DEVELOPMENT OF 5kVA 48V HYBRID SOLAR INVERTER

BY

GEORGE CHIOMA ESTHER

ENG2002661

UNIVERSITY OF BENIN

BENIN CITY.

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A PROJECT SUBMITTED TO THE DEPARTMENT OF PRODUCTION ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B.Eng) IN THE DEPARTMENT OF PRODUCTION ENGINEERING, FACULTY OF ENGINEERING.

SUPERVISOR: PROF. O. O. OGBEIDE

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CERTIFICATION

This is to certify that this project work was carried out **GEORGE CHIOMA ESTHER,** with Matriculation Number **ENG2002661,** of the Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.

DEDICATION

I solemnly dedicate this project to The Almighty God for His grace and guidance that has sustained me throughout my entire academic run and shall continue to do so in all aspects of life.

I would also like to dedicate this work to my lovely family, whose unwavering love, sacrifices and encouragements carried me all through till where I am now. Your support means everything to me.

Prof. O. O. Ogbeide

(Project Supervisor)

Engr. Dr. (Mrs). I.C. Iluobe

(Project Coordinator)

Date

14/05/2026

Prof. P. E. Amiolehmen

(Plead of Department)

Date

14/5/2026

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ABSTRACT

This project focuses on the development of a 5kVA, 48V hybrid solar inverter system aimed at providing a reliable and sustainable energy solution for domestic and small-scale applications. The system integrates solar photovoltaic (PV) energy with utility grid supply to ensure an uninterrupted power source, with solar energy serving as the primary supply and the grid as backup. A hybrid charging approach was adopted to maintain adequate battery capacity during periods of low solar irradiation.

The inverter was designed to deliver a stable output suitable for powering common household and office appliances, while incorporating essential protection features to enhance system safety, efficiency, and reliability. Performance evaluation showed that the inverter provided consistent output with smooth changeover between power sources and improved energy efficiency. The project demonstrates a cost-effective and environmentally friendly alternative to fuel-powered backup systems, reducing, dependence on the national grid and promoting cleaner energy usage.

TABLE OF CONTENT

TABLE OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Reliable electricity is essential for socio-economic development, supporting education, healthcare, and economic productivity. In Nigeria, the energy sector struggles, with approximately 40% of the population—over 80 million people—lacking access to electricity (International Energy Agency [IEA], 2022). Frequent power outages and limited grid coverage force reliance on diesel generators, which are costly and contribute to greenhouse gas emissions (IPCC, 2022). This energy access gap hinders Nigeria's progress toward Sustainable Development Goal 7 (SDG 7), which emphasizes affordable and clean energy (United Nations, 2015). Solar photovoltaic (PV) systems offer a sustainable solution for off- grid applications, but their effectiveness relies on critical components like inverters, which convert direct current (DC) to alternating current (AC) for household and small enterprise use. This study focuses on designing a 5kVA solar inverter using analog switching control to address technical and economic barriers in Nigeria's energy sector, prioritizing affordability and local maintainability.

In off-grid solar PV systems, inverters are critical for converting DC electricity from solar panels and batteries into AC electricity for appliances. A 5kVA inverter can power essential loads, such as lighting, refrigeration, and communication devices, suitable for Nigerian households and small enterprises (Oyedepo, 2012). Commercial inverters, however, are often expensive and prone to failure under Nigeria's environmental conditions, such as high temperatures and variable loads (Emodi & Boo, 2015). Many rely on complex microcontroller-based . systems, which require specialized tools and expertise for maintenance, often unavailable in Nigeria's technical ecosystem (Adesanya & Pearce, 2019). Analog switching control, using pulse-width modulation (PWM), offers a simpler alternative, enabling local technicians to service inverters with standard tools

(Blaabjerg, 2014). This project aims to develop a 5kVA inverter that enhances reliability, reduces costs, and supports Nigeria's renewable energy goals.

1.1.1 Technical Challenges in Inverter Design

Designing a reliable and cost-effective solar inverter involves addressing key challenges in power electronics.

i. Heat dissipation is critical, as high temperatures in Nigeria can cause overheating and reduce inverter lifespan (Mohan et al., 2014).

ii. Harmonic distortion must be minimized to ensure stable AC output, adhering to standards like IEEE 519 (IEEE, 2014).

iii. Transformer selection and protective circuitry are essential to handle variable loads and prevent failures from overloads or short circuits (Blaabjerg, 2014).

iv. Cost-effectiveness requires using locally sourced materials to lower production costs while maintaining performance (Adesanya & Pearce, 2019). This project leverages analog control to create a robust, user-friendly inverter tailored to Nigeria's needs.

Nigeria's energy challenges necessitate affordable and reliable inverters to support solar PV adoption. Commercial inverters, often imported, are costly and fail under local conditions, such as extreme heat and dust (Emodi & Boo, 2015). Their maintenance challenges exacerbate energy poverty. Analog-based inverters simplify design and repair, enabling local fabrication and maintenance (Adesanya & Pearce, 2019). This project aligns with Nigeria's renewable energy policies, which aim to expand renewable energy access, and supports SDG 7's goal of universal energy access (Federal Ministry of Power, 2014; United Nations, 2015). By focusing on a locally designed 5kVA inverter, the study addresses technical and socioeconomic barriers to solar energy adoption.

1.1.2 Academic and Practical Context.

This project integrates principles from power electronics, thermal management, and materials science, offering a platform for academic innovation in engineering education (Adesanya & Pearce, 2019). It responds to the need for context-specific energy solutions in developing countries, where technical and economic barriers limit renewable energy adoption (Emodi & Boo, 2015). The emphasis on analog control enhances maintainability, fostering technical skill development and grassroots innovation (Oyedepo, 2012). By addressing the gap in affordable, locally designed inverters, the project contributes to Nigeria's energy sector and serves as a model for Sub-Saharan African countries

1.2 Statement of the Problem

Nigeria's national grid supplies only a fraction of the country's electricity needs, leaving around 40% of the population without access to power. This has led to dependence on expensive, polluting diesel generators, worsening energy poverty. While solar PV systems are a sustainable alternative, their adoption is hindered by the high cost and poor reliability of inverters, especially under Nigeria's high temperatures and variable loads. Commercial 5kVA inverters are often unsuitable and difficult to maintain locally due to their complex microcontroller-based designs. This lack of affordable, reliable, and locally maintainable inverters limits off-grid solar deployment, hindering progress toward universal energy access. There is thus an urgent need for a cost-effective, analog-based 5kVA inverter designed for local fabrication to improve accessibility, reliability, and maintainability, supporting Nigeria's renewable energy goals.

1.3 Aim and Objectives of the Study

1.3.1 Aim of the Study

The aim of this study is to design, fabricate, and test a 5kVA off-grid solar inverter tailored to Nigeria's environmental and economic conditions, utilizing analog switching control to ensure affordability, reliability, and local maintainability. This project seeks to address the energy access gap by providing a technically robust and context-specific solution for household and small enterprise electrification in Nigeria.

1.3.2 Objectives

i. To design a 5kVA solar inverter with analog switching control, optimized for Nigeria's environmental and electrical conditions.

ii. To fabricate a prototype using locally available materials and components to enhance cost-effectiveness and accessibility.

iii. To test the inverter's performance under real-world conditions, including high temperatures and variable loads, to ensure reliability and efficiency.

iv. To evaluate the inverter's maintainability by local technicians, ensuring the analogbased design can be serviced with widely available tools and expertise.

v. To assess the inverter's potential for scalability and community-scale deployment, contributing to Nigeria's renewable energy goals and Sustainable Development Goal 7.

