Aviation Electronics, Information Technology, Telecommunications, Electricals, and Controls (AVITEC)
Vol. 8, No. 1, February 2026, pp. 215-223, p-ISSN 2685-2381, e-ISSN 2715-2626
http://dx.doi.org/10.28989/avitec.v8i1.3810

Research Article

Performance Comparison of Pure and Modified Sine Wave Inverters in an Off-Grid PV System

Nelly Safitri[1]*, Rudi Syahputra[2], Supri Hardi[3], Saifuddin Muhammad Jalil[4]
[1,2,3]Electrical Engineering Department, Politeknik Negeri Lhokseumawe, Indonesia
[4]Industrial Engineering Department, Faculty of Engineering, Universitas Malikussaleh, Indonesia

Article Info

Article history:
Submitted January 14, 2026
Accepted February 20, 2026
Published February 21, 2026

Keywords:
Inverter performance;
photovoltaic;
Pure Sine Wave (PSW) inverter;
Modified Sine Wave (MSW) inverter;
solar power plant.

ABSTRACT

This study evaluates the performance of Pure Sine Wave (PSW) and Modified Sine Wave (MSW) inverters within small-scale off-grid solar power generation systems. The assessment was conducted utilizing a 160 Wp monocrystalline solar panel, a 10 A solar charge controller (SCC), a 12.8 V–100 Ah lithium iron phosphate ($LiFePO_4$) battery, along with both 500 W PSW and MSW inverters, across varying panel tilt angles ranging from 45°-165°. The findings indicated that the PSW inverter delivered a more consistent output voltage between 221 and 222 V, exhibiting minimal fluctuation of ±1 V and low harmonic distortion at 2.5%. The MSW inverter produced an output voltage between 222 and 225.5 V, characterized by greater variability and higher harmonic distortion under both light and heavy load conditions. The analysis of the solar photovoltaic (PV) system provides critical insights into the performance differences between the two inverter types. Notably, the results related to tilt angle are not merely supplementary; they serve as indicators of varying irradiance conditions, enabling a more comprehensive evaluation of inverter performance concerning fluctuations in input power levels. Both PSW and MSW inverters achieved an efficiency rating of 85%, ensuring stable and smooth outputs. However, with regard to long-term reliability, the PSW inverter significantly surpasses its counterpart, rendering it a more appropriate choice for permanent solar PV installations. As the results, the PSW inverter is particularly suited for sensitive loads that demand high power quality, while the MSW inverter remains viable for less demanding applications when the cost is considered.

Check for updates
CC BY

Corresponding Author:
Nelly Safitri,
Electrical Engineering Department, Politeknik Negeri Lhokseumawe, Aceh, Indonesia.
Email: *nellysafitri@pnl.ac.id

1. INTRODUCTION

A solar power plant is an electrical energy generation system that utilizes solar energy absorption in solar panels and converts it into electrical energy using the photoelectric effect. PLTS is an environmentally friendly technology. The benefits of a solar power plant include being a form of environmentally friendly renewable energy. Indonesia has a tropical climate with abundant sunshine throughout the year, making solar power plant technology particularly suitable for generating electricity in the country. Additionally, a solar power plant can be installed in various locations, including homes, buildings, and industrial sites [1]. However, it should be noted that the initial cost of installing a solar power plant can be quite expensive [2][3]. Nevertheless, the use of solar energy is expected to help overcome the energy crisis and reduce the impact of global warming. One important component in a solar power plant is an inverter. The inverter is used to convert direct current (DC) from the battery into alternating current (AC) for household appliances. The main choices of inverters that are the focus of this research are Pure Sine Wave (PSW) inverters and Modified Sine Wave (MSW) inverters.

It is commonly known that an inverter is an essential device that converts DC electricity into AC electricity, enabling the use of standard electrical equipment and appliances that rely on AC power. Inverters come in various types, including PSW and MSW inverters. Several studies have been conducted to address the performance of inverters, including their advantages, drawbacks, and implementations. A PSW inverter produces a clean, smooth, and continuous waveform that closely resembles a pure sine wave, which is the ideal form of AC power from the grid. This type of inverter is commonly used in applications that require high-quality power, such as medical equipment, audio and video equipment, and precision instruments [4]. An MSW inverter produces a "choppy" or stepped waveform that approximates a sine wave but contains significant harmonic distortion. In other words, the MSW inverter has a waveform that mimics a stepped, square-like pattern. Unlike a PSW inverter, an MSW is more affordable and simpler, making it popular in various applications. It is especially useful for powering basic appliances, tools, and electronics that do not require ultra-clean power signals. As technology advances and the demand for portable, reliable power sources grows, modified sine wave inverters are becoming increasingly prevalent across different sectors [5].

One of the most studied issues of that type of inverters is the total harmonic distortion (THD). THD is an important issue related to energy quality caused by nonlinear loads and switching actions in electronic devices, especially in renewable energy systems [6][7]. To ensure that the grid meets standards and operates effectively, various strategies have been developed to reduce this problem [8][9][10]. The THD mitigation techniques that have been deployed in those references are active power filter (APF) [11], passive power filter (PPF) [12], hybrid filters, multilevel inverters, and superior control strategies together with pulse width modulation (PWM) [13], fuzzy logic [14], and AI-based management [15].

