proud to feature keynote speakers and presenters who bring fresh insights, bold ideas, and breakthroughs shaping tomorrow's world.

We would like to extend our heartfelt appreciation to the Faculty of Applied Sciences, Universiti Teknologi MARA, Perak Branch, Tapah Campus, for their outstanding support and assistance throughout the planning and execution of the event. Their dedication has been instrumental to the success of this colloquium. We would like to sincerely thank all participants and researchers for their valuable contributions. We also appreciate the reviewers for their careful evaluations and helpful feedback. Your hard work and support mean a lot to us.

As editors, we are proud to present this collection of proceedings. It is an honour to bring together the interesting and meaningful work of our speakers and authors. We hope the ideas shared will lead to new discoveries, encourage more research, and help solve global challenges through science and innovation.

Warm regards,

Dr. Emi Norzehan Mohamad Mahbob
Dr. Saiyidah Nafisah Hashim
Ms. Lili Widarti Zainuddin
Ms. Nurul Nazwa Mohammad
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ISETC 2025 Proceedings Editors

ANALYSIS OF SERIES-PARALLEL AND PARALLEL CONFIGURATIONS FOR CUSTOMISED SOLAR PANELS

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Abstract: This research analysed the impact of solar radiation on the electrical output of two solar panel configurations: parallel and series-parallel. The performance ratio (PR) was calculated to assess the system's performance under this weather condition. Both configurations employed identical solar panels (rated at 3 W each), with the parallel array consisting of eight modules and the series-parallel arrangement set up as four parallel strings of two series-connected panels. Time-series data were collected for each configuration over a full day of operation, capturing solar irradiance, ambient temperature, and electrical parameters (current, voltage, and power). As solar irradiance increased, the current and power of the panels increased. PR revealed significant insights into system performance. The series-parallel configuration exhibited a higher average PR of 29% compared to the parallel setup of 8.3%, indicating better alignment with the system load or operational conditions. This study demonstrates that real-time monitoring of PR provides critical insights into the operational health and fault detection of standalone PV systems.

Keywords: *Performance ratio, PV monitoring, parallel, series, solar irradiance, temperature*

INTRODUCTION

Due to the rise in global energy consumption, rising populations, and depletion of non-renewable resources, renewable energy has emerged as a significant alternative to fossil fuels. Due to its practically limitless supply, scalability, environmental friendliness, and affordability, solar energy, in particular, is a great option to provide and fulfill the growing energy demand. Off-grid PV systems are especially beneficial for providing electricity to remote areas when this option is more cost-effective than extending the electricity grid. These systems use solar panels to generate electricity on a smaller scale and store it in batteries.

Off-grid PV systems, also known as standalone systems, electricity generating systems (SEGS), require proper monitoring and regular self-checks to ensure optimal performance. The amount of electricity generated by the system depends on various factors, including solar radiation, temperature, shading, dirt, and the tilt angle and orientation of the modules (Hussin et al., 2010; Kaplanis & Kaplani, 2011). These factors can degrade the performance of the PV modules over time and affect the investment in the system. Moreover, these factors that degrade the performance of PV systems can cause faults that lead to high energy loss, accelerated degradation of system components, reduced system efficiency, and safety risks (Maghami et al., 2015). Besides that, the arrangement of solar panels also plays a crucial role in generating the desired power and can reduce power loss due to certain faults. The configuration of PV panels, such as series, parallel, or series-parallel, has a significant influence on system performance. In series arrangements, voltage increases, but current is limited by the weakest panel, making them highly sensitive to partial shading. Parallel connections allow current to add up while maintaining constant voltage, offering better shading tolerance but requiring thicker cables. Series-parallel configurations combine both topologies, balancing voltage and current output. The choice of configuration affects not only power output but also system cost, reliability, and response to faults. Selecting the optimal arrangement requires considering site-specific factors, such as irradiance, shading, and load profile.

Performance Ratio (PR) is a crucial metric for assessing the efficiency and health of a PV system. It represents the proportion of actual output to the theoretical production under optimal conditions (Reich et al., 2012). PR is generally expressed as a percentage. A well-functioning PV plant typically achieves a PR of around 80% under standard conditions. Values that fall significantly below this benchmark may indicate faults or losses in the system. In practice, achieving a 100% PR is impossible due to inherent losses, such as those from module heating and wiring. Highperforming systems usually reach a maximum PR of 80% to 90% (Kim et al., 2021). PR may temporarily exceed 100% on rare occasions due to underreported irradiance measurements or exceptional scenarios, such as cloud edge effects. However, these instances are rare and typically brief. This research paper aims to evaluate the influence of solar irradiance on the electrical output of the two configurations, thereby determining their performance ratio based on this factor.