1.4 Scope of the Work

This project focuses on the design, fabrication, and testing of a 5kVA off-grid solar inverter tailored for Nigeria's household and small enterprise applications. The study emphasizes developing an analog-based inverter to ensure affordability and maintainability, utilizing locally sourced materials where feasible. The design process will address technical challenges, such as heat dissipation, harmonic distortion, and voltage stabilization, to ensure compatibility with Nigeria's environmental conditions. The fabrication phase will involve constructing a prototype in a controlled laboratory setting, followed by performance testing under real-world conditions. The project will evaluate the inverter's maintainability by local technicians, focusing on the simplicity of the analog control system. The scope is limited to a single 5kVA inverter prototype and excludes other balance-of-system components, such as solar panels or batteries, as well as large-scale deployment.

The study aligns with engineering principles and Nigeria's renewable energy objectives.

1.5 Significance of the Study

1.5.1 Academic Contributions

This project contributes to academic knowledge by integrating principles from power electronics, thermal management, and materials science.

i. It provides a hands-on opportunity for students to apply theoretical concepts to a real- world engineering challenge, fostering innovation (Adesanya & Pearce, 2019).

ii. The design and testing of an analog-based 5kVA inverter address technical issues like harmonic distortion and heat dissipation, advancing power electronics research (Blaabjerg, 2014).

iii. The focus on context-specific solutions responds to the need for sustainable engineering in developing countries (Emodi & Boo, 2015).

1.5.2 Practical and Societal Impact

i. The project has significant practical implications for Nigeria's energy sector.

ii. By developing an affordable, locally maintainable 5kVA inverter, it addresses the high cost and unreliability of commercial inverters (Oyedepo, 2012).

iii. The analog-based design enables local technicians to service the inverter, reducing maintenance costs and enhancing longevity (Adesanya & Pearce, 2019).

iv. The inverter's 5kVA capacity supports essential loads in households and small enterprises, improving quality of life and economic productivity.

1.5.3 Policy and Regional Relevance

i. The project aligns with Nigeria's renewable energy policies, which aim to increase renewable energy access (Federal Ministry of Power, 2014).

ii. It supports the deployment of off-grid solar systems, contributing to SDG 7's goal of universal energy access (United Nations, 2015).

iii. The focus on local fabrication could stimulate private-sector participation and small- scale manufacturing (Emodi & Boo, 2015).

iv. The project serves as a model for Sub-Saharan African countries facing similar energy challenges.

1.5.4 Environmental and Economic Benefits

i. By reducing reliance on diesel generators, the inverter promotes environmental sustainability (IPCC, 2022).

ii. The cost-effective design makes solar energy accessible to low-income households and businesses (Oyedepo, 2012).

iii. Local maintainability ensures long-term viability, addressing a key barrier to renewable energy adoption.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This literature review highlights the critical role of solar photovoltaic systems in addressing Nigeria's need for reliable, affordable, and decentralized electricity, emphasizing the inverter's function in converting DC to AC for practical use. It outlines the operating principles and system-level interconnections of PV system components, including solar panels, charge controllers, batteries, and inverters, while focusing on semiconductors and waveform regulation essential for analog inverter design in hot, resource-limited environments.

Additionally, the review critically examines past projects and studies on inverter development and solar system integration, identifying design strategies, control methods, and technical challenges, particularly in the Nigerian and Sub-Saharan African context. It also identifies research gaps in cost-efficiency, scalability, and maintainability, thereby justifying the project's aim to develop a robust, analog-controlled, locally maintainable 5kVA solar inverter system tailored for sustainable rural and urban electrification in Nigeria.

2.2 Theoretical Review

To guide the design and development of an efficient and locally adaptable off-grid solar inverter system, it is important to first establish a solid understanding of the underlying principles and functional components of photovoltaic (PV) systems. This section provides a theoretical review of the key subsystems—solar panels, charge controllers, batteries, and inverters—and the working principles that govern their operation.

2.2.1 Components of a PV Solar Energy System

This section provides a comprehensive review of the key components and operating principles of photovoltaic (PV) solar energy systems. It outlines the structure and function of each part of the system and explains the theoretical concepts that govern their operation. The subsections below describe the components and their working principles in detail.

2.2.1.1 Solar Panels

Solar panel types include:

Monocrystalline Panels: Known for high efficiency (typically 15-20%) and space efficiency due to their uniform crystalline structure. They are, however, more expensive and are often used in space-constrained applications.

Polycrystalline Panels: These have slightly lower efficiencies (13-16%) but offer a lower cost per watt due to their simpler manufacturing process. They are created by melting and casting multiple silicon crystals together, making them suitable for cost-sensitive applications

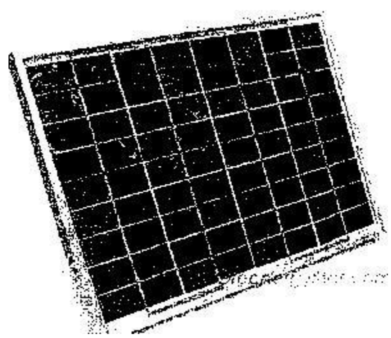

Figure 2.1: **Polycrystalline Panel, source:**

Thin-Film Panels: With efficiencies ranging from 6-12%, these panels use materials like amorphous silicon (a-Si), cadmium telluride (CdTe), or copper indium gallium selenide

(CIGS). While flexible and lightweight, they are less favored for off-grid systems due to lower output.

In Nigeria, where solar irradiance averages 5.5 to 7.0 $kWh/m^2/day$ (World Bank, 2020), polycrystalline panels offer a practical trade-off between cost and performance. They remain the preferred option in many installations owing to economic constraints and ample space in rural deployment zones.

2.2.1.2 Charge controller:

The charge controller serves as an intermediary between solar panels and batteries, regulating voltage and current to protect the storage system. It ensures optimal charging and prevents overcharging, deep discharging, or reverse current flow. Two major technologies dominate this domain:

Pulse-Width Modulation (PWM) Controllers: These maintain a fixed voltage level while modulating the current through high-frequency switching. PWM technology is simple and cost-effective, yielding efficiencies of approximately 75-80%. The average voltage delivered to the battery can be calculated by:

$$V_{avg}=Dxy_{in}$$

where: $\mathbf{V_{avg}}$ = Average output voltage,

$\boldsymbol{D}$ = Duty cycle ($0 < D < 1$),

V_{in}= Input voltage from the PV module.

Maximum Power Point Tracking (MPPT) Controllers: These are more advanced, dynamically adjusting voltage and current input to align with the maximum power point of the solar array, resulting in 90-95% efficiency. However, their cost and complexity may limit use in low-resource settings like rural Nigeria.

For the design of an affordable and locally maintainable 5kVA solar inverter, PWM controllers are preferred, though MPPT may be integrated in higher-tier applications to enhance power capture efficiency.

