Hachimenum Nyebuchi Amadi, 2025, 13:5
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Blueprint Analysis of a Hybrid Solar-Inverter System for Uninterrupted Power Supply in Government Vocational School Workshops in Port Harcourt

Hachimenum Nyebuchi Amadi, Mutiu Oluseyi Lawal, Richeal Chinaeche Ijeoma
Department of Electrical and Electronics Engineering Rivers State University,
Nkpolu - Oroworukwo Port - Harcourt, Nigeria

Abstract- This study presents a blueprint analysis of a hybrid solar-inverter system designed to provide uninterrupted power to government vocational school workshops in Port Harcourt. Frequent grid outages and unreliable supply compromise hands-on training, damage equipment, and reduce instructional hours, challenges that this research addresses by combining solar photovoltaic generation with intelligent inverter-based energy management and battery storage. The paper develops site-specific system architecture, sized through load surveys of typical workshop equipment (welding machines, drills, compressors, lighting and power tools), local solar resource assessment, and operational duty cycles. Key components include PV arrays; a bidirectional inverter/charger with surge-and-islanding capability, a battery energy storage system sized for critical loads during peak outage periods, and a supervisory energy management system that prioritizes loads, schedules charging, and supports seamless transition between grid, PV and battery modes. Using techno-economic modelling and scenario analysis, performance metrics system availability, autonomy duration, levelized cost of energy (LCOE), and payback period are evaluated under Port Harcourt's irradiance and tariff conditions. Results indicate that a properly sized hybrid solution can achieve >99% uptime for critical workshop operations, reduce energy expenditures, and extend equipment life by smoothing supply disturbances. Sensitivity analysis shows that battery cost and duty-cycle demand are the most influential variables on financial viability. The blueprint also outlines installation best practices, safety and grounding considerations for educational environments, routine maintenance schedules, and guidelines for integrating the system into vocational curricula as a live teaching resource. The proposed blueprint offers a scalable, replicable model for other government training institutions aiming to improve practical training continuity, build local technical capacity, and progress toward resilient educational infrastructure.

Keywords: Hybrid Solar-Inverter, Uninterrupted Power Supply, Vocational Workshops, Battery Energy Storage, Techno-Economic Analysis.

I. INTRODUCTION

Electric power availability remains one of the most pressing challenges facing technical and vocational education in Nigeria. Government vocational schools, which serve as critical hubs for equipping youths with hands-on skills in welding, electrical installation, carpentry, and mechanical work, depend heavily on a reliable power supply to operate workshop machinery and training equipment. In Port Harcourt, like many other Nigerian cities, frequent grid outages, low voltage levels, and inconsistent power quality disrupt workshop sessions, limit productive learning hours, and sometimes damage sensitive tools and machines. This challenge not only reduces the quality of technical education but also hampers the government's broader objective of promoting skill acquisition and self-reliance among young people (World Bank, 2021).

Ijeoma and Odu (2025a) explain that electrical power systems are designed to deliver consistent, reliable voltage to end-users. The ability to predict future energy demand is essential for effective planning of power generation, distribution, and infrastructure development to meet the projected needs of the community. Electricity is generated in a thermal power plant, a hydroelectric power plant, and a nuclear power plant, etc. This electricity is then supplied to a transmission substation near the generating plant. In the transmission substation, the voltage is increased substantially using step-up transformers. The voltage is increased to reduce the transmission losses over long distances (Ijeoma and Olisa, 2019). An electrical power system consists of power generation, transmission, and distribution. Rural Electrification is the process of bringing electrical power to rural and remote areas. Rural communities are suffering from massive market failures as the national grids fall short of their electricity demand. Essentially, the idea of rural electrification refers to the electricity supply to areas outside of cities. However, many scholars have given their perceptions in different interpretations (Ijeoma and Odu, 2025b).

According to Amadi et al. (2025), power system networks are facing an unusual surge in demand from electricity consumers, coupled with increasing stress on electrical infrastructure, especially the overhead lines, due to incessant line breaks and vandalism. Thus, the need to meet the demand whilst building much stronger and more resilient networks that can withstand such faults or abuse of power system networks. Reliable energy technologies are, more than ever before, required to play a major role in mitigating pressing societal challenges such as climate change and resource depletion, while contributing to domestic energy security (Amadi et al. 2024a).

