International Journal of Engineering, Science, and Environmental Research (IJESER)

Federal Polytechnic Wannune

Volume-1, Issue-1, pp-113-124

ISSN: 3121-8180

Research Paper Peer-Reviewed/Open Access/ www.ijeserfpw.com

Modification, Simulation and Performance Evaluation of a 1.5kVA Solar Inverter Power Pack for Application in TVET Electronic Laboratories and Workshops

[1]Iyoo, Godwin Mzaga, [2]Muokwe, Chijioke Tobias

[1,2]Department of Electrical and Electronic Engineering Technology, Federal Polytechnic, Wannune, Nigeria.

Corresponding Author: *E-mail: thegmtalternative@gmail.com*

Abstract

This paper presents a practical and educational framework for the design, implementation, and performance evaluation of an enhanced solar photovoltaic (PV) system tailored for Technical and Vocational Education and Training (TVET) electronic laboratories and workshops. The study focuses on determining the optimal tilt angle and orientation of PV panels, alongside the implementation of Maximum Power Point Tracking (MPPT) to improve energy efficiency and system performance. A MATLAB/Simulink-based model was developed to simulate real-life operating conditions and support hands-on learning in laboratory environments. The results demonstrate that panel positioning has a significant impact on energy generation, with an optimal tilt angle of 18° producing the highest power output of approximately 0.7902 kW. In addition, a south-facing orientation was found to yield maximum solar energy capture compared to east- and west-facing configurations. The implementation of Whale Optimization Algorithm based MPPT further enhanced system performance, increasing power output from 0.7114 kW to 0.7904 kW and improving efficiency from 89% to 99%. Overall, the findings confirm that proper system design, optimal panel configuration, and intelligent control strategies are essential for maximizing PV system performance. The developed framework serves as an effective instructional tool for TVET institutions, enabling students to acquire practical skills in renewable energy system design, system optimization, and performance analysis. This approach supports competency-based training and prepares learners for real-world applications in the renewable energy sector, particularly in regions with high solar energy potential.

Keywords: Solar Photovoltaic, TVET Laboratories, Tilt Angle Optimization, Orientation Angle, Whale Optimization Algorithm, MPPT, Renewable Energy Training, MATLAB/Simulink

---

Date of Submission: 04-02-2026 Date of Acceptance: 27-03-2026

1.0 Introduction

The solar inverter technology is a big market that can provide job opportunities for Nigerians. So far, most solar inverters are imported. By modifying and simulating solar inverters, prototypes fabrication can be locally constructed thus, employing many Nigerians, while at the same time saving a lot of forex which could be used for importation. More so, this local production can enhance skill acquisition in Technical and Vocational Education Training (TVET) institutions where knowledge and skills of electrical and electronic appliances, equipment and machines for self-employment can be obtained especially in Electrical/Electronic Engineering Technology.

Electrical/Electronic Engineering Technology in TVET institutions is provided with electronic laboratories and workshops which are equipped with hand tools and accessories for conducting practical classes in wiring, soldering and construction among others. Electronic workshops are equipped with alternating current (AC) and direct current (DC) power supplies, frequency generators, oscilloscopes, training kits for various circuits, integrated circuit testers (IC testers), solder and de-solder workstations, digital multimeters, inductive-capacitive-resistive meters (LCR meters) among others for training of students. The purpose of these workshops is for familiarizing basic concepts of technology and engineering as well as providing hands-on experience to the students in the field of science and engineering.

The electronic workshops require regular supply of electricity which is invariably the major resource input that is essential in all facets of the economy to boost the much-required technological advancement of the nation. (Audu et al., 2013), pointed out that there is no technological and vocational subject that can be offered at any level without regular electricity supply. (Afaor et al., 2017), identified numerous challenges and setbacks to the development of technical and vocational education in Nigeria as a country and maintained that paramount of these is fund and effective power supply system. (Afaor, et al., 2017), further emphasized that electric power is critical to the country's industrial development but the state of power in Nigeria is poor. Considering the poor state of electric power in the country, laboratories and workshops in the 21st century must be powered with a source of electricity to drive most of the portable hand tools as well as other workshop equipment for a successful practical skill acquisition. This is however, bedeviled by erratic power supply in and around these facilities. (Iorbee et al., 2018), opined that even enjoyment of basic social amenities on the school premises such as quality health care, adequate water supply, telecommunication service, becomes limited or even impossible due to long term electric power outages. These researchers maintained that effective learning is hampered by power failure as both teaching and learning becomes defective. Access to E-learning materials is often denied, practical classes cannot hold and processing of students' examinations and records are hampered (Iorbee et al., 2018). Again, despite huge budgetary allocations and expenditures for the acquisition of new power equipment and the repair of existing ones over decades, (Ale & Odesola, 2013), have observed that the installed power capacity has apparently increased but the available capacity is still a mirage or at least transient. In Benue State for instance, the implementation of practical curriculum and modules in Science and Technical Colleges is not up to date due to lack of adequate power supply to enhance the use of tools and equipment necessary for a practical education (Netherland Organization for International Cooperation in Higher Education (NICHE, 2010). This erratic power supply and prolonged power outages experienced in educational institutions has encouraged a significant percentage of workshop managers and technology teachers to seek alternative sources of power supply (Iorbee et al., 2018). The appalling part of some of the alternative power supply such as private generating set includes its relatively high operating cost, considerable power insufficiency and the accompanied health hazard due to massive emission of carbon monoxide and other related gases and this call for other alternative renewable energy sources such as the type considered in this work.