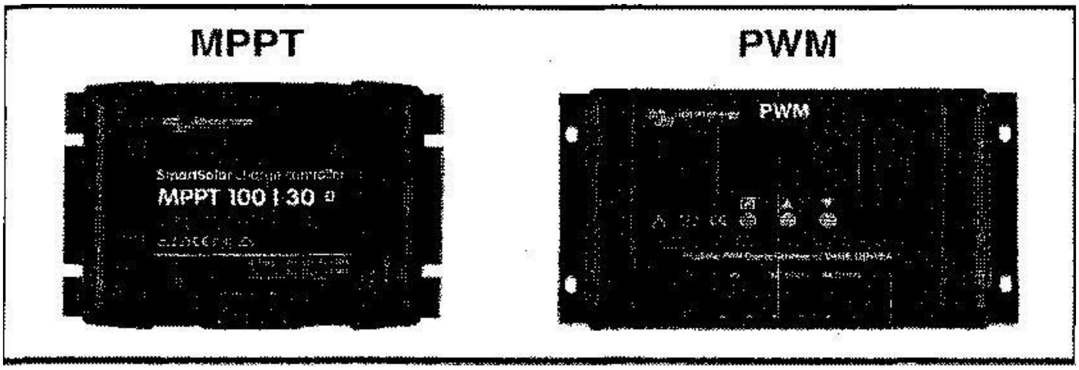

Figure 2.2: ***Maximum Power Point Tracking (MPPT) Controllers and Pulse-Width Modulation (PWM) Controllers***

2.2.1.3 Battery/Storage

Batteries store energy for use during nighttime or cloudy weather, ensuring continuous power availability. The most common battery types used in off-grid solar systems include:

Lead-Acid Batteries: These are relatively inexpensive and available in both flooded and sealed types. They have a typical lifespan of 3-5 years and support a depth of discharge (DoD) of approximately 50%. However, they require regular maintenance, including checking electrolyte levels and avoiding deep discharges that lead to sulfation.

Lithium-Ion Batteries (LiFePCL): Although expensive, these batteries offer superior performance, longer lifespan (up to 10-15 years), and higher DoD (up to 80-90%). They also have better thermal stability and efficiency but require protection circuitry to avoid damage from overcharge or overheating.

The energy storage capacity of a battery is expressed by:

$$\mathbf{E = V \times Ah}$$

where: ***E*** = *Energy (in watt — hours'),*

V = *Battery voltage (Volts),*

Ah **—** *Ampere — hour rating of the battery.*

2.2.1.4 Inverter

The inverter is a central component that transforms stored DC energy into usable AC power. For the proposed system, a 5kVA inverter will be developed using analog switching control. Unlike digital inverters that rely on microcontrollers or DSP chips, analog inverters employ PWM integrated circuits like SG3525 or TL494 to control gate signals for switching devices such as MOSFETs or IGBTs.

Analog control offers enhanced reliability and local maintainability since it requires no programming, firmware updates, or specialized diagnostic tools. A typical inverter block consists of a DC input stage, oscillator-based PWM generator, full-bridge (H-bridge) switching stage, and an LC low-pass output filter.

Inverter efficiency is evaluated as:

$$B = (Pout/Pin) \times 100\%$$

where: P_{out} = *Output AC power,*

P_{in} = *Input DC power.*

The inverter must also meet waveform quality standards, with Total Harmonic Distortion (THD) ideally below 5% to prevent overheating and malfunction of connected appliances.

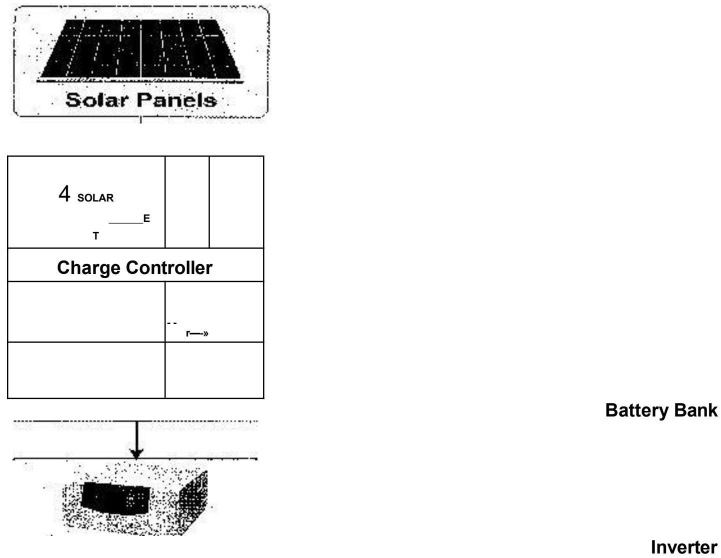

Figure 2.4: Stand-alone Solar Power System Diagram

2.2.2 Relevant Working Principles

Understanding the operational principles underlying each component of a photovoltaic system is crucial for optimizing its performance and ensuring proper integration. For a 5kVA inverter system, particular attention must be paid to the mechanisms of energy generation, regulation, conversion, and storage.

2.2.2.1 Photovoltaic Effect

The photovoltaic (PV) effect is the fundamental process by which sunlight is converted into electrical energy within a solar cell. When incident photons strike the surface of a

semiconductor, such as silicon, their energy is transferred to electrons. If this energy exceeds the band gap of the material (1.12 electron volts for crystalline silicon), electrons are excited from the valence band to the conduction band, creating electron-hole pairs.

These charge carriers are then separated by the built-in electric field at the p-n junction of the cell. Electrons move toward the n-type side, and holes toward the p-type side, generating a current when an external circuit is connected. The open-circuit voltage (Voc) and short-circuit current (Isc) define the electrical potential of the cell.

The power output at the Maximum Power Point (MPP) is expressed as:

$$P\_max = V\_mp \times I\_mp$$

where: V_mp = *Voltage at maximum power point,*

I_mp = *Current at maximum power point.*

The **quantum efficiency** of a solar cell—defined as the number of collected charge carriers per incident photon—is a key performance metric. High-quality monocrystalline and polycrystalline cells typically achieve quantum efficiencies of 80-90%.

2.2.2.1 Pulse-Width Modulation (PWM)

PWM is a switching technique used to control voltage and current delivery in both inverters and charge controllers. In PWM, a high-frequency signal (typically 10-20 kHz) rapidly switches the DC input voltage, producing a pulse train with variable duty cycle. The duty cycle determines the average voltage and power output.

The average output voltage of a PWM signal is given by:

$$V_{out} = D \times V_{in}$$ *where:*

V_{out} — *Average output voltage,*

V_{in} = *Input voltage,*

D = *Duty cycle* (0 *to* 1).

In an inverter, this high-frequency PWM signal is passed through a low-pass LC filter to approximate a sinusoidal waveform, suitable for powering AC appliances. PWM enables precise control of voltage and frequency, both of which are essential for appliance safety and system efficiency.

2.2.2.3 Battery Charging and Discharging

The charge controller regulates the flow of current into and out of the battery, ensuring safe charging while protecting battery life. For lead-acid batteries, charging typically proceeds in three stages: bulk, absorption, and float. PWM controllers modulate current during these stages to maintain battery health.

Overcharging causes excessive gassing and heat, while deep discharging leads to sulfation of the lead plates, significantly reducing battery capacity and lifespan. The depth of discharge (DoD) indicates the proportion of battery capacity that has been used and is a critical design consideration.