This research is a modification of a solar power plant model that has been developed in previous research using an off-grid configuration, with a monocrystalline solar panel capacity of 150 Wp, equipped with a 10A solar charger controller (SCC), a 12V-100Ah Lithium-ion battery, and a 300W pulse width modulation (PWM) inverter [16] [17] [18]. The results of the development of this designed solar panel model are the electrical parameters of the output voltage of the solar panel module, battery, and inverter, expects they should, with the output voltage values of the solar panel, battery, and inverter approaching the voltage listed on the nameplate of each component. The modification to be applied is the replacement of the inverter component with a larger capacity, specifically 500W, utilizing two types of inverters: PSW and MSW. To highlight the differences and advantages of these inverters, the switching-mode principle is employed, allowing for a comparison of the output quality and reliability parameters of the PSW and MSW inverter systems.

Although there is a substantial amount of literature concerning inverter technologies, the majority of earlier research has predominantly concentrated on harmonic mitigation methods, sophisticated control mechanisms, and grid-connected PV systems. While theoretical comparisons have been made between PSW and MSW inverters with respect to their waveform attributes and harmonic distortion, there exists a scarcity of empirical studies that assess their actual performance in small-scale off-grid PV systems under diverse operational scenarios. Notably, many prior investigations have prioritized THD reduction through advanced filtering techniques, multilevel architectures, or artificial intelligence-driven controls without systematically evaluating the real-world performance of commercially available PSW and MSW inverters under uniform environmental and load conditions. This gap is crucial because off-grid PV systems are extensively utilized in remote and rural regions where simplicity, cost-effectiveness, and reliability are paramount. Consequently, end users and designers of small-scale systems often choose between PSW and MSW inverters primarily on cost rather than empirical performance data from realistic outdoor settings. In the absence of controlled experimental comparisons, it becomes challenging to quantify variations in voltage stability, efficiency, energy output, and operational reliability—factors that significantly influence appliance longevity and system sustainability. The investigation aims to experimentally analyze and compare the electrical performance metrics, including voltage stability, energy generation capacity, and efficiency of PSW versus MSW inverters within a straightforward off-grid PV framework. This research also enhances the empirical basis for selecting inverters for off-grid photovoltaic applications by bridging the divide between theoretical waveform analysis and practical system performance assessment, thereby facilitating more informed technical and economic decision-making regarding renewable energy implementation.

The structure of this article is as follows: Section Introduction discusses the off-grid solar power plant that has been developed in the previous study using two types of inverters. Section Research Methods discusses the components of the developed solar power plant and the standard used to overcome THD. However, THD not yet become the focus of the current study. Section Results and Discussion show the data gained from the measurement outdoors. Finally, the section Conclusion summarizes all the information.

2. RESEARCH METHODS

2.1 Solar Power Plant Configuration

The developed simple solar power plant is an off-grid configuration that has mentioned previously, changed only for the inverter part. In this study, we used both 500-watt PSW and MSW inverters. The components, such as a solar panel, battery, and solar charger controller (SCC), are detailed in the following Table 1, whereas the solar panel has several considerations, namely,

- Output in Amps: a 160Wp panel can produce around 8.89 amps at peak performance (160W/~18V). When paired with an SCC, the expected generated current is around 53 amps per day in optimal summer conditions.

- Application: this panel is often used in 12V or 24V systems for off-grid applications such as RVs, caravans, motorhomes, and boats.
- Performance: the performance is measured under standard test conditions (STC: 1000 W/m² irradiance, 25°C cell temperature). Actual output in the field will vary with sunlight intensity, temperature, and shading.

Table 1. Solar panel specification

Feature	**Approximate Range**
Dimensions	Varies significantly. Common ranges: 1.2m to 1.6m (length) x 0.6m to 0.8m (width) x 35mm (depth)
Weight	8.6 kg to 16 kg (depending on frame/flexibility)
Frame	Anodized aluminium alloy (for rigid panels)
Front Glass/Surface	High-transparency tempered glass or ETFE (for marine/flexible panels)
Junction Box	IP65, IP67, or IP68 rated, with bypass diodes
Connectors	MC4 style connectors

The battery in use is the lithium-ion battery, namely the Lithium Iron Phosphate ($LiFePO_4$) [18]. This battery supplies around 1280Wh of energy, has a nominal voltage of about 12.8V, and can last for 4000 to over 6000 cycles even with high Depth of Discharge (DOD). It comes equipped with a sophisticated Battery Management System (BMS) that safeguards against overcharging, overdischarging, overcurrent, and temperature-related issues. It weighs around 10-12kg and has an IP65 rating. This battery has several advantages, namely, longer life, which is 5-10 times the cycle life of lead-acid, much lighter for the same usable energy. It also has high efficiency, which can be proved by its excellent charge/discharge efficiency and minimal self-discharge. In advanced, no watering or acid concerns. The ideal uses for this battery are in RVs and campervans, solar energy storage, marine applications, and off-grid cabins. The key features of the battery can be seen in Table 2.