Hence, the growing demand for sustainable and clean energy solutions has increased the relevance of solar photovoltaic (PV) systems in both industry and education (International Energy Agency [IEA], 2023; Jacobson et al., 2020). In Technical and Vocational Education and Training (TVET) institutions, there is a critical need to integrate practical and hands-on learning approaches that equip students with the technical skills required for the renewable energy sector (UNESCO, 2021). The performance of PV systems is strongly influenced by environmental conditions and system configuration. Key parameters such as panel tilt angle, orientation, and Maximum Power Point Tracking (MPPT) techniques play a significant role in determining energy output and system efficiency (Huld et al., 2021; Batzelis, 2020). However, many training laboratories still rely on simplified or fixed configurations that do not adequately reflect real-world system behavior (Kalogirou, 2020). Conventional PV systems typically use fixed tilt angles and basic MPPT techniques such as Perturb and Observe (P & O), which are easy to implement but suffer from power oscillations and reduced efficiency under varying environmental conditions (Ishaque et al., 2012; Rezk et al., 2021). These limitations reduce their effectiveness as teaching tools for advanced system optimization and control. To bridge this gap, this study proposes an enhanced solar PV system specifically designed for TVET electronic laboratories and workshops. The system integrates optimal tilt angle determination, optimal panel orientation, and an intelligent Whale Optimization Algorithm (WOA)-based MPPT technique. This approach not only improves system performance but also provides a practical platform for students to understand modern optimization techniques and control strategies (Mirjalili & Lewis, 2016; Singh et al., 2022).

2.0 Theoretical Background

2.1 Solar Photovoltaic (PV) System Fundamentals

A solar photovoltaic (PV) system converts solar energy directly into electrical energy using semiconductor materials through the photovoltaic effect. When solar radiation strikes the PV cell, photons transfer energy to electrons, causing them to move and generate direct current (DC) electricity. The output characteristics of a PV system are nonlinear and depend on environmental factors such as solar irradiance and temperature (Villalva et al., 2009; Razykov et al., 2019).

2.2 Effect of Tilt Angle on PV Performance

The tilt angle of a PV panel is defined as the angle between the panel surface and the horizontal plane. It significantly influences the amount of solar radiation incident on the panel. An optimal tilt angle ensures maximum solar energy absorption throughout the day (Yadav & Chandel, 2013; Jacobson et al., 2020). The received solar irradiance on a tilted surface can be expressed as a function of the tilt angle and solar position. In practical applications, the optimal tilt angle is often approximated based on geographical location (latitude) or determined experimentally (Huld et al., 2021). Improper tilt angles lead to reduced energy capture and lower system efficiency.

2.3 Effect of Orientation Angle on PV Performance

The orientation (azimuth angle) of a PV panel determines the direction it faces relative to the sun. For locations in the northern hemisphere, south-facing panels generally receive the highest solar irradiance over the day, resulting in maximum energy output (Masters, 2019). Deviation from the optimal orientation reduces the duration and intensity of sunlight exposure, thereby decreasing the total energy generated. Therefore, proper alignment of PV panels is essential for maximizing system performance (Kalogirou, 2020).

2.4 Maximum Power Point Tracking (MPPT)

Due to the nonlinear nature of PV characteristics, the maximum power point varies continuously with changes in irradiance and temperature. Maximum Power Point Tracking (MPPT) techniques are used to ensure that the PV system operates at this optimal point (Esram & Chapman, 2007; Batzelis, 2020). MPPT controllers adjust the duty cycle of a DC-DC converter to match the load with the PV source, thereby maximizing power extraction. Conventional MPPT methods, such as Perturb and Observe (P & O), are simple but suffer from steady-state oscillations and reduced efficiency under rapidly changing conditions (Ishaque et al., 2012; Rezk et al., 2021).