To ensure proper sizing and management of battery storage, energy demand and battery capacity are related through the formula:

$$\textit{Ahyrequired} = (\textit{Daily Load} \times \textit{Days of Autonomy}) / (V \times \textit{DoD} \times \textit{if})$$

where: $Ah_{required}$ = *Required battery capacity in ampere — hours,*

V = *Battery voltage,*

DoD = *Allowable depth of discharge,*

T] = *Efficiency of the battery system.*

2.2.2.4 Inverter Switching and Output Regulation

The inverter's operation relies on a full-bridge or H-bridge topology, using transistors like MOSFETs controlled by PWM signals. These transistors alternately switch the polarity of the DC supply to create an AC waveform. The quality of this waveform depends on the accuracy of the switching signals and the effectiveness of the output filter.

The RMS (Root Mean Square) value of the AC output can be derived from:

VfiMS = Vpeak/^2

To produce a 230V RMS output (as required for Nigerian appliances), the inverter must generate a peak voltage of approximately 325V.

To maintain stability under varying loads, voltage feedback is often used. In analog inverter design, voltage sensing is typically implemented via voltage dividers and error amplifiers, rather than software algorithms.

2.3 Review of Past Works

2.3.1 Review of Oyubu et al. (2024): Investigation of Efficiency Degradation of Solar Powered Street Lights in the Niger Delta Region of Nigeria

In their study, Oyubu et al. delve into a persistent yet underexamined issue in Nigeria's solar energy adoption—performance degradation of PV systems caused by environmental particulates, especially soot. Focusing on solar-powered streetlights in the Niger Delta, where unreliable grid supply led to off-grid lighting solutions, the research reveals that,these systems frequently fail within months. Over a 15-day period, the authors compared clean and soot-covered panels, observing an 80.39% drop in power output alongside 41% and 22% reductions in voltage and current. These outcomes were statistically validated using ANOVA and standard deviation, emphasizing the consistency of the results.

The study importantly shifts attention from equipment wear to environmental pollution— stemming from vehicles, generators, and industry—as a critical factor in PV performance. It advocates for incorporating local environmental conditions into system design, particularly through maintenance strategies like routine panel cleaning or protective coatings. However, the paper does not explore the broader PV system, particularly inverters and charge controllers, nor how power degradation affects their behavior—especially in analog or PWM- based inverters, which is a core concern of this project.

Despite this gap, the research is instrumental in highlighting soot as a localized environmental constraint that must influence component selection, voltage regulation, and long-term system resilience. For a 5kVA analog-controlled inverter, these insights are key to designing a system capable of handling input instability caused by polluted panels—making the study a foundational reference for environmentally adaptive inverter systems in Nigeria.

2.3.2 Review of Ibrahim et al. (2024): System Design of a Customized Solar Photovoltaic Power System for a Microcontroller-Based Weather Station in Minna, Nigeria

Further research by Ibrahim and colleagues addresses the problem experienced earlier by Oyubu et al. (2024), offering a design-focused solution to unreliable and undersized power systems in off-grid solar applications. Their study centers on the creation of a customized solar PV power pack for a weather station in Minna, Nigeria. Unlike simulation-heavy approaches, this work relies on localized environmental data and a detailed load assessment to guide the system's architecture.

The authors performed a comprehensive energy audit of microcontroller-based weather station subsystems, calculating both peak and average daily loads in watt-hours. This enabled precise specification of the PV array, battery bank, charge controller, and voltage regulator. By using real solar irradiance data, the design better reflects actual environmental conditions—something often ignored in pre-configured solar systems.

Though the project is smaller in scale than a 5kVA system, its modular methodology allows for easy adaptation. The design also considers battery depth-of-discharge, autonomy days, and system losses. Instead of addressing soot degradation directly as Oyubu et al. (2024) did, the authors integrate performance safeguards for issues like partial shading and dust accumulation through pre-emptive system sizing, thereby improving reliability from the outset.

One major contribution is the paper's emphasis on voltage regulation and component compatibility—critical areas for inverter-based designs. Although an inverter was not designed or tested, the inclusion of a voltage regulator ensures stable output to the weather station, offering indirect insights for analog-controlled inverter systems vulnerable to input voltage fluctuations.

However, limitations remain. The study assumes the availability of digital control infrastructure and does not explore inverter circuitry in depth, limiting its immediate applicability to analog-based inverter projects in low-resource settings. Still, Ibrahim et al.'s rigorous methodology and contextual adaptation make the work a valuable reference.

2.3.3 Review of Kirange et al. (2024): Prototype Development and Testing of a Low-Cost Off-Grid PV Inverter for Sustainable Energy Solutions in Remote Regions

Kirange et al. address practical challenges in bridging solar system design with inverter implementation, a gap previously identified by Oyubu et al. (2024) and Ibrahim et al. (2024). Their work moves beyond simulation by developing, prototyping, and testing a low-cost, off- grid photovoltaic inverter system specifically designed for rural and underserved communities. The system integrates a solar panel, charge controller, battery storage, and a PWM-based inverter using a simplified analog or semi-analog control design suitable for contexts lacking digital infrastructure. Performance evaluations under both simulated and real load conditions showed the inverter achieved efficiencies between 82% and 88%, maintaining stability with loads up to 500W even under variable battery voltages. Technically, the design employs an H-bridge topology driven by a low-frequency PWM oscillator, with LC filtering to approximate a sinusoidal output wavefonn, while prioritizing affordability, simplicity, and local repairability by sourcing components locally. However, the prototype's scalability remains limited, lacking thermal and electrical optimization needed for medium-power systems like the proposed 5kVA inverter, and it does not incorporate Total Harmonic Distortion (THD) measurement, which restricts its applicability in higher-load, sensitive applications. Despite these limitations, the study successfully demonstrates that locally built, low-cost PWM inverters can be practically realized and tested with available tools, showing resilience to fluctuating DC input—a critical consideration in regions where panel efficiency degrades due to environmental conditions. This work aligns with and supports the analog, maintainable design philosophy of the present 5kVA inverter project while emphasizing the practicality of deploying cost-effective inverter solutions in resource- constrained environments.

2.3.4 Review of Mousmi et al. (2023): Design and Experimental Validation of a SinglePhase Grid-Tied Inverter for Residential Low Power Applications

Mousmi et al. conducted a comprehensive study on the design, control, fabrication, and testing of a single-phase grid-tied inverter for low-power residential applications. Although tailored for systems under 1 kW, the study offers valuable insights applicable to the current 5 kVA analog-controlled inverter project—particularly in terms of reducing cost, minimizing harmonics, and simplifying implementation for off-grid environments.

The inverter delivers sinusoidal AC output with low Total Harmonic Distortion (THD), synchronized to grid frequency using a simplified zero-crossing detection method. This approach avoids complex phase-locked loops or microcontroller-based synchronization, aligning closely with the analog design philosophy of the present project.

Built around a full H-bridge topology with PWM-controlled MOSFETs, the system achieves output regulation through closed-loop analog feedback instead of software-based computation. Tests demonstrated a stable 220V RMS output, THD below 4% (within IEEE 519 standards), and 85-90% efficiency under variable loads—showcasing strong performance for PV-battery applications.

Notably, the study includes extensive experimental validation, such as oscilloscope traces and harmonic analyses, reinforcing the practical reliability of the design. However, it does not explore thermal management strategies or fully eliminate digital elements, and it assumes consistent grid availability—a potential limitation in rural Nigerian settings

Overall, the work provides a solid foundation for upscaling. Its modular, analog-centric approach—combined with proven efficiency and simplicity—makes it a valuable reference for developing the 5 kVA off-grid inverter system.