MATERIALS AND METHODS

The methodology of this research project involves conducting field tests of the flipped bookcase solar panel using the developed PV monitoring systems, as shown in Figure 1. The detailed specifications of the flipped bookcase solar panel are outlined in Table 1. Each side of the flipped bookcase features eight solar panels, allowing for adjustable series and parallel connections. The customised PV monitoring and data acquisition (DAQ) system utilises an Arduino MEGA as the control unit responsible for data storage, information display, and data transfer. The board includes essential sensors, such as current, voltage, ambient temperature, and humidity, which are critical for monitoring and interpreting the electrical data generated by the solar panels. The PV monitoring system is housed in a small black box with two wire connections: one from the solar panel and another to the load.

Figure 1. a) Customised flipped bookcase solar panels with b) PV monitoring system

In this analysis, two PV array configurations of equal rated power, 24 W peak at 1000 W/m² irradiance, were examined:

1. Parallel (8P): 8 modules in parallel (V_{tot} = 9 V, I_{tot} = 2.64 A).
2. Series-Parallel (2S × 4P): 4 strings in parallel, each with two series modules (V_{tot} = 18 V, I_{tot} = 1.32 A).

Table 1. Electrical characteristics data of the Reference PV module

Symbol	Name	Value
I_{sc}	Short circuit current (A)	0.36
V_{oc}	Open circuit voltage (V)	10.8
I_{max}	Current at max power (A)	0.33
V_{max}	Voltage at max power (V)	9
P_{max}	Rated power (W)	3

The data were collected based on time-series data from two specific days: February 22, 2025, for the parallel configuration, and February 23, 2025, for the series-parallel configuration. Each dataset provides one-day profiles of panel output and environmental conditions. Key variables such as panel current (A), voltage (V), power (W), ambient temperature (°C), and humidity were recorded using the customised PV monitoring; meanwhile, the solar radiation (irradiance, W/m²) was captured using the pyranometer. No fault is introduced in these data as they represent normal operation for each configuration. Based on these data set configurations, the performance ratio (PR) was computed at each timestamp. The formula is provided as (Astriani et al., 2021):

$$PR = \frac{Actual\ power\ output}{Irradiance \times Area \times Efficiency\ factor} \tag{1}$$

Eq. (1) is simplified using the rated array power as a reference without considering the panel area and efficiency factor information. The 24 W-rated power is adjusted to increase linearly with irradiance by assuming that 24 W is generated at 1000 W/m^2.

$$PR = \frac{Actual\ power}{Reference\ power} = \frac{Actual\ power}{24\ W \times \left(\frac{Irradiance}{1000\ W/m^2}\right)} \tag{2}$$

Therefore, this calculation adjusts performance based on different sunlight levels. A PR close to 1.0 indicates that the system produces 100% output. In contrast, a PR of 0.5 suggests it only delivers 50% of the expected power for the available sunlight, thereby indicating losses or faults.

RESULTS AND DISCUSSION

This report investigates two configurations of solar panels: panels connected only in parallel and panels with a series-parallel arrangement. The aim is to evaluate how solar irradiance influences the electrical output of the two configurations and, hence, determine their PR based on this environmental factor.

The effect of solar radiation on the generated current is very significant. For both configurations, the current from the panel rises almost proportionally as irradiance increases from morning to midday. Since solar radiation drives the photocurrent in the cells, higher irradiance results in a higher short-circuit current (Wail Hessen et al., 2021). In both configurations, the current increases in the morning alongside the rising intensity of sunlight. This demonstrates the positive correlation between irradiance and current output. Since power is the product of voltage and current, higher irradiance also boosts power output. Ideally, maximum power is achieved near peak irradiance with proper load matching. The 2S-4P recorded a maximum power of 5.2 W, slightly higher than the 4.4 W for 8P. However, day-to-day variations such as sun angle and cloud cover likely account for this difference rather than wiring issues. The total energy output for 8P was roughly estimated at 18 Wh, while for 2S-4P, it was around 20 Wh, assuming 6-7 hours of generation, averaging a few watts. Figure 2 illustrates the time-series of solar irradiance and output power for both configurations.