2.5 Whale Optimization Algorithm (WOA) for MPPT

The Whale Optimization Algorithm (WOA) is a nature-inspired metaheuristic algorithm based on the bubble-net hunting strategy of humpback whales (Mirjalili & Lewis, 2016). It consists of three main phases: encircling prey, bubble-net attacking (exploitation), and search for prey (exploration). In PV applications, WOA is used to optimize the duty cycle of the DC-DC converter by searching for the global maximum power point. Compared to conventional methods, WOA offers; faster convergence to the optimal solution, reduced oscillations around the MPP, and improved tracking efficiency under varying environmental conditions. Recent studies have demonstrated that WOA-based MPPT outperforms traditional algorithms in terms of tracking accuracy and dynamic response under changing weather conditions (Nagarajan et al., 2020; Singh et al., 2022). This makes it suitable for intelligent control of PV systems, especially in dynamic operating environments.

3.0 Methodology

This study adopts a systematic approach to the design, optimization, and performance enhancement of a solar photovoltaic (PV) system suitable for Technical and Vocational Education and Training (TVET) laboratories. The methodology integrates practical system design procedures with advanced optimization techniques to ensure both real-world applicability and instructional value. The major components were sized including the PV array, charge controller, battery storage, and inverter. Load assessment was first conducted to determine the total energy demand, which serves as the basis for selecting appropriate system ratings. The PV array was sized to meet the daily energy requirements under typical solar irradiance conditions, while the battery capacity was determined to provide adequate energy storage for periods of low or no sunlight. The charge controller and inverter were selected based on system voltage levels, power ratings, and efficiency considerations to ensure safe and reliable operation. Following system sizing, the study focuses on improving energy capture through the determination of optimal tilt angle and panel orientation**.** The tilt angle was varied within a practical range to identify the angle that maximizes solar irradiance absorption, while the orientation was adjusted to evaluate directional effects on energy yield. These parameters were analyzed through simulation and experimental procedures, allowing learners to observe their impact on system performance.

To further enhance power extraction, a Whale Optimization Algorithm (WOA)-based Maximum Power Point Tracking (MPPT) technique was implemented. The algorithm optimizes the duty cycle of the DC-DC converter by continuously searching for the global maximum power point under varying environmental conditions. This intelligent control strategy was compared with conventional MPPT methods to demonstrate its superior convergence speed, reduced oscillations, and improved efficiency.

The entire system was modelled and simulated using MATLAB/Simulink, providing a flexible platform for analysis and serving as a virtual laboratory tool for TVET applications. This integrated methodology ensures that both design principles and advanced optimization techniques are effectively demonstrated for educational and practical purposes.

The methodology is structured into four main stages:

a. Load assessment
b. System sizing
c. Determination of optimal tilt angle and orientation
d. Implementation of WOA-based MPPT
e. Simulation and performance evaluation using MATLAB/Simulink

3.1 Load Assessment

The daily energy demand was computed employing equation 1:

$$E_{load} = \sum(P_i \times t_i) \quad (1)$$

Where;

$P_i = Power\ rating\ of\ each\ appliance\ (W)$

$t_i = Operating\ time\ (hours)$

The total energy demand under consideration is contained in Table 1.

Table 1: Energy Demand

S/N	Individual loads	Quantity	Power Rating (W)	Usage Hours	Total Power (W)	Energy Demand (Watt-Hour)
1	Soldering station	10	40	2	400	800
2	Transistor radio	10	10	2	100	200
3	Television set	2	75	2	150	300
4	Satellite decoder	2	30	2	60	120
5	Oscilloscope	2	35	2	70	140
6	Laptop computer	6	18.36	2	110.16	220.32
7	Phone charger	10	6.6	1	66	66
8	Energy bulb	6	30	2	180	360
Total Demand					1136.16	2206.32

3.2 System Sizing

3.2.1 PV Array Sizing

The required PV array capacity was determined based on the daily energy demand and available solar irradiance given in equation 2.

$$\boldsymbol{P_{PV}} = \frac{\boldsymbol{E_{load}}}{\boldsymbol{H_{sun} \times \eta_{sys}}} \quad (2)$$

Where;

$\boldsymbol{P_{PV} = Required\ PV\ power\ (W)}$

$\boldsymbol{H_{sun} = Average\ daily\ sun\ hours\ (hours/day)}$

$\boldsymbol{\eta_{sys} = System\ efficiency}$

The number of PV modules is computed using equation 3.

$$\boldsymbol{N_{PV}} = \frac{\boldsymbol{P_{PV}}}{\boldsymbol{P_{module}}} \quad (3)$$

Where;