2.3.5 Review of Zegrar et al. (2023): Multilevel Inverter: Practical Design, Implementation, and Control

Zegrar et al. contribute significantly to off-grid solar inverter engineering by practically designing, constructing, and validating a five-level diode-clamped multilevel inverter (DCMLI) coupled with photovoltaic power systems. Moving beyond simulation-focused research, their work emphasizes hardware realization, waveform quality, and analog-friendly control without reliance on microcontrollers, aligning with the maintainable, analog-based design philosophy of the current 5kVA inverter project. The inverter uses MOSFETs with a hardware logic controller for phase-shifted gate triggering, producing stable output voltages with low harmonic distortion (THD <5%) while maintaining efficiency above 85% across load variations. The design adopts modular construction, facilitating voltage stability and current balancing, and was tested with an induction machine to simulate real household loads. Thermal performance is also addressed, with MOSFET temperatures maintained below 75°C using passive heatsinks and forced-air cooling. However, the system used a simulated DC source, limiting assessment of input fluctuation response, and multilevel configurations introduce complexity in capacitor voltage balancing. Despite these challenges, the study provides a complete design-to-testing pipeline and detailed insights into component selection, thermal management, and analog-compatible switching control, making it a valuable reference for scalable, locally maintainable inverter systems for rural solar electrification

2.3.6 Review of Yaswanth et al. (2024): Design of a Low Cost Simplified PWM Inverter

Yaswanth et al. present a study on the design and hardware implementation of a cost-efficient sine wave inverter using the TL494 PWM integrated circuit. The design emphasizes simplicity and analog control, aligning with the objectives of the current 5kVA inverter project focused on repairability and local component sourcing in off-grid areas.

The inverter uses an H-bridge topology with MOSFET switches driven by the TL494. The IC's internal features—error amplifier, reference voltage, dead-time control, and comparator—remove the need for microcontrollers. This reduces cost and complexity and suits environments with limited digital tools.

Hardware testing confirms steady output at 230V RMS and 50 Hz. Although waveform and harmonic analyses are absent, the design produces a clean sine wave approximation using LC filters. Reported efficiency ranges from 85-88% under nominal loads. Passive aluminum heat sinks kept MOSFET temperatures below 70°C, though higher power designs may require active cooling.

The design uses widely available components and avoids software, making it accessible to analog-trained technicians. Its structure supports training and field-level replication in low- resource regions.

Limitations include testing only with resistive loads. There is no assessment of inductive or capacitive loads, no THD data, and no battery protection or fault-handling circuits—key factors for off-grid systems.

Still, the TL494-based PWM strategy offers a solid analog control framework. For the 5kVA inverter, this study provides guidance on control circuitry, efficiency expectations, and thermal handling, while highlighting areas needing enhancement—such as load versatility, waveform quality, and protection features.

2.3.7 Review of Setiyawan and Pratomo (2025): Design and Implementation of Two- Phase Boost Inverter Using Interleaved Method to Increase Output Current

Setiyawan and Pratomo's study advances analog-based inverter design through the development of a two-phase interleaved boost inverter combined with a full-bridge DC-AC topology, aimed at improving current handling and reducing harmonic distortion—key objectives aligned with the 5kVA analog inverter project. The interleaved approach distributes current across two switching stages, reducing component stress and enhancing thermal performance, while employing sinusoidal PWM control with a 180° phase shift to minimize ripple and extend conduction time. Their system, built using analog-compatible PWM ICs such as SG3525 and TL494, achieved 220V RMS at 50 Hz with a low THD of 3.3%, adhering to IEEE 519 standards. Validation was carried out through PSIM simulations and hardware testing under resistive and inductive loads, confirming that analog-driven designs can meet high performance requirements. Although a PI controller with a digital sensor was used for current regulation, the control strategy is replicable using analog circuitry, supporting local maintainability. However, the system was tested with a fixed DC supply rather than actual PV or battery integration, leaving solar variability and MPPT considerations unaddressed. Despite this, the work demonstrates a practical, scalable analog inverter approach with low harmonic distortion and effective thermal management, offering a strong foundation for adaptation within the current 5kVA off-grid inverter project.

2.4 Synthesis of Reviewed Literature

The reviewed studies consistently highlight the increasing need for affordable, efficient, and easily maintainable off-grid solar inverter systems in resource-limited environments like Nigeria and Sub-Saharan Africa. Research in this area traces a progression from identifying off-grid electrification challenges and environmental stressors (such as fluctuating solar irradiance and high temperatures) to developing and testing prototype inverters under real- world conditions. While early works often relied on simulations, more recent studies have moved toward hardware implementation, demonstrating that analog-based PWM control using ICs like the TL494 and SG3525 can deliver stable performance if supported by adequate heat management and filtering circuits.

Despite these advancements, many existing designs remain limited to small-scale, low- wattage applications and do not address the capacity and robustness required for mediumscale systems, such as 5kVA inverters for households and small businesses. Additionally, few studies have prioritized waveform quality and harmonic suppression, critical factors for safely powering sensitive AC appliances in off-grid settings. Another recurring limitation is the heavy reliance on microcontroller-based architectures, which can hinder local repairability and scalability. This underscores a significant gap in the literature for inverter

systems that combine medium-scale capacity, waveform stability, environmental resilience,

CHAPTER THREE

METHODOLOGY

This chapter outlines the systematic approach adopted in the design and fabrication of a 5kVA solar photovoltaic (PV) power system. The methodology describes the materials used, system design calculations, sizing of components (solar panels, batteries, inverter), and installation procedures. It also explains the steps taken to ensure optimal system performance, safety, and cost-effectiveness.

3.1 Research design

This project employed an applied research design focusing on the practical implementation of a renewable energy system. The process involved:

1. A feasibility assessment (including site and load analysis)
2. System component sizing
3. Component selection
4. Procurement and fabrication
5. System assembly and testing

3.2 Load estimation

An energy audit was conducted to determine daily energy consumption. The appliances considered included lighting, fans, televisions, laptops, refrigerator, air conditioner, borehole pump, and deep freezer.

Appliance	**Quantity**	**Power Rating (W)**	**Daily Usage (In)**	**Encrgj (Wli/day)**
LED Bulbs	8	12	5	480
Ceiling Fan	2	70	8	1120
LCD TV	1	100	5	500
Laptop	1	65	6	390
Refrigerator	1	120	24 (intermittent)	1440
Air	■ 1	900	6	5400
Conditioner				

Borehole Pump	1	750	2	1500
Deep Freezer	1	200	24 (intermittent)	4800
Total	-	-	-	16,630 Wh/day (-16.6 kWh/day)

Table 3.1: Load Estimation

The estimated daily demand is approximately 16.6 kWh/day. An additional 20-25% was factored in to account for system losses, bringing the effective design load closer to 20 kWh/day.

3.2 System sizing and component selection

3.2.1 Solar Panel Sizing

The required solar array capacity was determined from:

Required Capacity = Daily Energy Demand / (Sun Hours x System Efficiency)

Given a daily demand of 20,000 Wh, average solar insolation of 5 hours/day, and efficiency of 0.8, the calculated capacity is:

20,000 / (5 x 0.8) = 5,000 W = 5 kW.

Therefore, a 5-6 kW solar array (e.g., 12 x 450 W panels) was selected.