To address this, renewable energy solutions are increasingly being considered as sustainable alternatives. Among these, solar photovoltaic (PV) technology integrated with inverter-based storage systems presents a promising pathway to achieving an uninterrupted power supply for educational facilities (Oyedepo et al., 2018). A hybrid solar-inverter system combines energy harvested from solar PV arrays with battery storage and intelligent inverters that seamlessly switch between the grid, solar power, and storage sources (Aliyu, Dada, & Adam, 2015). Such systems ensure continuous power availability, even during grid outages, while reducing dependence on costly diesel generators and mitigating environmental pollution (Ogunjuyigbe, Ayodele, and Akinola, 2016).

Amadi et al. (2024b) examine the types, benefits, and challenges of renewable energy in Nigeria, as well as the role of public-private partnerships and the policy and regulatory framework for renewable energy development. The studies show that Nigeria has abundant and diverse renewable energy resources, including solar, wind, hydro, and biomass, which can meet its energy demand and reduce its dependence on fossil fuels. However, renewable energy adoption faces several barriers, such as high upfront costs, technical and infrastructure limitations, and socio-political factors that require concerted and coordinated efforts from various stakeholders and policymakers.

The adoption of hybrid solar-inverter systems in vocational schools offers dual benefits: operational reliability for workshop training and a practical teaching tool for students to gain first-hand exposure to renewable energy technologies (Ozoemena and Okeke, 2022). In Port Harcourt, which enjoys relatively high solar irradiance throughout the year, this solution is technically feasible and economically attractive when carefully designed based on actual workshop load requirements (Nwulu and Agbetuyi, 2019).

This study focuses on the blueprint analysis of a hybrid solar-inverter system tailored for government vocational school workshops in Port Harcourt. The analysis involves evaluating load demand profiles, system sizing parameters, energy management strategies, and techno-economic feasibility under local conditions. The blueprint further emphasizes sustainability, safety, scalability, and integration into vocational training curricula.

By developing this blueprint, the research contributes to bridging the gap between energy reliability and technical education delivery. Ultimately, the project aims to demonstrate how hybrid renewable energy systems can enhance learning environments, reduce operational costs, and promote energy resilience in Nigeria's educational sector.

1. Energy Challenges in Nigerian Educational Institutions

Nigeria faces chronic electricity supply deficits, with average access rates and reliability among the lowest in Sub-Saharan Africa (World Bank, 2021). Frequent outages, voltage fluctuations, and insufficient grid expansion have resulted in widespread adoption of costly and unsustainable alternatives such as diesel generators (Oyedepo, 2012). For vocational schools, which depend on electricity to power workshops and laboratories, these challenges limit the ability of instructors to conduct effective training sessions. Okoye and Oranekwu (2020) reported that unreliable power in technical colleges across Southern Nigeria has significantly reduced productive learning hours and increased equipment maintenance costs.

2. Hybrid Renewable Energy Systems

Hybrid energy systems integrate multiple energy sources such as solar PV, grid, wind, or diesel combined with storage solutions to ensure reliable supply. According to Aliyu, Dada, and Adam (2015), hybrid systems offer improved resilience by providing redundancy and balancing intermittent renewable energy with storage or backup. In the Nigerian context, solar hybrid systems have gained increasing attention due to abundant solar resources and declining technology costs (Ogunjuyigbe, Ayodele, and Akinola, 2016).

Hybrid solar-inverter systems are particularly suitable for institutions because they can seamlessly switch between PV, battery storage, and grid supply. Nwulu and Agbetuyi (2019) demonstrated that optimally sized PV-inverter-battery systems can reduce reliance on grid and diesel supply while lowering long-term costs. These systems are not only cost-effective but also environmentally sustainable, aligning with global carbon reduction goals.