$\boldsymbol{P_{module} = Power\ rating\ of\ a\ single\ solar\ panel\ (W)}$

3.2.2 Battery Sizing

Battery capacity was calculated to ensure energy availability during periods of low sunlight using equation 4.

$$C_{bat} = \frac{E_{load} \times D_{aut}}{V_{bat} \times DOD \times \eta_{bat}} \quad (4)$$

Where:

$C_{bat} = Battery\ capacity\ (Ah)$
$D_{aut} = Days\ of\ autonomy$
$V_{bat} = Battery\ voltage\ (V)$
$DOD = Depth\ of\ discharge$
$\eta_{bat} = Battery\ efficiency$

3.2.3 Charge Controller Sizing

The charge controller rating was sized based on the short-circuit current of the PV array as shown in equation 5.

$$I_{cc} = 1.25 \times I_{sc} \times N_{parallel} \quad (5)$$

Where;

$I_{cc} = Controlleer\ current\ rating\ (A)$
$I_{sc} = Short - circuit\ current\ of\ one\ module$
$N_{parallel} = Number\ of\ parallel\ connected\ PV\ array$

3.2.4 Inverter Sizing

The inverter was sized based on the total load demand as given in equation 6.

$$P_{inv} = 1.25 \times P_{load} \quad (6)$$

Where:

$P_{inv} = Inverter\ rating$

$P_{load} = Total\ load\ power$

3.3 Determination of optimal tilt angle and orientation

The tilt angle affects the amount of solar radiation received by the PV panel as shown in equation 7.

$$G_{eff} = G\cos(\theta) \quad (7)$$

Where:

$G_{eff} = Effective\ irradiation$
$\theta = Angle\ of\ incidence$

The tilt angle was varied from 0° to 60° and the corresponding power output at each angle was measured. The optimal tilt angle was obtained based on the angle with the maximum power harvest. The tilt angle is determined empirically as given in equation 8.

$$\beta_{opt} \approx Latitude \pm 10^{\circ} \quad (8)$$

The orientation angle (γ) determines the direction the panel faces relative to the sun. The panel was oriented at East (−90°), South (0°), and West (+90°) where the power output at each orientation was recorded. The optimal orientation was selected based on maximum energy yield.

3.4 Implementation of WOA-based MPPT

The Whale Optimization Algorithm (WOA)-based Maximum Power Point Tracking (MPPT) controller was implemented using a MATLAB Function block within the Simulink environment. In this configuration, the photovoltaic (PV) system output voltage and current were continuously measured and supplied as inputs to the controller. The instantaneous output power (P) of the PV system, computed as the product of voltage and current, was used as the fitness function for the optimization process.

The WOA algorithm operates by iteratively updating a population of candidate solutions representing possible duty cycles of the DC-DC boost converter. Through mechanisms inspired by the hunting behaviour of humpback

whales-namely encircling prey, spiral bubble-net feeding, and random exploration, the algorithm searches for the optimal duty cycle corresponding to the global maximum power point (MPP).
At each iteration, the duty cycle is adjusted based on the best solution obtained, ensuring convergence toward the maximum power output under varying environmental conditions such as changes in solar irradiance and temperature. The optimized duty cycle was then fed into a Pulse Width Modulation (PWM) generator, which produces the switching signals required to control the power electronic switch (MOSFET) in the boost converter. This implementation enables real-time tracking of the maximum power point with improved convergence speed, reduced steady-state oscillations, and enhanced overall system efficiency compared to conventional MPPT techniques. The PV is expressed as shown in equation (9). The objective of the MPPT process is to maximize the output power PPP by optimally adjusting the duty cycle (D) of the DC-DC boost converter.

$$P = I \times V \tag{9}$$

3.4.1 Encircling Prey Mechanism

WOA assumes that the current best candidate solution represents the location of the prey (maximum power point). The position of each search agent (whale) was updated relative to the best solution as shown in equations (10).

$$\boldsymbol{X(t+1) = X^*(t) - A.D} \tag{10}$$

$$\boldsymbol{D = |C.X^*(t) - X(t)|} \tag{11}$$

Where;

$\boldsymbol{X^*(t) = Position\ vector\ of\ the\ best\ solution}$

$\boldsymbol{X(t) = Current\ position\ vector}$

$\boldsymbol{A, C = Coefficients\ vectors}$

3.4.2 Coefficient Vectors

The coefficient vectors are defined as:

$$\boldsymbol{A = 2a.r_1 - a} \tag{12}$$
$$\boldsymbol{C = 2.r_2} \tag{13}$$
$$\boldsymbol{a = 2 - \frac{2t}{T}} \tag{14}$$

Where:
$\boldsymbol{r_1, r_2 \in |0,1|\ are\ random\ vectors}$
$\boldsymbol{t = Current\ iteration}$
$\boldsymbol{T = Maximum\ number\ of\ iterations}$
The parameter $\boldsymbol{a}$ decreases linearly from 2 to 0, enabling a transition from exploration to exploitation.