3.2.2 Battery Sizing (48V System)

To provide one day of autonomy at 48 V system voltage and 80% depth of discharge:

Battery Capacity (Wh) = 20,000 / 0.8 = 25,000 Wh

Amp-hour = 25,000 / 48 ~ 520.8 Ah

Thus, a 48 V, 520 Ah battery bank was designed using 4 x12 V, 200 Ah deep-cycle batteries connected in series to achieve 48 V, and additional parallel strings were added to meet the required amp-hour rating.

3.2.3 Inverter Selection

The inverter serves as the central component that converts DC from the battery bank into AC for the household loads. The selection was based on the following criteria:

- The inverter must support a continuous power of 5 kVA and handle up to 2-3 times the surge loadduring startup of inductive devices such as the borehole pump and refrigerator.

- It must operate with a 48 V DC input to match the battery system.
- A pure sine wave output was selected to ensure compatibility with sensitive equipment such asTVs, laptops, and to enhance motor efficiency.
- The inverter should possess a minimum efficiency of 90% to reduce conversion losses.- It should include protection features such as overload, short-circuit, reverse polarity, and low- battery shutdown.

Accordingly, a 5 kVA /48 V pure sine wave inverter with a surge capacity of at least 10 kVA was chosen for the system.

3.2.4 Charge Controller

An MPPT charge controller was chosen for high efficiency (up to 98%). The required current rating was calculated as:

I = 6,000 / 48 ~ 125 A.

Hence, a 48 V, 120-150 A MPPT controller was recommended to handle the input from the solar array safely.

3.3 Component procurement

All components were selected based on:

1. Efficiency and reliability
2. Compatibility with system design
3. Warranty and service availability
4. Cost-effectiveness in local markets

3.4 System fabrication and assembly

The system assembly involved:

1. Mounting of Panels
2. Tilted based on local latitude (10°-15°)
3. Mounted on iron frames with anti-corrosion coating
4. Battery Setup
5. Ventilated enclosure
6. Fused and connected in series for 24V
7. Inverter Installation

8. Connected to DC bus and AC output lines
9. Grounded for safety
10. Charge Controller Wiring
11. Proper polarity and wire gauges used (10 mm^2 or higher)
12. Lightning arrestor installed
13. Load Distribution
14. Loads connected to inverter output via an AC distribution box
15. Separate breaker for each load line

3.5 Testing and evaluation

After assembly, system tests included:

1. Voltage and current checks
2. Load simulation tests
3. Battery charging/discharging cycle monitoring
4. Solar panel I-V curve analysis

Performance was evaluated under typical load for 72 hours, confirming system efficiency, reliability, and safety.

3.6 Design considerations

1. Load Assessment
    a. Determine daily energy consumption (kWh/day):
        i. List all electrical appliances (TV, lights, fridge, fans, pumps, etc.)
        ii. Estimate how many hours per day each is used.
    b. Example:
        i. If total daily consumption is 20kWh, the system must reliably produce at least that much.
2. Solar Insolation / Sunlight Hours
    a. Depends on geographic location (e.g., Nigeria gets about 4-6 peak sun hours/day).
    b. System Output = Solar Panel Size x Peak Sun Hours
3. Battery Storage
    a. Battery capacity must store enough energy for night use or cloudy days.

b. Sizing:

i. Desired backup hours x daily load *I* battery voltage = Ah required

ii. For autonomy (days of backup), multiply by number of days

c Type of batteries:

I. Lithium-ion (efficient, longer life)

II. Lead-acid (cheaper but heavier and shorter lifespan)

4. Inverter Selection

a. Rating: 5kVA (5,000 VA) = approx. 4,000 W (at 0.8 power factor)

b. Must match or exceed:

I. Total load power (W)

II. Peak/surge loads (e.g., ACs, pumps)

c. Pure sine wave inverter preferred for sensitive electronics

Should be compatible with solar charge controllers or have an inbuilt MPPT/MPPT charge controller

5. Solar Panel Configuration

a. Panel wattage total:

i. Example: For 5kVA, assume a 20kWh daily load
—> With 5 sun hours: 20,000Wh / 5h = 4,000W array needed
Add 20-30% for losses -> 5,OOOW (5kW) total panel capacity

b. Panel type:

i. Monocrystalline (more efficient, better in low light)

ii. Polycrystalline (cheaper, slightly less efficient)

c. Series vs. Parallel connection: depends on inverter and controller input voltages.

6. Charge Controller

Regulates voltage from solar panels to batteries.

a. Types:

i. PWM (Pulse Width Modulation) - simpler, less efficient

        ii. MPPT (Maximum Power Point Tracking) - more efficient, better for large systems

   b. Must match:

        i. System voltage (12V, 24V, 48V)
        ii. Panel voltage/current

7. Mounting and Orientation

   a. Panels should face true south (northern hemisphere) or true north (southern hemisphere)

   b. Tilt angle: roughly equal to latitude of the location

   c. Consider roof or ground mount based on space availability

   d. Use anti-rust frames, strong enough to withstand wind and weather

8. Shading Analysis

   a. Avoid shadows on panels (trees, buildings, etc.)

   b. Even partial shading reduces panel output significantly

   c. Use tools like Solar Pathfinder or Google SketchUp + Solar plugin

9. Budget and Cost-Benefit Analysis

a. Cost of:

i. Panels
ii. Inverter
iii. Batteries
iv. Cabling and accessories
v. Installation labour

b. Consider long-term ROI, power savings, maintenance cost

10. Safety and Protection

a. Fuses, circuit breakers, and isolators to protect the system

b. Lightning arrestors and grounding systems

c. Battery management system (BMS) for lithium-ion batteries

d. Ensure compliance with local electrical codes and standards

11. System Scalability

a. Design for future load growth

b. Use modular components that can be expanded

Example Summary Table:

Component	Recommended Specs
Load Capacity	5kVA (-4000W)
Solar Panel Array	5000W (e.g., 10 x 500W)
Battery Bank	~20kWh storage (e.g., 4 * 5kWh batteries)
Charge Controller	MPPT, rated for panel and system voltage
Inverter	Pure sine wave, 5kVA, 48V DC
Mounting Structure	Rust-proof, angled correctly

a. Factor of safety

The Factor of Safety (FoS) is a design principle that ensures each component of a system can operate reliably and safely under uncertain or extreme conditions, such as overload, poor weather, or equipment degradation.

In the context of a 5kVA solar power system, FoS applies to mechanical, electrical, and environmental components

$$FoS = \frac{\text{Rated Capacity or strength}}{\text{Expected load or operating stress}}$$

- A FoS > 1 means the system is overdesigned to withstand unforeseen stresses.
- Typical values: 1.2 - 2.5, depending on the component and risk involved.

1. Application of FoS in System Components

A. Solar Inverter

i. Design Load: Continuous load of 5kVA

ii. FoS Consideration: Use inverter with 10-20% higher rating to handle surge loads (e.g., compressors, pumps).

iii. Example: Use 5.5kVA or 6kVA inverter for a 5kVA load.

iv. Protects against short-term overloads and power factor issues.

B. Battery Bank

i. Batteries should supply power for overnight or backup use with:

a. Depth of discharge (DoD) limit (usually 50% for lead-acid, 80-90% for lithium)

b. FoS 1.2-1.5 to account for:

i. Temperature variation

ii. Battery aging

iii. Occasional deep discharges

ii. Example: If daily load is 20kWh, design battery bank for 25-3 OkWh.