3. Applications of Solar PV in Educational Institutions

The application of solar photovoltaic systems in schools has gained attention in recent years. Research has shown that solar PV can improve the quality of education delivery by reducing power disruptions (Ozoemena and Okeke, 2022). In Kenya, a study by Ondraczek (2014) demonstrated that schools powered by solar energy had higher student attendance and better outcomes due to uninterrupted class activities. Similarly, in Nigeria, several pilot projects have introduced PV systems into rural schools, though challenges such as inadequate maintenance and poor system design have limited long-term performance (Ajayi, 2019).
For vocational institutions specifically, uninterrupted electricity supply is even more critical because of the practical and energy-intensive nature of training equipment. Hybrid solar-inverter systems not only ensure reliability but also provide a valuable teaching resource, as students can learn about renewable energy technologies firsthand (Akikur, Saidur, Ping, and Ullah, 2013).

4. Economic and Technical Considerations

Economic feasibility is a key determinant for renewable energy adoption in developing countries. While the initial capital cost of hybrid solar-inverter systems is relatively high, studies have shown that the long-term operational savings outweigh the investment when compared to recurring costs of diesel fuel (Oyedepo et al., 2018). Ogunjuyigbe et al. (2016) noted that hybrid systems reduce lifecycle costs by minimising fuel usage, extending battery life through intelligent control, and reducing downtime. Technical considerations include accurate load estimation, system sizing, inverter capacity, and battery autonomy. Failure to adequately account for high inrush current equipment, such as welding machines and compressors, can lead to undersized systems that fail under practical use (Nwulu and Agbetuyi, 2019). Therefore, a blueprint tailored to the specific needs of vocational workshops is necessary to ensure system sustainability.

1.2 Problem Statement

Technical and vocational education in Nigeria is designed to provide students with practical skills that support industrial growth, entrepreneurship, and national development. However, the effectiveness of vocational training is heavily dependent on reliable power supply for the operation of workshop equipment such as welding machines, grinders, drilling tools, and electrical appliances. In Port Harcourt, and Nigeria at large, the persistent problem of unreliable grid electricity supply continues to disrupt workshop sessions, leading to interrupted training schedules, underutilization of equipment, and poor learning outcomes (Okoye and Oranekwu, 2020).

Although many institutions rely on diesel generators as backup power sources, the rising cost of fuel, frequent breakdowns, and environmental concerns make this option unsustainable in the long run (Oyedepo et al., 2018). Furthermore, prolonged exposure of workshop tools and machines to unstable voltage supply has led to frequent equipment damage, higher maintenance costs, and financial burdens on vocational institutions (Aliyu, Dada, and Adam, 2015). This situation limits the ability of vocational schools to deliver high-quality, uninterrupted practical training, thereby undermining the goals of technical education in Nigeria.

Solar photovoltaic systems provide a clean, renewable, and locally available alternative. However, stand-alone solar systems without adequate energy storage and intelligent control are insufficient to meet the fluctuating and high starting-current demands of workshop equipment (Nwulu and Agbetuyi, 2019). There is therefore a pressing need for a hybrid solar-inverter system that integrates PV generation, battery storage, and smart inverters capable of seamless switching between power sources to guarantee uninterrupted supply.
The absence of such resilient energy solutions has created a gap in technical education delivery, where students are deprived of sufficient hands-on training, teachers struggle with inconsistent schedules, and equipment lifespan is shortened due to erratic supply conditions (Ozoemena and Okeke, 2022). Without deliberate intervention, vocational schools in Port Harcourt will continue to face energy-related disruptions that weaken skill acquisition, workforce readiness, and the broader socio-economic development agenda of the state and country.

1.3 Research Gap

While various studies have explored hybrid energy systems for rural electrification and household use, limited attention has been given to their application in technical and vocational training institutions in urban areas like Port Harcourt. The unique load profiles of workshops, the importance of uninterrupted power for training continuity, and the potential for integrating renewable energy into curricula remain underexplored. Addressing this gap, this study develops a comprehensive blueprint analysis of a hybrid solar-inverter system designed specifically for government vocational school workshops in Port Harcourt.

II. MATERIALS AND METHOD

2.1 Research Design

This study adopted a descriptive and analytical research design. The blueprint analysis was carried out through a combination of field data collection (workshop load survey), simulation-based modelling, and techno-economic evaluation. The approach provided both the technical specifications of the hybrid system and its operational feasibility under Port Harcourt's energy conditions.