Table 2. $LiFePO_4$ battery specification

Key Specifications	Approximate Range
Nominal voltage	12.8V (often described as 12V)
Capacity	100Ah (Amp-hours)
Energy	~1280Wh (watt-hours)
Cycle Life	4000-6000+ cycles (at 0.2C, 80% DOD)
Weight	~10-12 kg (significantly lighter than lead-acid)
Dimensions	Varies by brand (e.g., ~330x175x220mm for Group 31 size).
IP Rating	Typically, IP65 (dust & splash resistant).

2.2 PSW Inverter

PSW inverter creates a smooth, steady wave that is very similar to or even better than the power from the utility grid. The THD levels are usually below 3-5%, with some high-end models reaching as low as 1.5%. This low level of harmonics helps decrease heat in motors and avoids interference with delicate electronics such as medical devices, audio equipment, and laptops [19]. In a PSW inverter, the voltage rises and falls smoothly with a smoothly changing phase angle, and also changes its polarity instantly when it crosses 0 volts. Table 3 lists the PSW inverter specification.

Table 3. PSW inverter specification

Feature	**Specification**
Rated Power	500 watts
Peak Power	1000 watts
Output Waveform	Pure Sine Wave
Input voltage	DC 12V (range 9V–16V)
Output voltage	AC 220V / 230V
Output Frequency	50Hz
Max Conversion Efficiency	94%
USB Output	2x 5V, 1000mA
Cooling	Smart fan (automatic start at high temperature/load)

2.3 MSW Inverter

An MSW inverter works well with common electronics such as TVs, laptops, phone chargers, and lights. However, it's not a good choice for sensitive devices, items with AC motors, or some medical equipment because the waveform might harm them or cause them to work poorly. It's best for use in cars, during camping trips, or as a backup power source for low-wattage appliances during power outages. For optimal performance and longevity, deep-cycle batteries are suggested instead of regular vehicle starting batteries. In an MSW inverter, the voltage rises and falls abruptly, the phase angle also changes abruptly, and it sits at 0 volts for some time before changing its polarity. Thus, any device that uses a control circuitry that senses the phase (for voltage/speed control) or instantaneous zero voltage crossing (for timing control) will not work properly from a voltage that has a modified sine waveform [5]. Table 4 lists the MSW inverter specification.

Table 4. MSW inverter specification

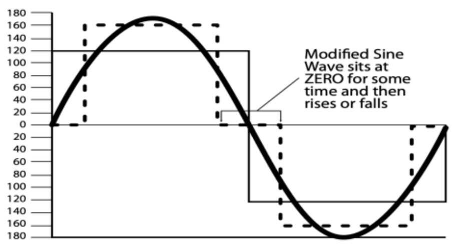
Specification	Detail
Continuous Power	500 W
Peak/Surge Power	1000 W
Output Waveform	Modified Sine Wave
Input voltage	12 V DC (range typically 9V-16V or 10.5V-15V)
Output voltage	220 V - 240 V AC
Output Frequency	50 Hz
Efficiency	>90% (some sources cite ≥90%)
No Load Current Draw	<0.5 A (typical for this class of inverter)
Cooling	Smart Fan (automatic start at high temperature and load)
Protections	Overload, over temperature, low/high battery voltage, short circuit

2.4 Differences between PSW Inverter and MSW Inverter

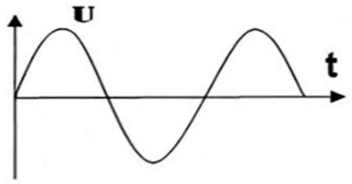
To address the differences between the two used inverters in this study, several points of view must be considered, namely, the waveform quality, compatibility with devices, efficiency & power consumption, price, and performance. The following Figure 1 illustrates the waveforms. A PSW inverter works well with almost all AC devices, particularly those that have sensitive electronics or motors. This includes items like computers, refrigerators, microwave ovens, and medical devices, which need the clean power from a pure sine wave inverter. Because of its high-quality waveform, it can handle all kinds of electronic devices and loads, including very delicate ones like computers and precision instruments. It's also good for connecting to the grid in systems that generate power, such as solar energy. On the other hand, an MSW inverter is suitable for simpler devices and loads that don’t need high-quality waveforms. This includes incandescent bulbs, electric heaters, basic power tools, older appliances, and lighting fixtures. These devices aren’t too affected by changes in voltage and current waveforms, so they work fine with modified sine wave inverters. However, MSW inverters might not be ideal for sensitive electronic equipment or inductive loads like motors or audio/video gear. These devices may run inefficiently, produce noise, or not function properly at all [4].

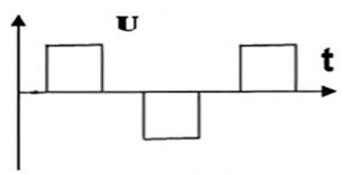
A PSW inverter is typically better at changing DC to AC, which means it wastes less energy and produces less heat. Their smooth waveform helps devices run more efficiently. On the other hand, an MSW inverter is not as efficient because its stepped waveform can lead to higher power usage by devices. Additionally, these inverters may generate more heat themselves. A PSW inverter tends to be pricier because it needs advanced electronics to create a true sine wave. This higher price usually reflects their superior performance and broader compatibility. On the other hand, an MSW inverter is more budget-friendly, making it a suitable option for simple tasks that don't need precise power output [20] [21].