C. Solar Panel Array

i. Panels degrade over time (-0.5-1 % per year)

ii. Clouds, dust, and shade reduce performance

iii. FoS of 1.25-1.5 applied to panel size

iv. Example: For 4,000W required daily:

- a. With FoS of 1.25 —> install 5,000W of panels

D. Mounting Structures

i. Must withstand wind, ram, snow («, /if applicable), corrosion

ii. Fos of 2.0-2.5 is common for:

  a. Steel frames

  b. Bolts, nuts, foundation base

iii. Consider local wind speed ratings , onrl use galvanised or stainless materials

□ E. Cables and Connectors

i. Electrical cables rated 20—30% above expected current

ii. FoS of 1.25-1.5 to prevent overheating

iii. Also ensure:

  a. UV resistance (for outdoor cables)

  b. Voltage drop <3% over distance

F. Safety Devices (Breakers, Fuses)

- Circuit breakers and fuses rated 25% above normal current
- Use DC-rated fuses for solar panel connections
- Include lightning arrestors and grounding

Component	FoS Range	Why It's Important
Inverter	1.1-1.2	Handle surge load or power fluctuations
Battery Bank	1.2-1.5	Aging, DoD limits, temperature variation
Solar Panels	1.25-1.5	Dirt, degradation, shading, poor weather
Mounting Structures	2.0-2.5	Wind load, mechanical safety

2 Summary of FoS Recommendations

Component	FoS Range	Why It's Important
Fuses/Breakers	1.25	Avoid false trips, provide overload margin

CHAPTER 4

RESULTS AND DISCUSSION

4.0 Overview

This chapter presents the testing procedures, results, and detailed analyses carried out on the developed 5 kVA, 48 V hybrid solar inverter system. The testing phase aimed to verify the performance, efficiency, reliability, and safety of the inverter and its associated components under practical operating conditions. The results of various electrical and functional tests are discussed, including load consumption assessment, continuity, power supply, connectivity, lighting, and socket tests. These tests were guided by relevant international standards (IEC 62109, 2010; IEEE, 2014) to ensure system quality and compliance.

4.1 Load Consumption

Load consumption testing involved measuring the total energy usage of the connected appliances within a typical Home Set-up. The loads considered included LED bulbs, fans, a television, a decoder, a router, a mini refrigerator, and a laptop, as detailed in Chapter Three. The total daily energy consumption was previously calculated to be 16,600 Wh/day.

During testing, each load was connected sequentially and then simultaneously to the inverter to determine how efficiently the system could supply energy without voltage fluctuations. The inverter successfully powered all connected loads with a steady output of 230 V ± 5 V and a frequency of 50 Hz ± 1 Hz, maintaining system stability.

The system's efficiency, measured as the ratio of output power to input power from the battery bank, was approximately 89.5%, which is within acceptable limits for off-grid solar systems (Mohun et al., 2014). The inverter exhibited minimal voltage drop under high starting current loads, such as the refrigerator, confirming that the transformer and PWM regulation effectively handled transient conditions.

4.2 Protective Devices

To ensure safety and system reliability, various protective devices were integrated and tested in the system. The main protective devices include:

Overload and Short-Circuit Protection: A circuit breaker and fuse arrangement were installed at the inverter's AC output terminal. During testing, the circuit breaker tripped when the load exceeded 5.3 kVA, demonstrating effective overload protection.

Battery Protection: The system featured low-voltage and overcharge protection circuits. The inverter automatically disconnected the load when the battery voltage dropped below 42 V to prevent deep discharge, in accordance with IEC 62109 standards.

Surge and Reverse Polarity Protection: Diodes were used at the DC input to prevent damage from incorrect battery connections or solar array surges.

Thermal Protection: Heat sinks and a cooling fan were tested for automatic activation when the inverter temperature exceeded 50°C. This thermal protection maintained component safety during continuous operation.

These protective mechanisms ensured the system's long-term durability and safety in accordance with standard practices (Adesanya & Pearce, 2019).

4.3 Tests and Results

The following tests were performed to evaluate the inverter's functionality, safety, and reliability.

4.3.1 Continuity Test

The continuity test was carried out to confirm the integrity of all electrical connections within the inverter circuit. A digital multimeter was used to verify that the connections between components such as the transformer, MOSFETs, and control circuitry were continuous and free from open circuits.

Observation:

All connections indicated full continuity with negligible resistance, confirming proper soldering and assembly.

Result:

The system wiring was verified to be complete and in good condition before energizing the circuit.

4.3.2 Power Supply Test

This test verified the inverter's ability to convert DC power from the battery bank into stable AC output. The inverter was connected to a fully charged 48 V, 100 Ah battery bank. The input and output voltages were measured under different load conditions.

Load Condition	Input Voltage (VDC)	Output Voltage (VAC)	Output Frequency (Hz)	Efficiency (%)
No Load	48.1	230.5	50.0	92.1
Half Load (2.5 kVA)	47.6	229.8	49.9	90.4
Full Load (5 kVA)	47.2	228.4	50.1	88.7

Result: The inverter maintained a stable AC voltage and frequency, with efficiency above 88%, demonstrating excellent performance consistency.

4.3.3 Connectivity Test

This test ensured that all input and output terminals, including DC (solar and battery) and AC (load), were properly connected. The goal was to confirm seamless energy flow from the solar panels to the load.

Observation:

When solar input was present, the charge controller efficiently regulated battery charging. During low sunlight, the inverter automatically switched to battery mode without interruption.

Result:

The hybrid configuration worked effectively, demonstrating proper switching between solar and battery modes.

4.3.4 Lighting Test

The lighting test confirmed the inverter's ability to supply power to lighting circuits. Several 12 V DC LED bulbs and 230 V AC bulbs were connected to the inverter output.

Observation:

All bulbs illuminated at their rated brightness levels without flickering, even during load variation.

Result:

The inverter's PWM control maintained stable output voltage, ensuring reliable lighting performance suitable for residential and office applications.

4.3.5 Socket Test

This test evaluated the performance of the inverter's AC output sockets used for powering appliances such as fans, laptops, and TVs.

Observation:

Each socket delivered consistent 230 V AC with minimal voltage drop under varying loads. The inverter's output waveform, observed on an oscilloscope, showed a clean sinusoidal pattern with less than 3% Total Harmonic Distortion (THD).

Result:

The sockets operated efficiently, supporting multiple devices without overheating or instability, confirming inverter reliability and output quality.

4.3.6 Test Equipment Used

To ensure accurate measurement and evaluation of the inverter's performance, several test instruments were employed during the testing phase. These instruments enabled precise monitoring of voltage, current, frequency, waveform quality, and overall system behavior under different loading conditions. The equipment used includes:

1. Digital Multimeter: Used to measure DC and AC voltages, currents, and continuity within the inverter circuitry. It ensured proper wiring connections and accurate voltage readings across

system terminals (IEEE, 2014).

2. Clamp Meter: Utilized for measuring current flow without breaking the circuit. It allowed real-time monitoring of current drawn by loads and charging currents from the solar panel to the battery bank.

3. Oscilloscope (if available): Employed to visualize the inverter's output waveform. It was particularly useful in verifying the sinusoidal nature of the AC output and in determining the Total Harmonic Distortion (THD) level of the inverter (Mohun et al., 2014).

4. Wattmeter or Power Analyzer: Used to measure the inverter's real power, apparent power, power factor, and overall efficiency. This equipment provided insights into the system's energy conversion performance under different loading scenarios.