3.4.3 Bubble-Net Attacking (Exploitation Phase)

WOA models the bubble-net feeding behaviour using two approaches:

- **Shrinking Encircling Mechanism**

This is achieved when $\boldsymbol{|A| < 1}$, forcing whales to move towards the best solution.

- **Spiral Updating Position**

$$\boldsymbol{X(t+1) = D'.e^{bl}.\cos(2\pi l) + X^*(t)} \tag{15}$$

Where:

$\boldsymbol{D' = |X^*(t) - X(t)|}$
$\boldsymbol{b = Constant\ defining\ spiral\ shape}$
$\boldsymbol{l \in [-1,1] = Random\ number}$

3.4.4 Exploration Phase (Search for Prey)

When $\boldsymbol{|A| > 1}$, the algorithm emphasizes exploration by selecting a random search agent as shown in equations (16) and (17).

$$\boldsymbol{X(t+1) = X_{rand} - A.D} \tag{16}$$

$$\boldsymbol{D = |C.X_{rand} - X(t)|} \tag{17}$$

Where:

$X_{rand} = Random\ whale\ position$

3.4.5 Duty Cycle Optimization for MPPT

In this study, each whale represents a candidate duty cycle (D) of the DC-DC converter. The WOA iteratively updates these duty cycles to maximize the PV output power. The optimal duty cycle is expressed in equation (18).

$$D_{opt} = argmax(P(V,I)) \tag{18}$$

The optimal duty cycle was then applied to the PWM generator, which produces the switching signals for the boost converter.

3.5 Simulation and performance evaluation using MATLAB/Simulink

The designed solar photovoltaic (PV) system was modelled and simulated using the MATLAB/Simulink environment to evaluate its performance under varying operating conditions. The simulation model comprised key system components, including the PV array, DC-DC boost converter, WOA-based MPPT controller implemented via a MATLAB Function block, Pulse Width Modulation (PWM) generator, battery bank and load. The PV array block was configured to operate under specified irradiance and temperature conditions, enabling the analysis of system behaviour under realistic environmental variations. The output voltage and current of the PV system were continuously measured and fed into the WOA-based MPPT controller, which dynamically adjusted the duty cycle of the boost converter to ensure operation at the maximum power point. The design system parameters were inputted into the model accordingly. The Simulink model of the system is shown in Figure 1 while the WOA-based MPPT is shown in Figure 2.