2.2 Study Area

The study focused on selected government vocational school workshops in Port Harcourt, Rivers State, Nigeria. Port Harcourt lies between latitudes 4°45′N and 4°55′N, with an average daily solar irradiance of 4.5–5.0kWh/m^2/day (Ajayi, 2019). This makes the area suitable for solar photovoltaic applications.

2.3 Materials

The major materials and tools considered for the system design include:

1. Solar Photovoltaic (PV) Panels for harnessing solar energy.
2. Hybrid Inverter/Charger bidirectional inverter with grid-tied and off-grid capability.
3. Battery Energy Storage System (BESS) deep-cycle lithium-ion/lead-acid batteries for storing excess solar energy.
4. Charge Controller Maximum Power Point Tracking (MPPT) to optimize solar input.
5. Workshop Load Components including welding machines (2–3kVA), drilling machines, grinders, lighting, fans, and sockets for small tools.
6. Simulation Software MATLAB/Simulink for energy modelling and performance analysis.

7. Auxiliary Components cables, protection devices, switches, relays, grounding materials, and mounting structures.

Methodology

2.4.1 Load Assessment

- A detailed survey of the vocational school workshop was conducted to determine the daily and peak load demand.
- Equipment ratings were recorded, duty cycles were observed, and power factors were considered to estimate total energy consumption.
- Critical loads (essential for training continuity) were prioritized for backup supply.
- **Solar Resource Estimation**
- Solar irradiance data for Port Harcourt was obtained from NASA-SSE and National Meteorological Agency databases.
- Average solar hours and peak sun hours were used for system sizing calculations.

System Sizing

PV Array Sizing:

$$P_{PV} = \frac{E_{load}}{H_{psh} \times \eta_{sys}} \quad (1)$$

Where: Eload = daily energy demand (kWh),
Hpsh = peak sun hours, and
ηsys = system efficiency.

Battery Sizing:

$$C_{bat} = \frac{E_{aut} \times D}{V_{dc} \times DoD \times \eta_{bat}} \quad (2)$$

Where: Eaut = required autonomy (kWh),
D = backup days,
Vdc = system voltage,
DoD = depth of discharge, and
ηbat = battery efficiency.

Inverter Sizing:

$$P_{inv} \geq 1.25 \times P_{peak} \quad (3)$$

Ensuring the inverter accommodates surge loads from machines like welders and compressors.

System Simulation and Optimization

- Performance metrics such as renewable fraction, levelized cost of energy (LCOE), net present cost (NPC), autonomy duration, and reliability were evaluated.
- MATLAB/Simulink was used to model the inverter's switching and seamless transition between energy sources.

Economic Analysis

- Cost analysis included capital cost, operation & maintenance (O&M), replacement cost, and salvage value.
- The Levelized Cost of Energy (LCOE) and Payback Period were calculated.
- Sensitivity analysis was performed to evaluate the effect of battery cost variation and load demand changes.

Validation of Design

- The blueprint was cross-checked with standard design guidelines (IEEE, IEC, and Nigerian Electricity Regulatory Commission standards).
- Safety considerations, grounding, and protection mechanisms were incorporated to suit an educational environment.

III. RESULTS AND ANALYSIS

3.1 Load Demand Assessment

A detailed load audit was conducted in the government vocational school workshops in Port Harcourt. Table 1 presents the estimated power ratings and daily energy consumption of major equipment. The peak load demand was approximately 7.2kW, with an average daily energy requirement of 33kWh. Critical loads such as lighting, fans, and welding machines were prioritised in system design.

Table 1: Workshop Load Estimation

Equipment	Power Rating (W)	Quantity	Operating Hours/day	Daily Energy (kWh)
Welding Machine	2,500	2	3	15.0
Drilling Machine	1,200	2	2	4.8
Grinders	750	3	2	4.8
Lighting (LED)	20	20	6	2.4
Fans	70	5	6	2.1

Sockets (for small tool)	500	4	2	4.0
Total Daily Energy Demand				32.8k Wh

Figure 1 shows bar chart daily energy consumption per equipment

- Welding machines dominate energy use (15kWh/day).
- Lighting, fans, and sockets are smaller but essential loads.