A PSW inverter delivers steady and dependable power, which is essential for devices needing accurate voltage and frequency control. This helps ensure that sensitive electronics and appliances work correctly without the risk of harm. On the other hand, an MSW inverter can lead to issues with certain devices, such as louder noise from audio equipment, strange behavior from electronics, or lower efficiency in motors. Some devices might overheat, malfunction, or have a shorter lifespan when using a modified sine wave inverter [22] [23].



(a) The form of waves





(b). Pure sine wave produced by PSW inverter (c). Square sine wave produced by MSW inverter

Figure 1. Waveform differences [19]

2.5 Total Harmonic Distortion

Although many studies mitigated THD in certain ways [24] [25] [26] [27]. To lower THD in both PSW and MSW inverters, engineers apply various hardware and software methods to meet the International Standards & Technical Guides IEEE 519-2022/2025 Compliance Guide [28]. This guide states that for systems up to 1.0 kV, the THD should be at or below 8%. However, many off-grid designers strive for a THD of 5% or less to protect sensitive electronics. The guide also explains that individual voltage harmonics shouldn't exceed 3%, and the overall voltage THD should stay under 5%. Typically, this standard requires that the voltage THD remain below 5% for systems connected to the grid. The following Table 5 shows the comparison. The mentioned comparison techniques will be discussed in further study.

Table 5. Comparison technique used to reduce the PSW and MSW inverters

Technique	Primary Application	Potential THD Reduction
SPWM / SVPWM	PSW	Down to ~4.2%
LCL Filtering	PSW/MSW	From ~11% to ~1.4%
DT Compensation	PSW	From ~18% to ~0.3%
Multilevel (7+ Levels)	MSW	High (inherently lower THD)
AI/ML Optimization	MSW	Custom reduction via angles

3. RESULTS AND DISCUSSION

3.1 Research Results

Measurements and data collection were conducted over one day with a 7-minute resolution. Testing was conducted from 10:00 AM to 1:00 PM. The measured data included solar radiation, battery voltage, solar panel voltage, and inverter output voltage (for both PSW and MSW inverters) at the solar power plant, with panel tilt angles varying from 45° to 165°.

Solar radiation measurements were conducted using a solar power meter with a measurement unit of watt/^{m2}. The solar radiation measurement data for 4 hours of exposure for varying solar panel angles can be seen in Figure 2. The position of the measuring instrument follows the angle of incidence between the direction of sunlight and the normal to the panel surface (degrees). Measurements were conducted at several solar panel angles (45° to 165°). The highest solar radiation was observed at 12:00 noon.