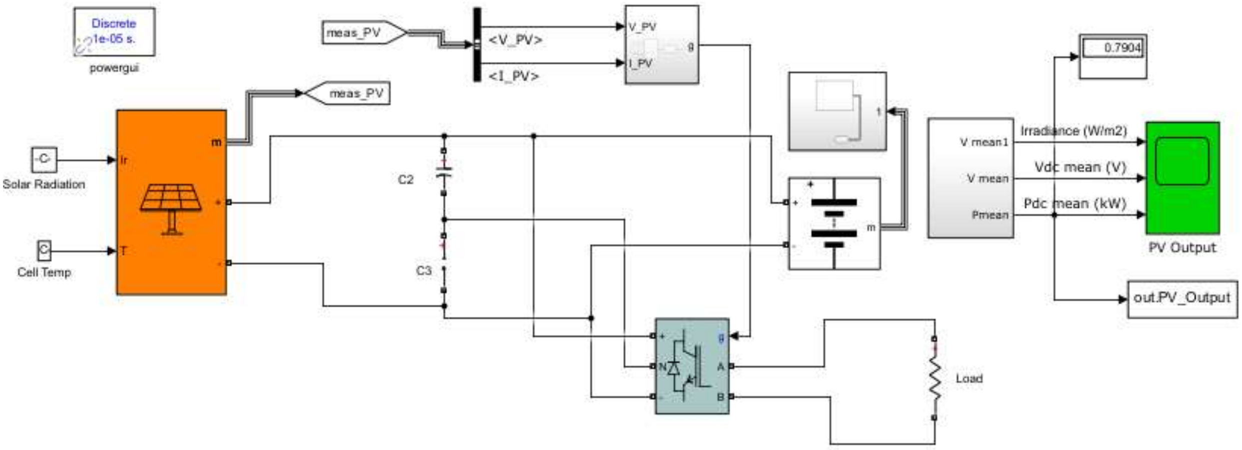

Figure 1: Simulink model of the system

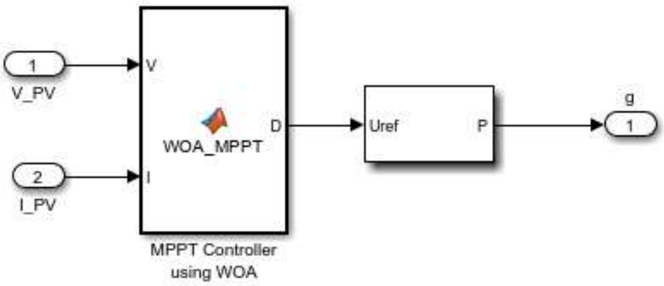

Figure 2: Simulink model of the WOA-Based MPPT

4.0 Results and Discussion

This section presents the results obtained from the design and simulation of the solar photovoltaic (PV) system. The results are analyzed to evaluate the effects of system sizing, tilt angle, panel orientation, and Maximum Power Point Tracking (MPPT) on system performance.

4.1 Results

The sizing results obtained after simulation are presented in Table 2 while Figure 3 shows the result in MATLAB environment. Table 3 through Table 5 contained the PV power out based on the effect of tilt angle, effect of PV orientation, and effect of WOA-based MPPT respectively. Figure 4 and Figure 5 depicts the PV power output with/without MPPT and optimal tilt angle respectively.

Table 2: System Design Summary

Components	**Required Capacity**	**Rating Selected**	**Qty Required**
PV Panel	538.48 W	400 W	2
Battery	432.61 Ah	100 Ah	5
Charge Controller	10.62 A	15 A	1
Inverter	1420.20 W	1500 W	1

Table 3: Effect of Tilt Angle

Tilt Angle (°)	**Power Output (kW)**
3	0.6025
6	0.6543
12	0.6764
15	0.7565
18	**0.7902**
21	0.7424
24	0.7267
27	0.7163
30	0.7026

Table 4: Effect of PV Orientation

Orientation (°)	**Power Output (kW)**
East (-90°)	0.7105
South (0°)	**0.7903**
West (+90°)	0.7116

Table 5: Effect of MPPT

MPPT Scenario	**Power Output (kW)**	**Efficiency (%)**
Without MPPT	0.7114	0.89
With MPPT	0.7904	0.99