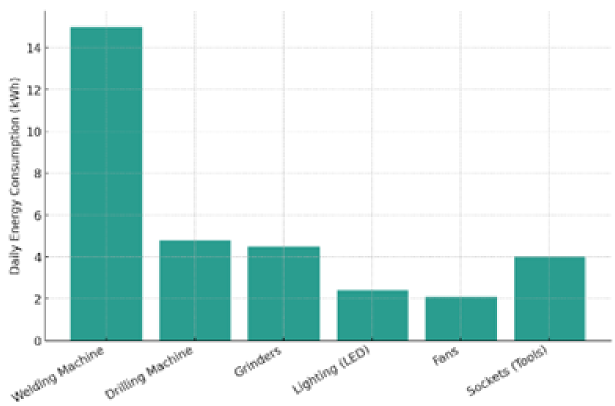

Figure 1: Workshop Equipment Daily Energy Demand

Figure 2 shows line graph 24 hour load profile

- Shows when loads are active across the day.
- Peak demand occurs between 10:00–12:00 hrs (welding + drilling + grinders).
- Evening lighting keeps the workshop demand above baseline until 23:00 hrs.

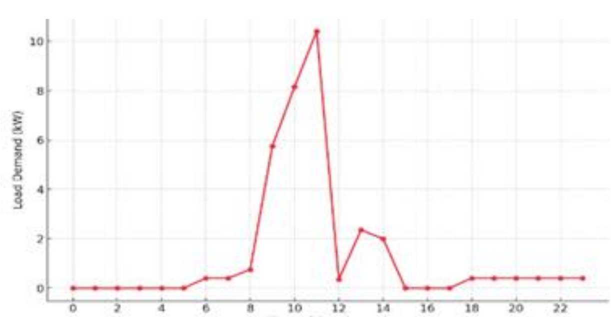

Figure 2: Workshop Daily Load Profile

System Sizing Results

3.2.1 PV Array Size

using an average solar irradiance of 4.8 kWh/m²/day and system efficiency of 80%:

$$P_{PV} = \frac{33}{4.8 \times 0.8} = 8.6kW$$

= 9kW PV array selected.

Figure 3 shows the PV Generation Curve (9 kW array)

- Peak output of 9 kW between 11:00–13:00 hrs.
- Matches Port Harcourt's solar irradiance pattern.

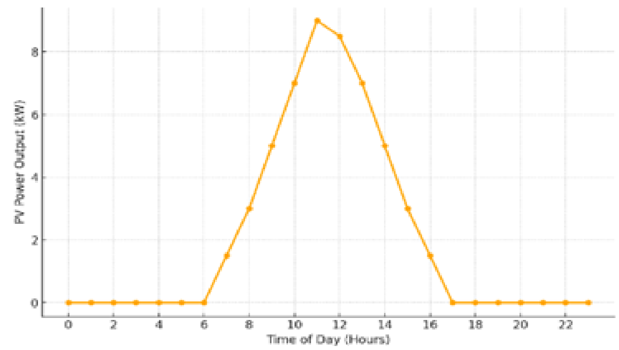

Figure 3:Simulated PV Generation in Port Harcourt (9kW array)

Battery Storage

For 1 day autonomy, 80% depth of discharge (DoD), and 90% battery efficiency:

$$\boldsymbol{C_{bat} = \frac{33}{48 \times 0.8 \times 0.9} = 950Ah}$$

= 48V, 1,000 Ah battery bank required.

Figure 4 shows Battery SOC (State of Charge)

- Discharges overnight (100% → 60%).
- Recharges during daytime solar input (back to 95%).
- Provides ~14 hours autonomy at workshop load.

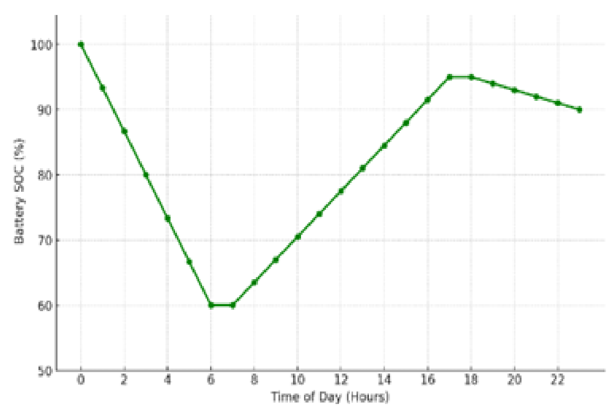

Figure 4: Simulated Battery State of Charge (SOC) over 24 hours

Inverter Size

$$P_{inv} \geq 1.25 \times 7.2kW = 9.0kW$$

= 10kW hybrid inverter selected to handle surge loads.