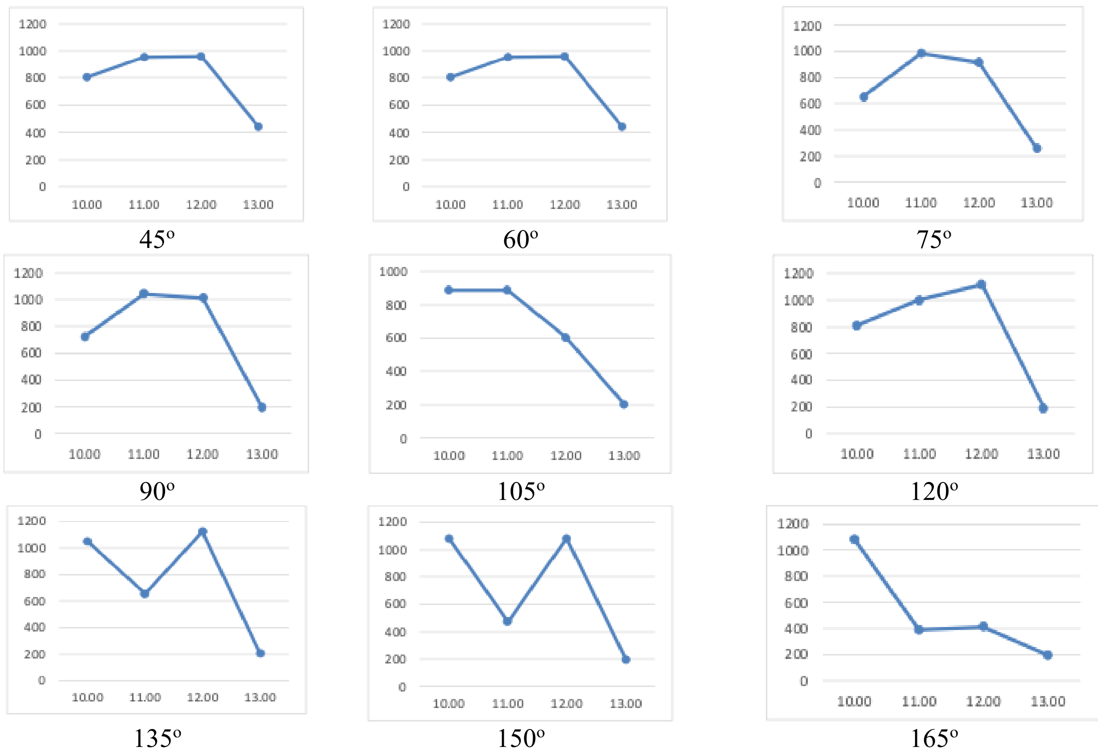


Figure 2. Sun irradiance with varying tilt angles

Figure 2 indicates that the best tilt angle for generating the most energy during the tested period is between 45° and 90°, with the greatest production happening around noon. Tilt angles that are too extreme, such as those nearing 165°, produce less energy and may be more affected by shifts in the sun's position.

This study investigates the influence of solar panel tilt angle on power output and voltage stability. Although the tilt angle is not the main emphasis of this research, its consideration is warranted and can be articulated more explicitly to enhance the comparison of inverters. Consequently, the findings related to tilt angle are not merely ancillary; rather, they serve as a proxy for different irradiance conditions, thereby facilitating a more comprehensive evaluation of inverter performance in response to fluctuations in input power levels.

3.2 Solar Power System with PSW Inverter

The results obtained from the measured and calculated parameters when utilizing a PSW inverter are detailed in Table 6.

Table 6. Measured parameter values for a solar power plant with a PSW inverter

Tilt Angle	Produced Energy (kWh)	System voltage (volt)	System Current (Ampere)	System Output Power (watt)	System Input Power (watt)	System Efficiency (%)
45	1.28	222.0	1.69	318.90	375.18	85.00
60	1.26	221.8	1.70	315.26	370.88	85.00
75	1.24	221.5	1.65	310.20	364.92	85.01
90	1.23	222.0	1.64	308.47	364.08	84.72
105	1.21	221.0	1.60	302.94	356.36	85.01
120	1.24	221.5	1.64	309.30	363.81	85.02
135	1.24	222.0	1.65	310.20	365.75	84.81
150	1.21	221.0	1.60	302.94	356.36	85.01
165	1.26	221.75	1.67	315.26	370.88	85.00

The energy produced (in kWh) varies from 1.21 to 1.28 kWh, with the highest output at a 45° angle (1.28 kWh) and the lowest at angles of 105° and 150° (1.21 kWh). The difference in energy between these angles is minor, about 5.5%, suggesting that solar radiation intensity remains stable. A tilt of 45° gives a slight boost in energy production, while 60° and 165° angles also perform well at around 1.26 kWh. The system's voltage stays steady between 221 and 222 V, showing that changing the panel angle has little effect on it; instead, the inverter/converter design plays a bigger role in voltage stability. The system's current ranges from 1.6 to 1.7 A, peaking at a 60° angle (1.70 A) and dropping to 1.60 A at angles of 105° and 150°. Current levels change slightly with variations in input energy linked to the solar panel's tilt angle. The difference between input and output power remains consistent, highlighting a stable system overall. System efficiency stays within the range of 84.7-85.0%, indicating that panel angle changes have minimal impact on efficiency, with only slight drops (<0.3%) at angles of 90° and 135°. Figure 3 illustrates how the system parameters behave during measurements.

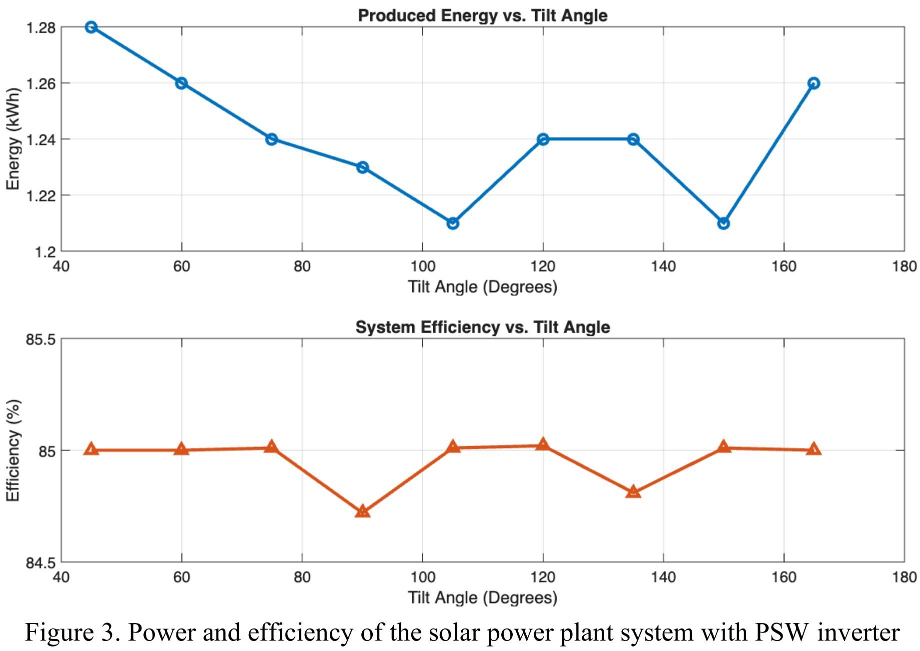


Figure 3. Power and efficiency of the solar power plant system with PSW inverter

The system consistently shows a stable difference between its input and output power, which suggests it operates reliably. Its efficiency remains steady, ranging from 84.7% to 85.0%. This means that the angle of the panels influences how efficient the system is. The PSW inverter adjusts based on changes in power levels. When the panel angles are set at 90° and 135°, there is only a slight drop in efficiency, less than 0.3%. Therefore, these results are practically close to the study in [8] and [29].