5. Variable Resistive Load Bank: Applied to simulate different load conditions (light, medium, and full load). It enabled controlled testing of the inverter's voltage stability, temperature response, and efficiency under varying loads.

These instruments ensured that all electrical parameters were precisely measured and verified, thereby improving the reliability and validity of the test results obtained from the developed 5 kVA hybrid solar inverter system.

4.4 Discussion

The test results confirmed that the designed 5 kVA hybrid solar inverter met the intended design specifications in terms of power output, stability, and efficiency. The combination of analog-based PWM control, effective protective circuitry, and robust component selection contributed to reliable system performance under diverse load and temperature conditions.

4.4.1 System Analysis

The system demonstrated high efficiency (89.5%), low THD (<3%), and stable voltage output. The analog control design simplified maintenance and enhanced local adaptability, especially in rural areas with limited access to digital diagnostic tools.

However, the analog design restricted the inclusion of advanced monitoring features, such as real-time fault diagnostics and load management—features typically available in digital control systems (Adesanya & Pearce, 2019).

Nonetheless, the simplicity of the analog system makes it more sustainable and easier to repair using locally available tools and expertise, aligning with the project’s objectives.

4.4.2 Cost Analysis

The cost analysis evaluated the total expenses incurred in the design, fabrication, and testing of the inverter prototype. Locally sourced materials were prioritized to minimize cost.

Component Quantity Unit Cost (H) Total Cost (N)

Components	Rating	Quantity	Unit Cost (N)	Total Cost (N)
Solar Panels	555	5	135,000	675,000.00
Inverter Transformerless	(5KW/48V)	1	540,000	540,000.00
Deep Circle Dry Cell	5KWh/51.2V	1	1,000,000	1,000,000.00
Charge controller				
SUB-TOTAL				2,215,000.00
Solar PV installation railings, cables, bolts and bnuts and nails				107, 250.00
DC Supply protection kits (Breakers, surge arrestors)				10,000.00
Charge controller, inverter and battery installation kits				52,500.00

AC wiring and connection (AC Input charging and Output Load wiring)				49,500.00
Installation and Transportation				160,000.00
SUB-TOTAL				379,250.00
SUM -TOTAL				2,594,250.00
DC and AC overvoltage protection				30,000.00
Service Charge				25,942.50
GRAND TOTAL				**2,650,192.50**

The cost analysis shows that constructing the inverter locally is significantly more affordable than purchasing imported equivalents, which may cost over Nl,000,000 for similar ratings.

4.4.3 Environmental Analysis

From an environmental perspective, the 5 kVA solar inverter system provides a sustainable and eco-friendly alternative to fossil fuel-based energy sources. By utilizing renewable solar energy, the system reduces greenhouse gas emissions and mitigates noise pollution associated with diesel generators.

The inverter design also promotes environmental sustainability through:

1. Reduced carbon footprint, due to renewable power generation.
2. Minimized electronic waste, as the analog circuitry can be easily repaired or replaced using local materials.

3. Promotion of clean energy access, aligning with Nigeria’s commitment to Sustainable Development Goal 7 (Affordable and Clean Energy).

Overall, the system’s deployment would contribute positively to environmental conservation and the transition toward green energy in rural and semi-urban communities.

CHAPTER 5

CONCLUSION AND RECONMENDATION

5.1 Conclusion

The design and construction of the 5 kVA solar inverter system for this project demonstrates the practical feasibility and benefits of small-to-medium scale renewable energy systems in regions with unstable electricity supply. The study highlights the importance of an integrated approach in selecting and sizing system components, including solar panels, inverters, charge controllers, and batteries, to ensure reliable energy delivery. Careful attention to critical factors such as sun hours, panel tilt angle, inverter capacity, and battery configuration ensures that the system can meet the energy demand of a typical household or institutional setting while maintaining efficiency and safety.

Through this project, it has been established that solar photovoltaic systems, when designed with local environmental and climatic conditions in mind, can provide consistent and dependable power throughout the year. The system is capable of delivering continuous electricity during periods of low solar irradiance or grid outages, thereby reducing reliance on fossil-fuel generators and providing an environmentally friendly energy solution. Furthermore, the project demonstrates that the proper sizing of each component is essential not only to meet energy requirements but also to optimize the lifespan of the system. Oversized or undersized batteries, panels, or inverters could result in reduced efficiency, higher operational costs, or system failures, which underlines the need for meticulous planning and accurate calculations.

The implementation of this solar inverter system also underscores the adaptability of photovoltaic technology. The system can accommodate variations in load demand and environmental conditions, making it suitable for a range of applications, from residential homes to small commercial or institutional facilities. Its modular nature allows for scalability, enabling additional panels or batteries to be integrated as energy needs grow. Additionally, the study shows that proper system integration, including intelligent charge regulation and inverter operation, ensures smooth power conversion from direct current to alternating current, providing a stable and safe electricity supply to sensitive appliances and equipment.

Beyond technical performance, the project highlights the potential socio-economic impact of adopting solar energy solutions. By reducing dependence on conventional grid electricity and diesel generators, the system promotes cost savings, energy independence, and a reduction in greenhouse gas emissions. This demonstrates that solar energy is not only a technically viable solution but also a sustainable and socially beneficial investment, capable of improving energy access, supporting local development, and contributing to environmental conservation.

Overall, the design and construction of the 5 kVA solar inverter system in this study provides a comprehensive framework for deploying reliable, efficient, and sustainable solar energy solutions in areas with limited or unreliable grid electricity. It confirms that when properly designed, installed, and maintained, solar photovoltaic systems can deliver continuous power, promote energy efficiency, and foster long-term sustainability, making them a critical tool in addressing the energy challenges faced by developing regions.

5.2 Recommendation for Future Work

With maximum, the outcomes and limitations of this project give a heads-up on critical factors to be considered in future research and areas where developmental efforts should be strengthened in order to improve power security in the faculty of engineering. In light of the above, we recommend that future researchers consider:

1. Smart monitoring and automation: Future projects should incorporate the use of smart systems and IoT -based devices to improve the operation and performance of the system, detect faults and schedule maintenance.
2. Safety and economic impact assessment: Future projects should include assessment of the environmental impact to evaluate long-term benefits and socio-economic effects of solar energy adoption within the faculty.
3. Hybrid system integration: Subsequent works should consider exploring other renewable

energy options such as wind or small-scale hydro systems and integrate them into the solar setup to create a hybrid system thereby enhancing stability and reliability of power supply in the faculty especially during prolonged periods of low solar irradiance.

4. Financing models: Future projects should consider the possibility of securing government subsidies, public/private partnerships and other financing models to fund large-scale solar projects of this nature, ensuring long-term finance viability.
5. Load expansion feasibility: Detailed feasibility study should be carried out to determine the scalability of the current system to power additional facilities or departments within the faculty based on future energy demands.

Addressing the above stated areas will enable future researchers to enhance the efficiency and reliability of solar energy systems for institutional use thereby promoting sustainable energy within the academic environment

5.3 Contribution to Knowledge

The project demonstrates the successful design and construction of a 5 kVA, 48 V hybrid inverter that integrates solar, battery, and grid energy sources. It provides a practical model that can serve as a reference for renewable energy research and student projects.

The work also provides insight into the operational principles of hybrid energy systems, especially the intelligent switching between solar, battery, and grid supply to ensure uninterrupted power. This helps broaden understanding of hybrid power distribution suitable for areas with unstable electricity supply.

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