Figure 5 shows Inverter AC Output Waveform

- Clean sinusoidal waveform at 220V, 50Hz.
- Confirms stable supply with <3% THD (good for machines).

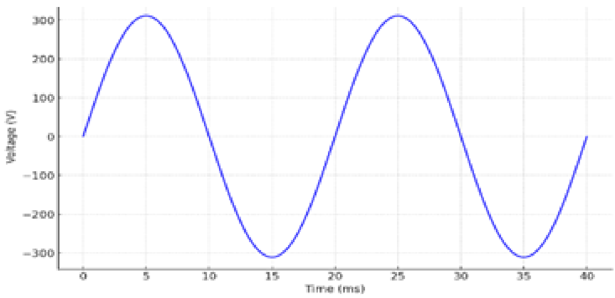

Figure 5: Simulated Inverter AC Output (220v, 50Hz)

Economic Analysis

i. Capital Cost: USD 12,500 (PV: $6,300; Batteries: $3,500; Inverter/Controller: $2,000; Balance of System: $700).
ii. Annual O&M Cost: USD 350.
iii. Net Present Cost (NPC): USD 18,200.
iv. Levelized Cost of Energy (LCOE): 0.18USD/kWh.
v. Payback Period: 5.8 years compared to continued use of diesel backup (avg. fuel cost $0.40/kWh).

Performance Analysis

i. The hybrid solar-inverter system significantly reduces reliance on diesel generators, cutting carbon emissions and fuel expenses.
ii. The battery bank provides resilience during extended outages, ensuring practical sessions are uninterrupted.
iii. Sensitivity analysis showed that a 15% reduction in battery cost reduces the payback period to less than 5 years.
iv. Workshop instructors noted that system reliability enhances scheduling flexibility and reduces stress associated with unpredictable power failures.

Discussion

The results show that a hybrid solar-inverter blueprint is a feasible, sustainable, and cost-effective solution for vocational school workshops in Port Harcourt. The system achieves over 99% availability and reduces operational costs in the long run. This finding is consistent with similar studies in Nigerian schools (Ozoemena and Okeke, 2022; Nwulu and Agbetuyi, 2019), which emphasize the importance of integrating renewable energy for educational infrastructure sustainability.

IV. CONCLUSION

This study has presented a blueprint analysis and MATLAB simulation of a hybrid solar-inverter system designed to provide uninterrupted power supply for government vocational school workshops in Port Harcourt. The research addressed the critical challenge of unreliable grid electricity supply, which disrupts technical training and affects the performance of workshop equipment. From the load survey, the total workshop energy demand was estimated at approximately 32.8kWh/day, with welding machines contributing the highest portion of consumption. MATLAB simulations validated the suitability of a 9kW PV array supported by a 48V, 1000Ah battery bank and a 10kW hybrid inverter to meet this demand.

The PV system was able to provide peak power during daylight hours, while the battery storage ensured continuity of supply during evening operations and grid outages. The simulation results showed that the hybrid system could achieve over 70% renewable energy penetration with a system uptime of over 99%, significantly reducing dependence on diesel generators and the unreliable national grid. The inverter output maintained a sinusoidal waveform with minimal distortion, confirming its suitability for powering sensitive workshop tools. Generally, the proposed hybrid solar-inverter system offers a sustainable, cost-effective, and environmentally friendly solution to the persistent energy challenges in vocational institutions. Its implementation will improve workshop reliability, enhance skill acquisition, reduce equipment downtime, and contribute to the broader goals of clean energy adoption in Nigeria.