3.3 Solar Power System with MSW Inverter

When the system operates with an MSW inverter, the results for the measured and calculated parameters are shown in Table 7. The energy generated ranges from 1.30 to 1.37 kWh, with the peak value of 1.37 kWh occurring at panel tilt angles of 45° and 90°. The lowest value of 1.30 kWh is observed at an angle of 165°. The difference between these angles is only about 5.4%, indicating that the energy output remains fairly stable despite changes in panel tilt. The measured voltage varies from 222.0 to 224.2 V, with the highest recorded voltage of 224.18 V at a tilt angle of 90°, and the lowest at a tilt of 150° (222.4 V). The voltage does not change much because it is primarily affected by the inverter rather than the angle of the panel. The current measured in the system ranged from 1.72 to 1.80 A, with the highest current of 1.80 A at a tilt angle of 90°, and the lowest at a tilt angle of 45° (1.72 A). The increase in current at a 90° angle suggests that the panel was more effectively capturing solar radiation when positioned perpendicularly during testing. Figure 4 illustrates how the system parameters behave during measurements.

Table 7. Measured parameter values on a solar power plant with an MSW inverter

Tilt Angle	Produced Energy (kWh)	System voltage (volt)	System Current (Ampere)	System Output Power (watt)	System Input Power (watt)	System Efficiency (%)
45	1.37	223.2	1.72	326.82	384.46	85.01
60	1.34	223.53	1.77	335.40	394.52	85.01
75	1.33	223.73	1.75	333.32	392.08	85.01
90	1.37	224.18	1.80	342.05	402.39	85.00
105	1.32	223.65	1.74	330.35	388.59	85.01
120	1.34	223.65	1.77	335.43	395.30	84.85
135	1.31	222.98	1.73	326.95	384.63	85.00
150	1.31	222.4	1.74	328.47	386.42	85.00
165	1.30	222.48	1.73	326.24	383.77	85.01

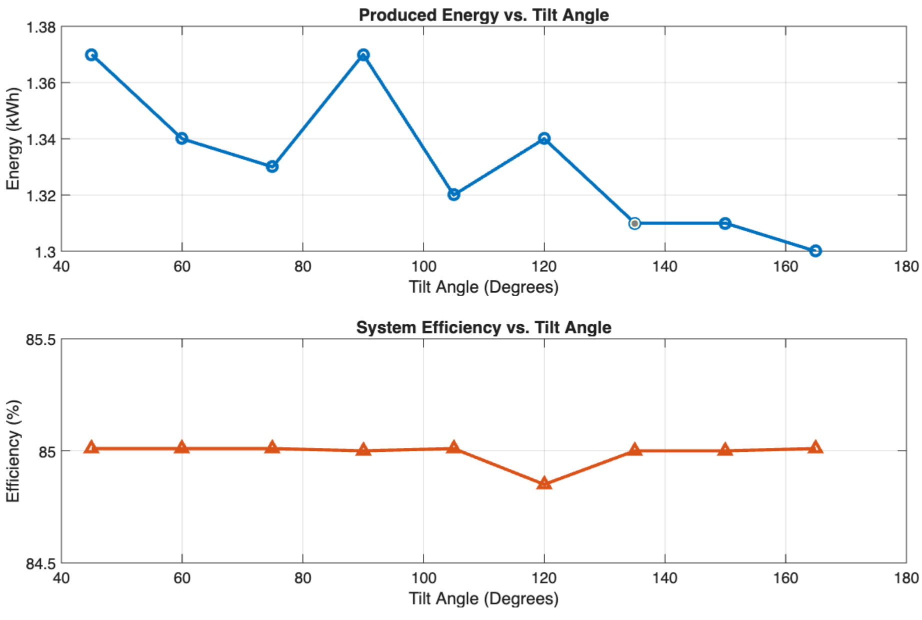


Figure 4. Power and efficiency of the solar power plant system with MSW inverter

The input and output power of the system show a consistent difference, which means the system is quite stable. The efficiency of the system remains steady between 84.85% and 86.01%. This shows that changing the angle of the panel has little effect on its efficiency. Overall, this points to a reliable conversion system (inverter and circuit). The only exception is at a 120° angle, where there is a slight decrease of less than 0.15%. Therefore, these results are practically close to the study in [8] and [23].