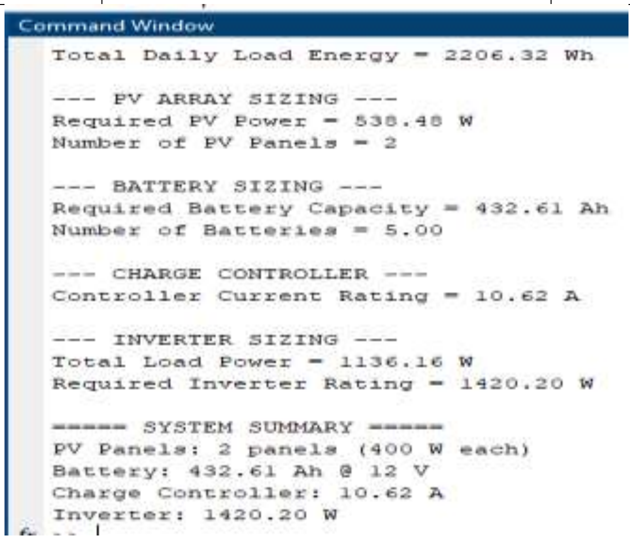

Figure 3: MATLAB Command Window Showing Simulated Results

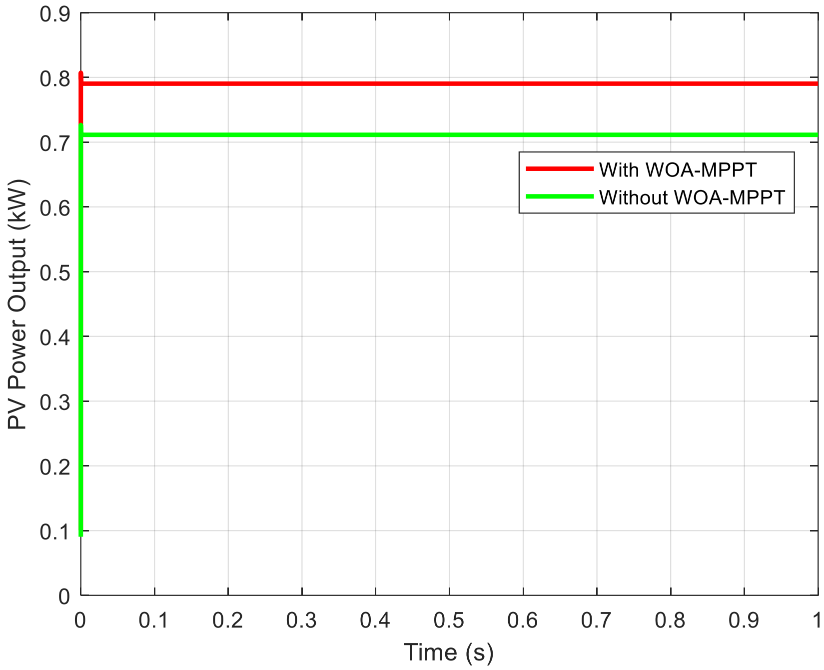

Figure 4: PV Power Output With/Without MPPT

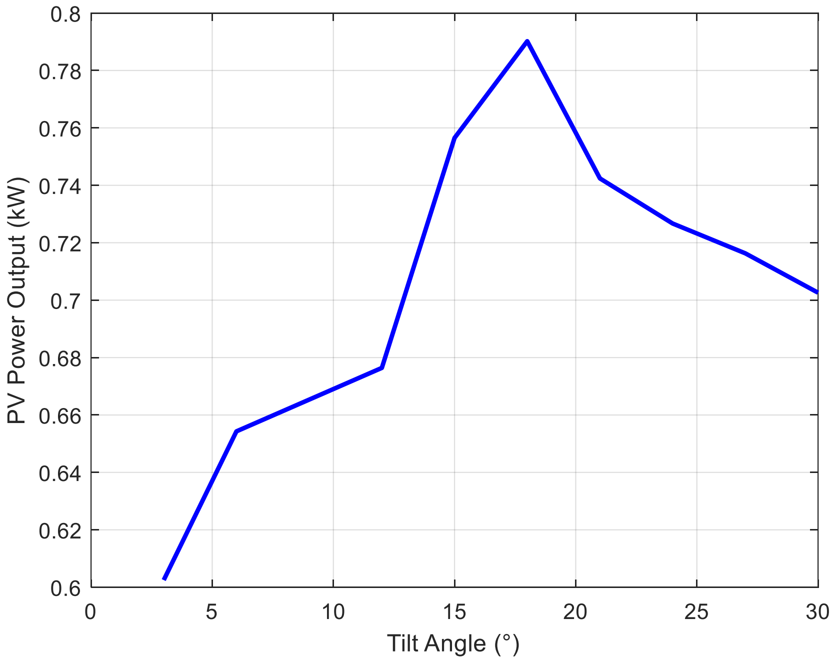

Figure 5: Graph Showing Optimal Tilt Angle

4.2 Discussion

The system design summary presented in Table 2 shows that all selected components satisfy the required design specifications with appropriate safety margins. The PV array consists of two 400 W panels, which exceed the calculated requirement of 538.48 W, thereby ensuring adequate power generation under varying environmental conditions. Similarly, the battery bank capacity of 500 Ah (five 100 Ah batteries) exceeds the required 432.61 Ah, providing sufficient energy storage for periods of low solar irradiance. The charge controller and inverter ratings were also selected above the required values to prevent overloading and ensure reliable operation. This design approach enhances system stability, efficiency, and lifespan. Table 3 illustrates the relationship between tilt angle and power output. The results indicate that the power output increases progressively from 0.6025 kW at 3° to a maximum value of 0.7902 kW at 18°. Beyond this angle, the power output decreases gradually. This behavior is attributed to the variation in solar irradiance incident on the panel surface as the tilt angle changes. At 18°, the panel achieves optimal alignment with the sun, resulting in maximum energy absorption. Therefore, 18°

is identified as the optimal tilt angle for the system. Table 4 presents the effect of panel orientation on PV output power. The results show that the south-facing orientation (0°) yields the highest power output of 0.7903 kW, while east and west orientations produce lower outputs of 0.7105 kW and 0.7116 kW, respectively. This is because a south-facing panel receives more consistent and direct sunlight throughout the day compared to east- and west-facing panels, which are limited to morning and evening sunlight exposure. Hence, south orientation is optimal for maximizing solar energy generation. The results presented in Table 5 demonstrate the significant impact of MPPT on system performance. The power output increases from 0.7114 kW (without MPPT) to 0.7904 kW (with MPPT), representing an approximate 11% improvement.

Additionally, system efficiency improves from 89% to 99% with the implementation of MPPT. This improvement occurs because MPPT continuously adjusts the operating point of the PV system to ensure maximum power extraction under varying environmental conditions. Figure 3 shows the MATLAB command window displaying the simulation results, while Figure 4 illustrates the comparison of PV power output with and without MPPT. The graphical results confirm that MPPT enhances system performance by maintaining operation at the maximum power point.