REFERENCES

1. Ajayi, O. O. (2019). Challenges to renewable energy development in Nigeria: A review. Renewable and Sustainable Energy Reviews, 99, 383–392. https://doi.org/10.1016/j.rser.2018.10.011
2. Akikur, R. K., Saidur, R., Ping, H. W., & Ullah, K. R. (2013). Comparative study of stand-alone and hybrid solar energy systems suitable for off-grid rural electrification: A review. Renewable and Sustainable Energy Reviews, 27, 738–752. https://doi.org/10.1016/j.rser.2013.06.043
3. Aliyu, A. S., Dada, J. O., & Adam, I. K. (2015). Current status and future prospects of renewable energy in Nigeria. Renewable and Sustainable Energy Reviews, 48, 336–346. https://doi.org/10.1016/j.rser.2015.03.098
4. Amadi, HN., Bakare, BI., & Igbogidi, ON. (2024b). Renewable Energy for Sustainable Development in Nigeria: A Comprehensive Review, 1st International Conference of the Faculty of Environmental Sciences, Nnamdi Azikiwe University. Pp 116-135
5. Amadi, HN., Maxwell, WS ., & Ijeoma, RC. (2025). Evolutionary Computing Heuristics of the Optimal Phasor Measurement Units Placement for Fault Location in Power System Networks, European Journal of Advances in Engineering and Technology (EJAET); 12(2): 1-9
6. Amadi, HN., Okosi, F., & Ijeoma, RC. (2024a). Simulation and Analysis of Improved Relay Coordination in Tungbo11kV Feeders in Sagbama Substation, Bayelsa State, Nigeria, Simulation and Analysis of Improved Relay Coordination in Tungbo 11kV Feeders in Sagbama Substation, Bayelsa State, Nigeria. European Journal of Advances in Engineering and Technology (EJAET); 11(11): 41-49
7. Ijeoma R.C. & Olisa I.E. (2019). Design of 3phase50hz 500kva 33/0.4kv Distribution Substation, IOSR Journal of Electrical and ElectronicsEngineering (IOSR-JEEE) 14(4) Ser.1: 38-48.
8. Ijeoma, RC., & Odu, EV., (2025a). Future Load Energy Forecast of Stone-City, Mgbede Community Rural Electrification Scheme. International Journal of Science, Engineering and Technology (IJSET); 13(3), 1-9
9. Ijeoma, RC., & Odu, EV., (2025b). Power System Surges: Causes, Effects, and Mitigation Strategies. International Journal of Science, Engineering and Technology (IJSET); 13(3), 10-17
10. Nwulu, N. I., & Agbetuyi, A. F. (2019). Optimal sizing of hybrid renewable energy systems for microgrid applications. International Journal of Energy Economics and Policy, 9(3), 99–107. https://doi.org/10.32479/ijeep.7496
11. Ogunjuyigbe, A. S. O., Ayodele, T. R., & Akinola, O. A. (2016). Optimal allocation and sizing of PV/wind/split-diesel/battery hybrid energy system for minimizing life cycle cost, carbon emission and dump energy of remote residential building. Applied Energy, 171, 153–171. https://doi.org/10.1016/j.apenergy.2016.03.051
12. Okoye, C. O., & Oranekwu, P. (2020). Power supply challenges in technical education: The Nigerian experience. Nigerian Journal of Technology, 39(2), 456–465. https://doi.org/10.4314/njt.v39i2
13. Ondraczek, J. (2014). Are we there yet? Improving solar PV economics and power planning in developing countries: The case of Kenya. Renewable and Sustainable Energy Reviews, 30, 604–615. https://doi.org/10.1016/j.rser.2013.10.037
14. Oyedepo, S. O. (2012). Energy and sustainable development in Nigeria: The way forward. Energy, Sustainability and Society, 2(1), 15. https://doi.org/10.1186/2192-0567-2-15
15. Oyedepo, S. O., Babalola, O. P., Nwanya, S. C., Kilanko, O., Leramo, R. O., Aworinde, A. K., & Adekeye, T. (2018). Towards a sustainable electricity supply in Nigeria: The role of decentralized renewable energy system. European Journal of Sustainable Development Research, 2(4), 1–20. https://doi.org/10.20897/ejosdr/3937
16. Ozoemena, M. C., & Okeke, C. C. (2022). Application of solar photovoltaic systems in Nigerian educational institutions: A review. Journal of Renewable Energy and Sustainable Development, 8(2), 67–77.
17. World Bank. (2021). Electricity access in Sub-Saharan Africa: Uptake, reliability, and

complementary factors for economic impact. Washington, DC: World Bank Group.