The experimental analysis primarily emphasizes the measured output voltage stability and voltage fluctuation as practical indicators of inverter performance in small off-grid PV systems. Based on the field measurements, the PSW inverter maintained a tightly regulated output within approximately 221–222 V, corresponding to a fluctuation of about ±1 V. In contrast, the MSW inverter exhibited a wider voltage range of approximately 222.0–224.2 V, indicating higher voltage variability under similar operating conditions.

This difference highlights the superior voltage regulation behavior of the PSW topology in maintaining a steady AC output despite variations in solar irradiance represented by different panel tilt angles. The relatively narrow voltage band of the PSW inverter suggests better control and filtering performance, which is particularly

important for sensitive electronic loads. Meanwhile, although the MSW inverter showed acceptable operation for general-purpose loads, its larger voltage spread indicates less consistent voltage regulation.
It is important to note that both inverter types demonstrated comparable efficiency (around 85%) and similar energy output trends during the test period. Therefore, within the scope of this short-duration outdoor experiment, the primary distinguishing performance indicator between the two inverters is the measured voltage stability rather than conversion efficiency.

4. CONCLUSION

This research conducted an experimental assessment and comparison of the performance of PSW and MSW inverters within a small-scale off-grid PV system, maintaining uniform outdoor conditions throughout. The objectives of the study were fulfilled through field measurements taken at various tilt angles that corresponded to different irradiance levels. The results obtained from the experiment indicate that the PSW inverter delivered a more consistent output voltage, remaining stable within a range of approximately 221–222 V with minimal fluctuations. In contrast, the MSW inverter displayed a broader voltage variation, oscillating between approximately 222–224 V. These outcomes suggest that PSW inverters possess superior voltage regulation capabilities under the tested parameters. Conversely, both types of inverters exhibited similar conversion efficiencies, around 85%, and followed comparable energy output patterns across the assessed tilt angles. This finding implies that, within the confines of this short-duration experiment and the specified loading conditions, there are no significant efficiency disparities between PSW and MSW inverters. In summary, these findings highlight that the selection of inverters for small off-grid PV systems should take into account specific application requirements: PSW inverters are preferable when voltage stability and power quality are critical considerations, whereas MSW inverters may be deemed acceptable for less sensitive loads when cost is a primary factor. Future investigations should encompass extended monitoring periods, a wider range of load profiles, and comprehensive harmonic analyses to further elucidate performance differences.

ACKNOWLEDGMENTS

The author thanks the Politeknik Negeri Lhokseumawe for research funding from the 2025 DIPA PNL budget through the Center for Research and Community Service.

REFERENCE

[1] D. Dahliya, S. Samsurizal, and N. Pasra, "Efisiensi panel surya kapasitas 100 Wp akibat pengaruh suhu dan kecepatan angin [Efficiency of a 100 Wp Solar Panel under the Influence of Temperature and Wind Speed]," *SUTET*, vol. 11, no. 2, pp. 71–80, 2021. https://doi.org/10.33322/sutet.v11i2.1551 (In Indonesian)
[2] M. K. Joyo, D. Hazry, S. F. Ahmed, M. H. Tanveer, F. A. Warsi, and A. T. Hussain, "Altitude and horizontal motion control of quadrotor UAV in the presence of air turbulence," in *Proc. 2013 IEEE Conf. Systems, Process & Control (ICSPC)*, Kuala Lumpur, Malaysia, 2013. https://doi.org/10.1109/SPC.2013.6735095
[3] K. Tuck, *Tilt sensing using linear accelerometers*. Freescale Semiconductor, 2017.
[4] INVERTERS.com, "What are the differences: Pure sine wave inverter vs modified sine wave inverter," 2024. [Online]. Available: https://www.inverter.com/what-are-the-differences-pure-sine-wave-inverter-vs-modified-sine-wave-inverter. [Accessed: Jan. 13, 2026].
[5] Electrical Academia, "Inverter types, working principle: Sine wave, square wave, modified sine wave inverter," 2024. [Online]. Available: https://electricalacademia.com/renewable-energy/inverter-types-working-principle-sine-wave-square-wave-modified-sine-wave-inverter-working/. [Accessed: Jan. 13, 2026].
[6] M. Kumar, A. K. Singh, and S. Lal, "THD reduction and power quality enhancement in solar-wind hybrid systems: A comprehensive review," *International Journal of Science and Engineering Invention (IJSEI)*, vol. 11, no. 1, pp. 7–14, 2025. https://doi.org/10.23958/ijsei/vol11-i01/279
[7] F. N. Budiman and M. R. Ramadhani, "Total harmonic distortion comparison between sinusoidal PWM inverter and multilevel inverter in solar panel," *KINETIK*, vol. 3, no. 3, pp. 191–202, 2018. https://doi.org/10.22219/kinetik.v3i3.617
[8] M. H. J. Bollen, *Understanding power quality problems: voltage sags and interruptions*. IEEE Press, 2020. https://doi.org/10.1109/9780470531886
[9] M. Esmaeili *et al.*, "Artificial intelligence-based control strategies for power quality improvement in renewable energy systems: A review," *Renewable and Sustainable Energy Reviews*, vol. 36, pp. 281–293, 2014. https://doi.org/10.1016/j.rser.2014.04.051
[10] P. Kumar and R. P. Saini, "A review on power quality improvement techniques for grid integrated renewable energy sources," *Renewable and Sustainable Energy Reviews*, vol. 148, Art. no. 111279, 2021. https://doi.org/10.1016/j.rser.2021.111279