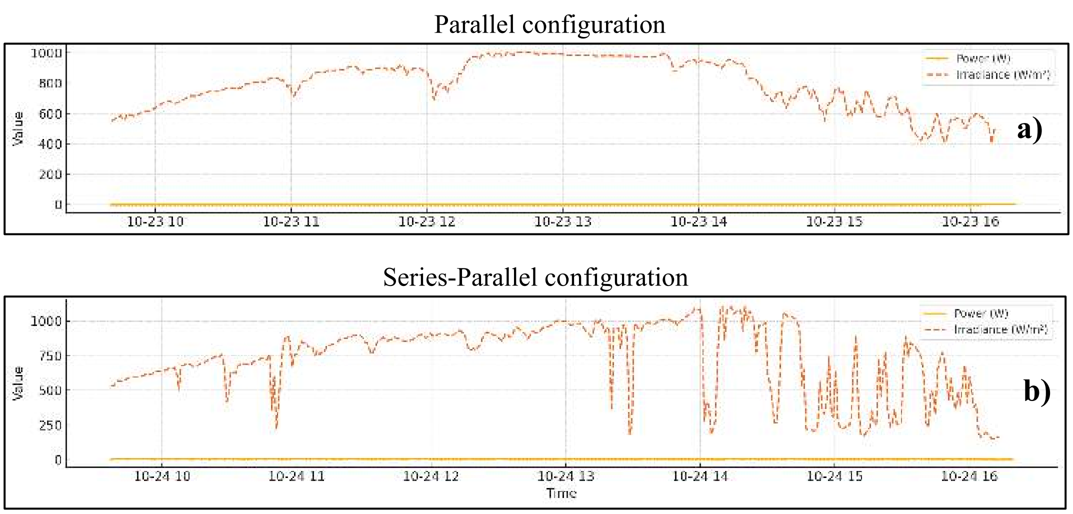

Figure 2. Time-series solar irradiance and output power plots for a) Parallel and b) Series-Parallel configurations

Under normal conditions, the overall energy performance of the two configurations was quite similar. The 2S-4P connection delivered the same power output as the 8P setup for the same irradiance levels. However, in terms of system design, the higher voltage of series strings might be preferable for reducing cable losses or fitting the MPPT input range. In contrast, the parallel setup's higher current requires thicker wiring and a combiner but maintains a lower voltage for safety. From a fault tolerance perspective, one advantage of a fully parallel setup is that if one panel or string fails, the others can continue to operate unaffected. In an 8P system, losing one panel (3 W) ideally only cuts the total power by 12.5%. In comparison, in a 2S-4P system, if one panel in a series string fails or is heavily shaded, the entire string (6 W) may be lost unless bypass diodes mitigate it, resulting in a 25% loss of array power. Therefore, a parallel configuration is expected to be more resilient to partial faults, such as a single module failure or shading on one panel, than a series-parallel connection.

Using eq. (2), PR was calculated and plotted for each configuration. Both days exhibited high irradiance, peaking at 1000–1100 W/m², providing a clear view of performance under intense sunlight. The PR curves for both configurations are shown in Figure 3. The series-parallel array (2S-4P) consistently achieved a higher fraction of its rated output than the parallel array under the same conditions, that is, approximately 3 to 4 times higher PR in the morning and early afternoon. This improvement may be attributed to better voltage matching with the load, as the 2S strings produce 18 V, whereas the 8P array at 9 V may have been operating off its MPP. Therefore, during standard (non-fault) periods, the series-parallel wiring delivered more power relative to its potential.

Both systems operated significantly below the typical 80% PR benchmark for most of the day. The parallel 8P array averaged only 8–10% PR, while the series-parallel array averaged 29–30% PR over these two days. The actual output ranged from only 0.08 to 0.30 of the ideal. These values are strikingly low compared to a healthy PV system. For reference, new PV plants typically achieve a PR of around 78–80% in real-world conditions. The consistently low PR here suggests substantial performance issues or inherent limitations in the setup, likely due to improper load management. Table 2 displays the PR values for each configuration.

Table 2. Summary of PR statistics for each configuration

Configuration	PR mean	PR maximum	PR minimum
8P	8.3 %	33.9%	5.3%
2S-4P	29%	127%	77%

CONCLUSIONS

Under normal conditions, both wiring configurations yield similar performance when properly configured. The parallel-only arrangement operates at a lower voltage and higher current, while the series-parallel arrangement doubles the voltage and halves the current for the same irradiance. PR values are expected to range from 70% to 80% in a healthy solar panel operation. However, based on the analysis of the daily PR curves for both configurations, the PR was below the healthy range, which probably because of the improper load matching.

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Sekian, terima kasih.

Setuju.

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