5.0 Conclusion

This study presented the design and performance evaluation of an enhanced solar photovoltaic (PV) system developed for Technical and Vocational Education and Training (TVET) laboratories. The findings demonstrate that optimal panel configuration and intelligent control strategies significantly improve system performance and energy efficiency. The study highlights that proper selection of tilt angle and orientation plays a critical role in maximizing solar energy capture, while the integration of an advanced Maximum Power Point Tracking (MPPT) technique enhances power extraction and overall system efficiency. These improvements make the proposed system more suitable for practical training environments, where students can gain hands-on experience with modern renewable energy technologies. From an educational perspective, the developed framework provides a valuable platform for bridging the gap between theoretical knowledge and real-world application. It enables learners to understand key concepts such as system optimization, performance evaluation, and intelligent control, thereby supporting competency-based training in TVET institutions. However, this study is limited to simulation-based analysis using MATLAB/Simulink, and the system performance may vary under real-world conditions as environmental variations such as long-term weather patterns were not extensively modelled. Future work will focus on improving model adaptability under varying environmental conditions and exploring advanced optimization techniques to enhance overall system performance.

References

Afaor, N. N., Agbese, O. D., & Kurungu, A. A. (2017). Technical and vocational education and training (TVET) and industrial development. *Journal of Nigerian Association of Teachers of Technology (JONATT), 12*(4), 61–65.

Ale, T. O., & Odesola, A. O. (2013). Effects of distance transmission: Akure 33 kV line as a case study. *International Journal of Research Findings in Engineering Science and Technology, 3*(1), 27–32.

Audu, R., Aede, H. B. M., Yusri, B. K., & Muhammad, S. B. S. (2013). Provision of workshop tools and equipment necessity for technical vocational education graduates' skills. In *Proceedings of the 2nd International Seminar on Quality and Affordable Education*.

Batzelis, E. I. (2020). A comprehensive review of photovoltaic maximum power point tracking techniques. *Renewable and Sustainable Energy Reviews, 113*, 109142.

Esram, T., & Chapman, P. L. (2007). Comparison of photovoltaic array maximum power point tracking techniques. *IEEE Transactions on Energy Conversion, 22*(2), 439–449.

Huld, T., Müller, R., & Gambardella, A. (2021). A new solar radiation database for estimating PV performance. *Solar Energy, 188*, 112–122.

International Energy Agency. (2023). *Renewables 2023: Analysis and forecast to 2028*.

Iorbee, M. M., Ajon, R. A., Atem, J. A., & Ejeh, E. (2018). Protection of power supply equipment. *Journal of Science Advance Innovative Research, 3*(4), 15–22.

Ishaque, K., Salam, Z., & Taheri, H. (2012). PV model development. *Solar Energy Materials and Solar Cells, 95*(2), 586–594.

Jacobson, M. Z., Jadhav, V., & Delucchi, M. A. (2020). Renewable energy systems. *Renewable Energy, 152*, 1156–1172.

Kalogirou, S. A. (2020). *Solar energy engineering* (3rd ed.). Academic Press.

Masters, G. M. (2019). *Renewable and efficient electric power systems* (3rd ed.). Wiley.

Mirjalili, S., & Lewis, A. (2016). The whale optimization algorithm. *Advances in Engineering Software, 95*, 51–67.

Nagarajan, A., Ravi, G., & Karthikeyan, S. (2020). MPPT performance using WOA. *International Journal of Renewable Energy Research, 10*(3), 1205–1213.

Netherlands Organisation for International Cooperation in Higher Education. (2010). *Strategy on technical vocational education and training*.

Razykov, T. M., et al. (2019). Solar PV prospects. *Solar Energy, 85*(8), 1580–1608.

Rezk, H., et al. (2021). MPPT improvements. *Energy Reports, 7*, 175–189.

Singh, B., Kumar, R., & Chandra, A. (2022). MPPT using WOA. *Energy Reports, 8*, 1234–1245.

UNESCO. (2021). *Reimagining our futures together*.

Villalva, M. G., Gazoli, J. R., & Filho, E. R. (2009). PV modeling. *IEEE Transactions on Power Electronics, 24*(5), 1198–1208.

Yadav, A. K., & Chandel, S. S. (2013). Tilt angle optimization. *Renewable and Sustainable Energy Reviews, 23*, 503–513.

How to cite this article: Iyoo, G. M., & Muokwe, C. T. (2026). Modification, simulation and performance evaluation of a 1.5 kVA solar inverter power pack for application in TVET electronic laboratories and workshops. *International Journal of Engineering and Science Research, 1*(1), 113–124.