[11] A. S. Siva and M. Bhavani, "Mitigation of harmonics by shunt active power filter using synchronous detection method," *International Journal of Engineering Trends and Technology (IJETT)*, vol. 4, no. 6, pp. 2584–2588, 2013. https://doi.org/10.14445/22315381/IJETT-V4I6P170
[12] A. S. Abbas *et al.*, "Optimal harmonic mitigation in distribution systems with inverter based distributed generation," *Applied Sciences*, vol. 11, no. 2, Art. no. 774, 2021. https://doi.org/10.3390/app11020774
[13] K. Gurumoorthy *et al.*, "Reduction of harmonic distortion by applying various PWM and neural network techniques in grid connected photovoltaic systems," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 2, no. 11, pp. 5892–5899, 2013.
[14] S. N. Sivakumar and A. Sumathi, "THD analysis of cascaded H-bridge inverter with fuzzy logic controller," *Circuits and Systems*, vol. 8, pp. 171–183, 2017. https://doi.org/10.4236/cs.2017.87011
[15] M. Zahid *et al.*, "AI-driven optimization techniques for power quality improvement in microgrids: Trends, techniques, and future directions," *Energy Science & Engineering*, vol. 14, no. 1, 2025. https://doi.org/10.1002/ese3.70342
[16] N. Safitri, A. M. S. Yunus, F. Fauzi, and N. Naziruddin, "Integrated arrangement of advanced power electronics through hybrid smart grid system," *TELKOMNIKA (Telecommunication, Computing, Electronics and Controls)*, vol. 18, no. 6, 2020. https://doi.org/10.12928/telkomnika.v18i6.13433
[17] N. Safitri, R. Syahputra, and Suprihardi, "Analysis of battery technologies for use as battery management systems in a simple solar power plant," *Journal of Innovation and Technology*, vol. 1, no. 24, 2024.
[18] N. Safitri, R. Syahputra, and R. Widia, "Simulation of lithium-based battery in off-grid photovoltaic system as intermittent renewable energy resources in Indonesia," in *Proc. iCAST 2025*, Denpasar, Indonesia, 2025. https://doi.org/10.2991/978-94-6463-926-1_14
[19] Xantrex, "Sine wave vs. modified sine wave: Which is better?," 2023.
[20] S. Zhang *et al.*, "An improved SPWM strategy for effectively reducing total harmonic distortion," *Electronics*, vol. 13, Art. no. 3326, 2024. https://doi.org/10.3390/electronics13163326
[21] I. N. E. Ifeagwu, M. Alor, and C. I. Ugwu, "Performance analysis of better designed pure sine wave inverter in mitigating frequent power outages in Nigerian homes," *International Journal of Trend in Research and Development*, vol. 3, no. 4, pp. 515–519, 2016.
[22] O. S. Adeoye, M. Ogunlowo, and A. J. Ojo, "Performance and harmonic evaluation of a modified sinewave 1 kVA solar powered inverter," *International Journal on Advanced Research and Innovations*, vol. 10, no. 4, pp. 1–9, 2022. https://doi.org/10.51976/ijari.1042201
[23] F. E. Abdel-Kader, S. A. Kalilah, H. E. Abdel-Maksoud, and A. Maher, "Effect of load type on PV modified sine wave inverter characteristics," *Engineering Research Journal*, vol. 39, no. 3, pp. 191–196, 2016.
[24] V. Sharma, "Advantages of pure over modified sine wave inverters," Samlex America, 2019. [Online]. Available: https://samlexamerica.com/wp-content/uploads/2019/12/13005-0614_AdvantagesofPureOverModifiedSineWaveInverters.pdf.
[25] Y. Yudhistira *et al.*, "Identification of harmonic current at off-grid PV inverters connected to the load," in *Proc. 2021 Asia-Pacific Int. Symp. Electromagnetic Compatibility (APEMC)*, 2021. https://doi.org/10.1109/APEMC49932.2021.9596675
[26] E. Janssen and L. St. Hilaire, *Power quality assessment of solar photovoltaic inverters*. Toronto and Region Conservation Authority, Toronto, 2016.
[27] F. MaxSavio *et al.*, "Design of a solar-wind hybrid renewable energy system for power quality enhancement: A case study of 2.5 MW real-time domestic grid," *Engineering Reports*, 2025. https://doi.org/10.1002/eng2.13101
[28] IEEE Standards Association, *IEEE 519-2022: IEEE recommended practice and requirements for harmonic control in electric power systems*, 2022. https://doi.org/10.1109/IEEESTD.2022.9848440
[29] H. Hadiyanto *et al.*, "Design and development of a PV inverter system with a real power concept for induction motor loads," *Multica Science and Technology (MST)*, vol. 5, no. 1, pp. 1–6, 2025. https://doi.org/10.47002/mst.v5i1.997